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Assessment of geotechnical strength properties of road construction soils stabilized with lime in Southwestern Nigeria

S. O. Faluyi[1]*, O. O. Amu[2], A. E. Adetoro[3], F. O. Ayodele[4]

[1]Department of Civil Engineering, Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria
[2]Department of Civil Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria
[3,4]Department of Civil Engineering, The Federal Polytechnic. Ad0-Ekiti, Ekiti State, Nigeria
*fsundayolubunmi@yahoo.com

Research Article

Abstract

The quality of the roads in Southwestern Nigeria is appalling; most are inaccessible owing to pavement failures, prompting research into the feasibility of underlying soil courses if lime is used to stabilize them. Eighteen (18) borrow pit soil samples for road construction (one from each Senatorial district in Southwestern Nigeria) was used for this study. The index properties of the natural soil and strength properties (compaction, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS)) of both the natural and stabilized soils were assessed following BS 1377 (1990) standard procedures. Lime of 2, 4, 6, 8, and 10% of the dry weight of soil was used to obtain the varied stabilized soil samples. The particle size distribution results showed that EK1, EK2, OS2, OS3, OG1, LG1 were predominantly fine (Clay + Silt) soils while samples from Oyo, Ogun and Lagos states are predominantly sand as well as OD1 and OD2. The gravelly-rich soils are EK3, OD3, OS1. The subgrade rating (AASHTO) of the natural soils is Fair – Poor for EK1, OD1, OS2, OS3, OY1, OG1, OG2, and LG2 soils while the Excellent – Good soils are EK2, EK3, OD2, OD3, OS1, OY2, OY3, OG3, LG1, and LG3 soil samples. The Maximum Dry Density (MDD), CBR, and UCS values all improved as the lime content increased, with the optimum being obtained at 6% lime addition. Although, there was an exception for OMC, which continued to increase with the increase in lime content by up to 10%. Evidently, unsuitable soil samples became suitable as pavement layer materials after stabilization with 6% lime. MDD results showed % gain ranging from 3.6 %, 16.4 %, 7.8 %, 21.0 %, 14.9 % and 11.7 % for Ekiti, Ondo, Osun, Oyo, Ogun and Lagos states. The Soaked CBR % gain are 72.8 %, 145.8 %,708.0 %, 1861.5 %, 525.9 % and 54.0 % while UCS % gain are 208.1 %, 132.1 %, 305.4 %,43.4 %, 25.0 % and 95.6 % for the states respectively. Comparatively, the effect of the optimal 6 % lime addition on soil was prominent in Oyo state soils. Hence, due to the improvement in the properties of the lime-stabilized soil, the subgrade soil in Southwestern Nigeria roadways may be stabilized with 6% lime content for construction of durable pavements.

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Keywords
Geotechnical characteristics, Lime, Road construction, Southwestern Nigeria, Stabilization

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1. Introduction

There are times, naturally occurring lateritic soil must be blended with various additives to improve engineering properties. Soil improvement can be divided into two categories: soil modification and soil stabilization. Soil improvement, in its broadest sense, refers to several techniques for altering soil properties to improve engineering performance. It has been utilized for civil engineering construction works (Adeboje *et al.*, 2017) such as earth (unlined) drains, embankments, landfills, airplane runways, erosion control, and road construction around the world. Its primary purpose is to increase soil stability at the lowest possible cost. Short-term soil enhancement that occurs during or immediately after mixing is referred to as soil modification (Alhassan & Alhaji, 2017; Behak, 2017; Nnochiri *et al.*, 2017). Its primary objective is typically to enhance soil properties at the lowest cost. Short-term strength is obtained instantly and within 7 days of compaction. Even if no pozzolanic or cementitious reaction is evident, the texture changes that occur as a result of consistency changes typically result in significant strength improvements (Edeh & Joel, 2015; Qasim *et al.,* 2015; Nnochiri & Aderinlewo, 2016; Nnochiri et al., 2017).

Stabilization is an old concept dating back over 5000 years. In ancient Egypt and Mesopotamia, as well as the Greek and Roman empires, lime was utilized to stabilize roads. In 1904, the first soil stabilization tests were conducted in the United States of America (Firoozi *et al*., 2017). It is a method of altering the geotechnical parameters of soil to meet predefined engineering requirements. It saves money, reduces weather-related delays, eliminates supply issues, and lessens the amount of material used. It takes place when there is a considerable long-term reaction and this is because of the pozzolanic reactivity of free lime with soil pozzolan, or the hydration of calcium silicates and calcium aluminates in Portland cement or class C fly ash. Because some soils (primarily lateritic soils) have limited bearing capacity and strength in their natural forms due to high clay content, soil stabilization is critical in Civil Engineering projects.

