Professional paper

Received: July 31, 2013
Accepted: November 13, 2013

An attempt to improve geotechnical properties of some highway lateritic soils with lime

Poskus izboljšave geotehničnih lastnosti nekaterih lateritnih tal za ceste z dodajanjem apna

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Abstract

An attempt to stabilize some soils from failed sections of the Sagamu–Papalanto road, southwestern Nigeria with lime was undertaken with a view to improve the geotechnical properties of the soils. The soils were treated with 0 % to 20 % by mass of lime, compacted at the Modified AASHTO level and subjected to consistency limits, unconfined compressive strength (UCS) and California bearing ratio (CBR) tests. Increasing content of lime addition resulted in soils with reducing plasticity with an optimum range of 6 % to 8 % while the UCS and CBR increased. Furthermore addition of between 6 % and 10 % of lime produced soils with desirable strength for use as base course materials. However despite the continuous increase in CBR with increasing lime addition, none of the soils meet the unsoaked CBR requirement for use as base course materials. However the soils qualify for use as subbase materials. Thus, it can be concluded that, the soils responded positively to lime addition; however the degree of response and the eventual effect on its suitability for use varied from soil to soil.

Key words: lime, geotechnical properties of soil, lateritic soils, base course, aggregation

Izvleček

Preizkusili smo možnost izboljšanja geotehničnih lastnosti tal na poškodovanih odsekih ceste Sagamu–Papalanto v jugozahodni Nigeriji z dodajanjem apna. Tlom smo dodajali masni delež apna od 0 % do 20 %, jih stiskali na modificiran AASHTO-nivo in določili njihove konsistenčne meje, nezaprto tlačno trdnost (UCS) in opravili geomehanski CBR-preizkus. Dodajanje apna v razponu od 6 % do 8 % je zmanjšalo plastičnost tal, zvečala sta se UCS in CBR. Z nadaljnjim dodajanjem apna, med 6 % in 10 %, smo dosegli trdnost, ki je potrebna za cestno nosilno plast. Kljub povečanju CBR z dodanim apnom nobena od preiskovanih tal ni zadostila zahtevam neovlaženega CBR. Ugotavljamo, da se dodajanje apna tlom obnese, vendar sta stopnja izboljšanja lastnosti in vpliv na primernost za uporabo odvisna od vrste tal.

Ključne besede: geotehnične lastnosti tal, apno, laterit, nosilna plast tal, struktura tal

Introduction

Frequent failure of structures, particularly roads in Nigeria, leading to loss of lives and properties has necessitated the need to find ways of ensuring the stability of the road pavements. In southwestern Nigeria, lateritic soils which are referred to as tropical red soils are by far the most abundant and most common materials used for road construction works either as subbase or subgrade options. They have found wide application and have been used extensively in construction of dams, embankments as well as buildings. Thus, as opined by Oyediran et al.[1], lateritic soils with appropriate geotechnical properties are indispensable. However, the engineering characteristics of lateritic soils as indicated by Townsend[2], vary considerably, depending on factors such as parent material, climate, topography, drainage, vegetation, age, and they usually form in tropical and other similar hot and humid climatic regions, where heavy rainfall, warm temperatures and good drainage lead to the formation of thick horizons of reddish soil profiles rich in iron and aluminum. CIRIA[3] confirmed that laterite in all its form is a highly weathered natural material formed by the concentration of the hydrated oxides of iron and aluminum. This concentration may be by residual accumulation or by solution, movement and chemical precipitation. Goswami and Mahanta[4] noted that they occur mostly as the capping of hills and therefore provide excellent borrow areas for extensive use in various construction activities. However the relative abundance of lateritic soils notwithstanding, the soils must satisfy requirements for its intended use and when this is not the case the need to seek ways of improving the soil becomes imperative.

Lime stabilization of soils is not new. Several researchers Remus and Davidson[5], Ingles and Metcalf[6], Sherwood[7], Little[8], Bell[9], Rajasekaran and Rao[10], Nalbontoglue and Tuncer[11], Khattab et al.[12], Hebib and Farrell[13], Petry and Glazier[14], Koslanant et al.[15], Khattab et al.[16], James et al.[17], Chen et al.[18] and Harris et al.[19], have worked on lime stabilisation of soils, albeit with temperate soils. As noted by Attoh-Okine[20] however, the geotechnical properties of lateritic soils are quite different from the soils developed under cold or temperate climates. Though, several other authors including Ola[21], Osula[22], Osinubi[23], Galvao et al.[24], Huat et al.[25] and Mohd Yunus et al.[26] have stabilised tropical residual soils with lime, yet these instances with tropical soils, are still very scanty in literature. More work still needs to be done to surmount the barrier of limited information. More so, the results obtained from these studies and those from previously reported work on tropical residual soils show no well defined or uniform trend for the change of some geotechnical properties of these soils upon the addition of lime. These variations and uncertain trends observed may not be unconnected with the individual soil mineralogy and parent material. This investigation is therefore an attempt to determine the effect of addition of varying quantities of lime (0 % to 20 % by weight) on the geotechnical properties of some residual lateritic soils from failed sections of the recently constructed Sagamu-Papalanto road. Furthermore, the optimum content of lime required to produce desired results (improving the soil properties) while achieving better pavement soils will be deduced. Moreover, a significant contribution to the existing literature on lime stabilisation of residual lateritic soils and assessment of its response to varying lime content is expected will be presented.

Study Area

The study area lies within Latitude 3° 12’ to 3° 30’ and longitude 6° 51’ to 6° 54’ and is located in the southwestern part of Nigeria. In terms of Geology the area is underlain by the Sedimentary rocks of southwestern Nigeria (Omatsola and Adegoke[27]) and falls within the Ewekoro formation. The Ewekoro formation which is Paleocene in age is highly fossiliferous and consists of economic deposits of limestone presently quarried by the West African Portland Cement Company in Ewekoro and Sagamu. The general succession of the rock units comprising of the Ewekoro Formation has been described by several authors (Kogbe[28]; Adegoke et al.[29]). Specifically the soils from the sampling points (Figure 1), developed over claystone and shale (Makelu and Ikereku), and shale and limestone (Someke).