Soil's flexibility can cause damage to Civil Engineering projects and it's critical to improve the soil's strength and durability (Amu & Adetuberu, 2010; Ogunribido, 2012; Bello et al., 2015; Nnochiri & Aderinlewo, 2016; Kanyi, 2017; Nnochiri et al., 2017). Compaction and drainage are the most basic methods of stability (if water drains out of wet soil it becomes stronger). On the other hand, soil stability can be accomplished by blending and mixing diverse components. Increased dry unit weight, bearing capacities, volume changes, and performance of in situ sub-soils for road surface reinforcement and other geotechnical applications are achieved as a result of this (Firoozi et al., 2017). Soil stabilization methods such as mechanical, chemical, and biological are used to improve soil characteristics and make them more suitable for construction (Onyelowe, 2012; Nnochiri & Aderinlewo, 2016; Nnochiri & Ogundipe, 2016). In soil stabilization, additives help to improve the first process of particle aggregation and the second process of pozzolanic reaction (Solanki & Zaman, 2012). The pozzolanic reaction occurs between the additive and the silica and alumina inherent in clay to form cementitious compounds in an alkaline environment (Seco et al., 2012). When calcium-rich stabilizers are used, cementitious gels are more likely to form, though an increase in soil pH is always a good thing because it encourages Smectite (the most expansive clay mineral) to be modified (Drief et al., 2002).

Lime is a common additive for improving fine-grained soil properties. Clay soils, clay-contaminated aggregate bases, and even calcareous bases with very little clay content respond favourably to lime stabilization. Treatment of soil with lime lowers the Plasticity Index (PI) of the resultant stabilized soil and because of the lowered PI, the treated soil is more workable. Second, a reaction mechanism between soil and lime reduces the water content, resulting in less compacted wet soils. Finally, lime alters compaction characteristics (the MDD and OMC), resulting in an immediate increase in strength and modulus, as well as a more stable foundation for equipment movement (Jawad et al., 2014; Ige & Ajamu, 2015; Nnochiri et al., 2017).

When lime and clayey materials are mixed in the presence of water, carbonation, cation exchange, flocculation-agglomeration, and pozzolanic processes occur (Firoozi et al., 2017). Cation exchange and flocculation-agglomeration are the primary reactions, which occur nearly instantaneously after mixing. Divalent calcium ions replace monovalent cations of clay minerals during these processes. The plasticity index, workability, and strength are altered instantly as a result of these processes. A pozzolanic reaction occurs between the lime, silica, and alumina hydrates while carbonation occurs as a result of the CO_2 and lime interaction, resulting in carbonate rather than calcium silicate-hydrates. This is an unfavourable reaction in terms of soil improvement (Jawad et al., 2014; Nnochiri et al., 2017).

Many studies have recently reported properties of industrial by-products, natural resources, lime and chemical compounds for soil stabilization. Previous research by Faluyi and Amu (2005), Singh et al. (2008), Amu et al. (2011a), Faluyi & Adetoro (2013), Ige & Ajamu (2015), Amadi & Okeiyi (2017), focused on lateritic soil that had been stabilized with lime, causing a change of soil texture. Lateritic soil particles agglomerate together to form larger particles, which reduces the soil's LL, PI, and swelling potential. As PL, SL, and workability improved, so did the soil's strength. However, due to a lack of data, a detailed understanding of the influence of lime on soils in the southwestern area of Nigeria is required. The specific goals of this study are to evaluate the influence of lime on the naturally occurring soil of Southwestern Nigeria and as well to provide necessary data on some engineering properties of the soil samples in a natural and stabilized state.

2. Materials and Methods

2.1 Sampling

Three soil samples were taken from borrow pits along major Federal roadways in every one of Southwestern Nigeria's senatorial districts. The samples are described in detail in Table 1. To prevent moisture loss, samples were placed in polythene bags before being transported to the Laboratory. The soil samples were air-dried, pulverized, and sieved prior to testing. This study made use of hydrated lime. A 25 kg bag of hydrated lime ($Ca(OH)_2$) was purchased from a chemical store in Ado - Ekiti. The lime was kept cool and dry, away from rain and other forms of moisture. The specimens were prepared with potable water (free of dissolved solids and particulates).