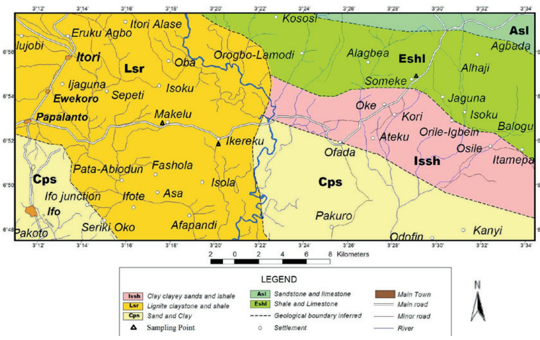

Figure 1: *Geological map of the study area showing sampling points.*

Materials and Methods

Three bulk residual lateritic soil samples were obtained at depths between 0.5 m and 1.0 m from borrow pits at failed sections along the recently constructed Sagamu–Papalanto road for this work. The choice of the sampling points was guided by proximity to failed portions on the road. The lateritic soils were air dried for two weeks prior to laboratory analyses and later subjected to geotechnical tests for the determination of grain size distribution, consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS). The geotechnical tests were done in accordance with Bs1377[30] test procedures with some slight modification in some cases to accommodate the lateritic nature of the soils. For example, wet sieving was used for the determination of particle size distribution to ensure effective detachment of the fine grained particles from the coarse grained particles. About 500 g of air-dried soil mixed with distilled water and calgon (deflocculating agent) was stirred for about 20 min for effective dispersal of the soil grains. The wet suspension was then passed through a 63 μm sieve to separate the coarse fraction from the fines fraction. The coarse fraction retained on the sieve was then oven dried, allowed to cool and sieved through a set of sieves. The fraction retained on each sieve was eventually weighed. The fines fraction which passed through the 63 μm sieve was separated into silt and clay size fractions using sedimentation analysis based on Stokes law. CBR tests were performed on compacted samples in both unsoaked and soaked conditions Soaking of the samples in water was done for 24 h in accordance with the Nigerian general specification (FMWH, 1997[31]) before the determination of the soaked CBR to simulate natural conditions and assess the extent to which the ingress of water would expand and weaken the soils. For completeness of investigation effective segregation of soil grains was achieved through constant agitation. Varying quantities of (2, 4, 6, 8, 10, and 20) % of lime (mass fractions) was added to soil samples and mixed thoroughly to allow for intimate mixing. The mixed soil samples were left for 48 h to cure and mellow and subsequently remixed to achieve a homogenous mix prior to compaction at Modified AASHTO level of compaction. The Modified AASHTO compaction was desirable because it is usually achievable with conventional field equipment. In the determination of the UCS all the samples were cured for 7 d and were compacted at OMC to simulate field moisture compaction conditions. The bulk chemical composition of the soils was determined with use of atomic absorption spectrophotometer (AAS) technique which involved the use of air-dried ground soil weighed and placed in an Erlenmeyer flask with the addition of 0.05N HCl + 0.025N H_2SO_4 as the extracting solution. The samples were subsequently placed in a mechanical shaker and then filtered. The extract was then analyzed directly for the determination of concentration of elements using atomic absorption. Furthermore the mineralogical composition of the soils was determined using x-ray diffraction (XRD). Powdered samples of the soil were pelletized and sieved to 0.074 mm. These were later mixed with acetone to produce a thin slurry and each sample mixture was applied to a glass was scanned through the Siemens D500 Diffractometer (using MDI Data Scan and JADE 8 softwares) for the determination of XRD.

Results and Discussion

Soil Properties

The particle size distribution of the studied soils is summarized in Table 1 and the grading curves displayed on Figure 2. The summary shows that Makelu soil contained the highest amount of clay size fraction (12.0 %), Someke soils contained the highest amount of silt size

(57.0 %) and amounts of fines (65.0 %) fraction while the Ikereku soils possessed the highest amount of gravel size (14.0 %) and sand size (43.0 %) fractions. The grading curves shows all the soils are well graded and hence will be expected to compact to a lower porosity and permeability than uniformly graded soils (Oyediran and Adeyemi[32]). However as indicated by Oyediran and Williams[33], soils with amounts of fines less than 50 % are expected to possess better engineering properties while those with amounts of fines greater than 50 % are expected to pose field compaction problems when used either as base course or subbase materials. Hence on the basis of amounts of fines Someke and Makelu soils are not suitable for use as subbase or base course materials in the construction of roads as they will pose problems.

Furthermore none of the soils satisfy the requirements of the Nigerian Federal Ministry of Works and Housing (FMWH[31]) specification (amounts of fines 5–15 % for base-course materials) for highway construction. Thus, the materials do not qualify for use as base-course materials. The AASHTO classification of the soils also shows that they fall in the A-6 and A-7-6 subgroup, which indicates that the materials are fair to poor subgrade soils. These characteristics displayed by the soils, may in part be responsible for the failures noticed on the road sections.

In terms of consistency, Casagrande chart (Figure 3) classification shows the soils are all inorganic soils of medium plasticity and hence compressibility. All the soils fall above the A-Line possibly indicating close or similar clay mineralogy. The soils are expected to undergo

Table 1: *Index, chemical and mineralogical properties of studied soils*

Parameter (%)	Sample	Someke	Makelu	Ikereku
Particle Size Distribution	Gravel	8.0	8.0	14.0
	Sand	27.0	35.0	43.0
	Clay	8.0	12.0	7.0
	Silt	57.0	45.0	36.0
	Fines	65.0	57.0	43.0
Consistency Limits	Liquid Limit	33.0	44.0	32.0
	Plastic Limit	14.0	18.0	20.0
	Plasticity Index	19.0	26.0	12.0
Classification	Casagrande Classification	Medium Plasticity and Compressibility		
	AASHTO Classification	A-6	A-7-6	A-6
Bulk Chemical Composition	Al_2O_3	1.71	21.86	15.96
	CaO	0.57	0.10	0.32
	Fe_2O_3	5.73	10.01	6.05
	K_2O	1.87	0.19	2.19
	MgO	0.42	0.18	0.57
	Na_2O	0.24	0.04	0.35
	P_2O_5	0.02	0.08	0.04
	SiO_2	88.21	66.11	73.18
	TiO_2	1.23	1.43	1.34
	Silica sesqui-oxide ratio	27.95	3.98	6.28
Mineralogical Composition	Quartz	51.18	61.73	61.38
	Kaolinite	27.97	18.75	31.53
	Labradorite	20.85	19.52	-
	Haematite	-	-	7.09

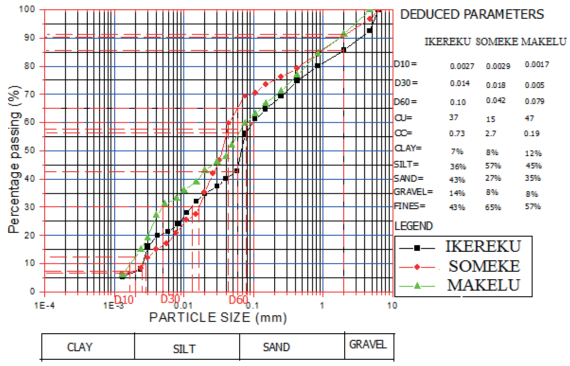

Figure 2: *Grading curves of studied soils.*

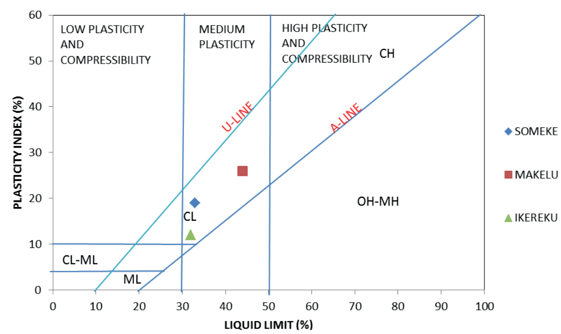

Figure 3: *Casagrande chart classification of studied soils.*

moderate swelling and shrinkage when loaded as a result of their medium plasticity. According to FMWH[31], soils suitable for use as base course materials must possess liquid limit and plasticity index values < 30 % and < 13 % respectively. All the soils have liquid limits greater than 30 % and all except the Ikereku soil (12 %) possess plasticity index greater than 13 % and hence will not perform creditably well as base course materials. However for use as subbase materials, suitable soils must display liquid limit and plasticity index < 35 % and < 16 % respectively. It can be concluded that only the Ikereku soil meets both conditions of this requirement.

The chemical composition of the soils indicate that all the soils contain high amounts of SiO_2 with the Someke soils having the highest (88.21 %) and the Makelu soil possessing the lowest (66.11 %). The Someke soil also possesses the highest silica sesquioxide ratio (27.95 %) and Makelu soil the lowest (3.92 %). However a reverse trend was noticed with the Makelu soil having the highest amounts of Al_2O_3 (21.86 %) and Fe_2O_3 (10.01 %) while Someke soil has the lowest Al_2O_3 (1.71 %) and Fe_2O_3 (5.73 %). Moh[34], Ola[21, 35] and Anifowose[36] have shown that soil type and its composition influence the results of stabilisation. It should be noted that Makelu soil has the highest clay content, plasticity values, Fe_2O_3 and Al_2O_3 content. The x-ray diffraction analysis further revealed that quartz is the most abundant mineral in all the soils. All the soils contain kaolinite as the clay mineral with the Makelu soil having the lowest amount (18.75 %). Minor amounts of Hematite (7.09 %) were observed in the Ikereku soil while the Someke and Makelu soils possess 20.85 % and 19.52 % of labradorite respectively.

Effect of Lime on Consistency limits

The consistency limits of the soils in response to lime stabilisation are presented in Table 2, while the pictorial variations are displayed on Figures 4, 5 and 6. There was a reduction in liquid limit (LL) of all the soils as lime content increased from 0 to 20 %. The same trend was observed for the plastic limit (PL) of all the soils. The highest reduction in LL and PL was observed at the addition of 20 % by weight of lime. Makelu and Ikereku soils showed a uniform trend of continuous reduction in plasticity with increase in lime content. The PI reduced steadily with the highest change of 12 % and 14 % respectively for Makelu and Ikereku soils with the addition of 20 % lime. The immediate impact of lime on the soils leading to reduction in plasticity with lime addition is attributed to cation exchange and aggregation.

The reactions take place rapidly and produce immediate improvements in soil plasticity (reduced plasticity and shrink/swelling potential) and workability. Initially the water content is reduced followed by flocculation and agglomeration of clay particles which brings about textural change which lead to eventual decrease in PI and increase in workability (Terrel et al.[37]). The flocculation and agglomeration are caused by the increased electrolyte content of the pore water and as a result of ion exchange by the clay to the calcium form. The net result of cation exchange and flocculation–agglomeration is soil modification (Little[38]). This brings about substantial reduction and stabilization of the adsorbed water layer, increased internal friction among the agglomerates and greater aggregate shear strength and finally much greater work-

Table 2: *Consistency limits of soil-lime mix*

Sample	Someke				Makelu				Ikereku			
Lime (%)	LL (%)	PL (%)	PI (%)	Change in PI (%)	LL (%)	PL (%)	PI (%)	Change in PI (%)	LL (%)	PL (%)	PI (%)	Change in PI (%)
0	33.0	14.0	19.0	-	44.0	18.0	26.0	-	32.0	20.0	12.0	-
2	30.0	13.8	17.0	–11	42.9	17.5	25.4	–2	30.8	19.4	11.4	–5
4	29.3	13.3	16.0	–13	41.5	16.5	25.0	–4	29.7	18.7	11.0	–8
6	28.2	12.9	15.3	–19	40.6	15.9	24.7	–5	29.5	18.6	10.9	–9
8	27.8	12.8	15.0	–21	39.3	14.9	24.4	–6	27.9	17.2	10.7	–11
10	27.2	11.0	16.2	–15	35.2	12.0	23.2	–11	27.6	17.1	10.5	–13
20	26.0	10.1	15.9	–16	34.9	11.9	23.0	–12	26.3	16.0	10.3	–14

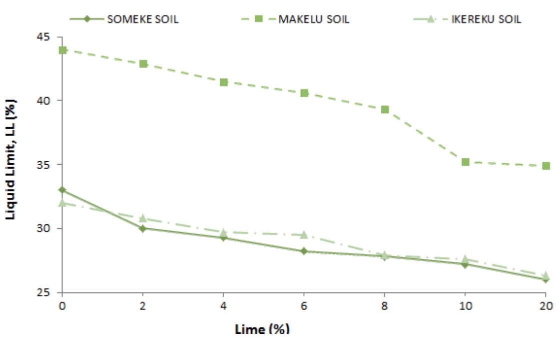

Figure 4: *Variation in liquid limit of studied soils.*

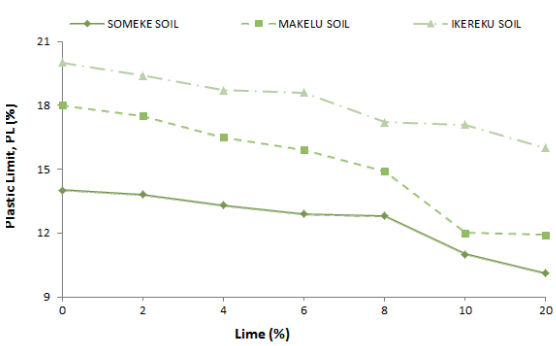

Figure 5: *Variation in plastic limit of studied soils.*

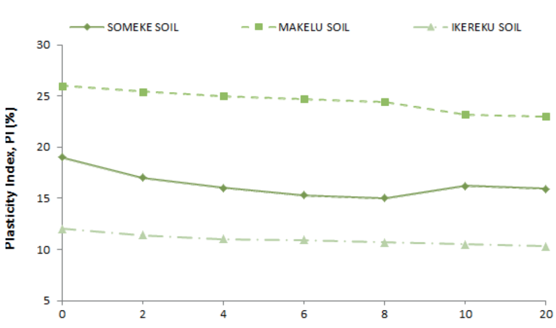

Figure 6: *Variation in plasticity index of studied soils.*

ability due to the textural change from plastic clay to a friable, sand-like material.

According to Townsend et al.[39], the principal components of tropical lateritic soils that are responsible for pozzolanic reactions are amorphous silica and alumina. It is believed that clay minerals that are usually found in tropical residual soils such as kaolinite, halloysite, and crystallized aluminum hydroxides also contribute to the pozzolanic reactions, while iron compounds are considered harmful or neutral. Little and Shafee Yusuf[40], did indicate that the reactivity of lime with soil is predicated on the type and the amount of clay minerals present in the soil. However in terms of plasticity index (PI), Someke soil responded to lime addition with an initial reduction up to 8 % lime addition. Upon addition of 10 % by weight of lime the PI increased but later reduced when the lime content was increased to 20 %. This reaction may not be unconnected with the high sesqui-oxide ratio of the Someke soil due to the fact that increase in sesqui-oxides results in decrease in cation exchange capacity and moisture retentivity of soil.

The Ikereku and Someke soils changed from medium plasticity soils to low plasticity soils while the soil from Makelu also recorded 12 % reduction in plasticity with 20 % lime addition. The reduction in plasticity (from medium to low) results in soils with low swelling and shrinkage potential. As indicated by Little[8], soil swell potential and swelling pressure are normally significantly reduced by lime treatment. Furthermore, the reduction in PI associated with virtually all fine-grained soils upon the addition of lime is a significant indication of the reduction of swell potential due to lime stabilization. The reduction in PI of these soils compares well with findings of Ola[35], Anifowose[36], Osula[22], and Osinubi[23] who worked on lime-soil mixtures. It must however be noted that despite the reduction in plasticity occasioned by increasing lime content, Makelu soil still did not meet the requirement for use as either base course or subbase course material. However Someke and Ikereku soils can be said to have met the requirements for use as subbase course materials.

Effect of Lime on Strength parameters

The Unconfined Compressive Strength (UCS) of the studied soils in response to lime addition is displayed on Table 3 and shown for clarity with Figure 7. The UCS of the soils increased with the addition of lime from 0 % to 20 %. It was observed that on initial addition of lime up to 6 % there was a change of about 100 % in UCS for all the soils. Further increase in lime addition brought an exponential increase in UCS between 274 % and 503 %. 20 % addition of lime resulted in maximum increase in UCS with Someke soil showing the greatest response with a 503 % increase in UCS. The addition of between 6 % and 10 % by mass of lime produced soils (Makelu and Ikereku) with desirable strength which meet the requirements (FMWH[31]) of > 103 kN/m^2 for use as subgrade materials. Results obtained from this study are similar to that which occurs in soil-lime mixtures with an immediate cation exchange reaction, followed by a time-dependent pozzolanic reaction, during which strength is developed. The UCS gain of the lime-treated soil may not be unconnected to the formation of calcium aluminate hydrate as a result of the pozzolanic reaction between lime and kaolinite (Osinubi[41]). This assertion is further supported by Little[42] who showed on the basis of the Energy Dispersive X-Ray (EDX) test analysis that the pozzolanic reaction had already converted some of the clay minerals to (calcium silicate hydrate) CSH after a cure period of 7 d.

These improvements are largely the result of the flocculated particle structure and cementation process that must have taken place. The addition of lime increases the soil strength thereby increasing the mobility of wheeled vehicles involved in construction operations and they help provide a stable working platform for all construction equipment. An increase in load bearing capabilities of the subgrade and continuous increase results in increased longevity of roadway by continued strength gains of the treated soil, creating a permanent pavement foundation.

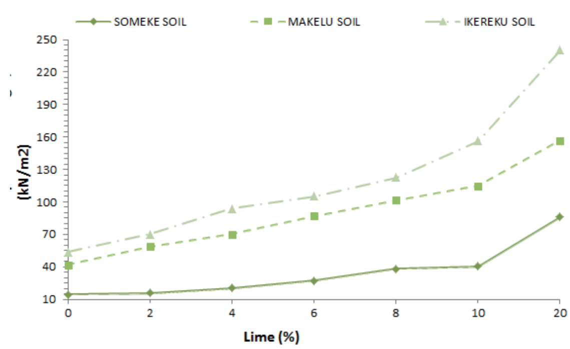

Figure 7: *Variation in Unconfined Compressive Strength (UCS) of studied soils.*

Table 3: *Unconfined Compressive Strength (UCS) of soil-lime mix*

Sample Lime (%)	Someke UCS (kN/m^2)	Someke Change (%)	Makelu UCS (kN/m^2)	Makelu Change (%)	Ikereku UCS (kN/m^2)	Ikereku Change (%)
0	14.3	-	41.9	-	53.7	-
2	15.8	10	58.6	40	70.0	30
4	20.2	41	70.0	67	93.6	74
6	27.1	90	86.7	107	105.4	96
8	37.9	165	101.5	142	122.7	128
10	40.4	183	114.8	174	156.2	191
20	86.2	503	156.7	274	240.4	348

The effect of lime addition on the CBR (Table 4 and Figures 8 and 9) shows an increase in CBR for all the soils at both soaked and unsoaked conditions. Maximum increase of up to 33 % and 40 % were achieved for the soils respectively under unsoaked and soaked conditions. The increase in CBR is thought to be due to the formation of various cementing agents due to pozzolanic reaction between silica present in the soil and lime. The effect of soaking, though very marginal was observed particularly for the Someke soil. The difference in CBR between soaked and unsoaked soils is as a result of water absorption which further weakened the soil. Despite the continuous increase in CBR with increasing lime addition, none of the soils meet the ≥ 80 % unsoaked CBR (FMWH[31]) for soils that can be used as base course materials. However the soils qualify for use as sub base materials. Thus from the results, the strength characteristics were improved with increasing lime content.

Conclusions

An attempt to improve some highway lateritic soils from failed sections of the Sagamu -Papalanto road has led to the following conclusions;

— All the soils studied responded positively to lime addition; however the degree of response and the eventual effect on its suitability for use varied from soil to soil.

— There was a reduction in liquid limit (LL) and plastic limit (PL) of all the soils as lime content increased from 0 % to 20 %, with the highest reduction observed on addition of 20 % lime. Makelu and Ikereku soils showed a uniform trend of continuous reduction in plasticity with increase in lime content as the PI reduced steadily with the highest change of 12 % and 14 % respectively for the soils with the addition of 20 % lime. Reduction in PI is expected to result in increased workability of the soils.

Table 4: *California Bearing Ratio (CBR) of soil-lime mix*

Sample	Someke				Makelu				Ikereku			
	Soaked		Unsoaked		Soaked		Unsoaked		Soaked		Unsoaked	
Lime (%)	CBR (%)	Change (%)	CBR (%)	Change (%)	CBR (%)	Change (%)	CBR (%)	Change (%)	CBR (%)	Change (%)	CBR (%)	Change (%)
0	22.6	-	22.9	-	23.7	-	32.1	-	17.4	-	27.9	-
2	23.9	7	24.4	7	24.4	3	33.1	3	18.1	4	28.4	2
4	24.7	8	24.8	8	25.7	8	36.5	14	19.7	13	29.2	5
6	26.0	16	26.5	16	27.0	14	36.7	14	20.5	18	29.9	7
8	27.0	23	28.1	23	28.6	21	37.9	18	22.1	27	31.0	11
10	28.4	27	29.1	27	29.9	26	38.1	19	23.1	33	32.0	15
20	29.1	33	30.5	33	31.5	33	38.9	21	24.4	40	33.1	19

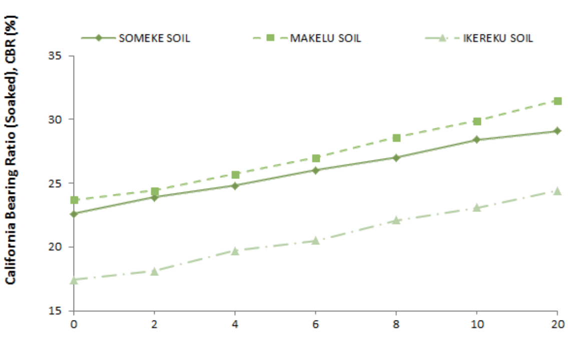

Figure 8: *Variation in soaked California Bearing Ratio (CBR) of studied soils.*

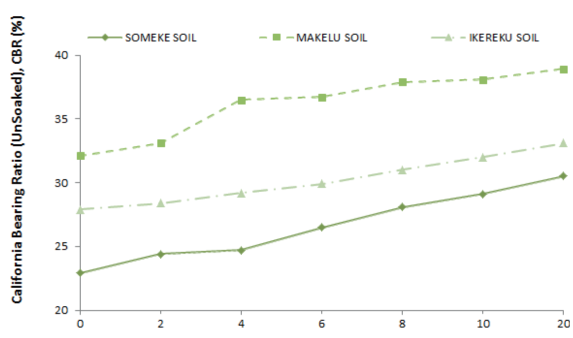

Figure 9: *Variation in unsoaked California Bearing Ratio (CBR) of studied soils.*

— The plasticity index of the Someke soil increased on addition of 10 % by weight of lime after initial steady and continuous decrease between 2 % and 8 % lime addition. It is thus safely assumed that for all the soils, 6 % to 8 % lime content which produced a decrease of 21 %, 6 % and 11 % in PI respectively for Someke, Makelu and Ikereku soils is the optimum range of lime addition. Addition of lime reduced the plasticity of the soils from medium to low as observed in the Casagrande chart classification hence producing soils with low swelling and shrinkage potential.
— The UCS of all the soils increased with increasing lime content with a maximum increase of 503 % (Someke soil) on addition of 20 % lime. It was observed that on initial addition of lime up to 6 % there was a change of about 100 % in UCS for all the soils. The addition of between 6 % and 10 % by weight of lime produced soils (MAKELU and IKEREKU) with desirable strength for use as base course materials.
— The unsoaked and soaked CBR of all the soils increased with increasing lime content respectively up to 33 % and 40 %. Despite the continuous increase in CBR with increasing lime addition, none of the soils meet the unsoaked CBR requirement for use as base course materials. At best, however the soils qualify for use as sub base materials.

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