Table 1: Description of the soil samples

S/N	State	Sample label	Location (Road)	Coordinates	
				Latitude	Longitude
1	Ekiti(EK)	EK1	Itawure - Aramoko Ekiti	7° 32′32″	8° 49′27″
		EK2	Ikole - Ijesa Isu Ekiti	7° 45′28″	5° 31′08″
		EK3	Aisegba – Iluomoba Ekiti	7° 36′38″	5° 28′08″
2	Ondo(OD)	OD1	Akure - Ogbese	7° 56′39″	8° 04′57″
		OD2	Owo – Ikare Akoko	8° 29′11″	8° 01′15″
		OD3	Ondo-Ore	7° 06′20″	7° 54′13″
3	Osun(OS)	OS1	Osogbo - Ikirun	7° 47′47″	4° 34′16″

		OS2	Ilesha - Ijebujesa	7° 38′32″	4° 43′14″
		OS3	Owode – Ode omu	7° 33′48″	4° 24′00″
		OY1	Ogbomoso - Oko	8° 31′15″	4° 17′12″
4	Oyo(OY)	OY2	Igbeti - Ogbomoso	8° 44′43″	4° 08′17″
		OY3	Ibadan - Fiditi	7° 34′21″	3° 55′31″
		OG1	Abeokuta – Itori	5° 29′28″	8° 19′31″
5	Ogun(OG)	OG2	Shagamu - Ishara	6° 11′05″	8° 06′33″
		OG3	Ilaro - Papanlato	5° 32′36″	8° 02′07″
		LG1	Apapa Wharf – Apapa Expressway	6° 27′16″	3° 22′05″
6	Lagos(LG)	LG2	Lekki – Ajah Expressway	6° 26′21″	3° 31′25″
		LG3	Oshodi – Agege Expressway	6° 33′33″	3° 20′21″

2.2 Methods

2.2.1 Oxide composition of lime

The oxide analysis of the lime was however carried out at the laboratory of the National Steel Raw Materials Exploration Agency, Kaduna.

2.2.2 Natural and Stabilized Soil

In their natural air-dried form, soil samples were collected and subjected to engineering testing. BS 1377 (1990) was followed in conducting the various geotechnical tests. After that, the soil samples were stabilized by adding lime in amounts of 2, 4, 6, 8, and 10% to the dry weight of the soil. California Bearing Ratio (CBR), compaction, and unconfined compression strength (UCS) of the soil samples were all measured. The following are the procedures for the tests:

2.2.3 Compaction test

Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the samples were obtained. The established OMC was later used in CBR and UCS experiments. In compliance with BS 1377 (1990), a standard proctor method was employed. The natural soil and blended soil samples were compacted using a Proctor mould. The mould has a volume of 1000 cm^3 while the rammer used is about 2.5 kg. The compaction was done in three (3) layers and each of the layers received twenty-five (25) blows after which specimens were taken. This was taken at the bottom and top of the mould for the determination of moisture content.

2.2.4 California Bearing Ratio

The California State Highway Department developed this empirical test for estimating subgrade strength. A specimen with a height and diameter of 127 and 152 mm was compacted into the CBR mould according to BS 1377 (1990). The specimens were prepared in 5 (five) layers with each layer getting 56 (fifty-six) blows of the heavy rammer. The load necessary to cause a 49.65 mm diameter and penetrate the soil sample at a rate of 1.25 mm/min was then calculated. To calculate the CBR value from the test results, the corrected plunger force values for specific penetrations (2.5 and 5.0 mm) were expressed as a percentage of a standard force. The loads that caused the specimens to penetrate the same amount were compared using the 2.5 and 5.0 mm penetration. The standard loads are 13.24 kN and 19.96 kN for 2.5mm and 5.0mm penetration respectively.

2.2.5 Unconfined Compressive Strength

This is the ability of the soil to withstand compression failure as well as its drainage condition. The specimens were extracted from the Proctor mould. The results were adjusted by a factor of 1.04. This conforms to cylindrical specimens with a height/diameter ratio of 2:1 or 150 mm cube. The evaluation of the soil's strength was done by crushing the specimens, and the weight that caused the specimen to fail was divided by the cross-sectional area of the specimen.

2.2.6 Statistical analysis

A two-way analysis of variance (ANOVA) was done using IBM SPSS 25 statistical package. A 5% significance level was used to obtain the inferential result. The dependent variables are MDD, OMC, Soaked CBR and UCS while the independent variables are the lime content and location.

3. Results and Discussion

3.1 Lime

The chemical composition (%) of the hydrated lime is shown in Table 2. The hydrated lime has high CaO content with a composition of 74.75 %. The cementing potential i.e. CaO/SiO_2 (Edeh et al., 2020) is 17.84 which is quite high.

Table 2: Chemical Composition of the Lime (in percentage)

Parameters	SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	K2O	P2O5	TiO2	LOI
Lime	4.19	4.56	0.32	74.75	14.76	0	0.13	0	0	4.68

Source: Ayodele *et al.,* (2022)

3.2 Index properties of the unstabilized soil

The engineering properties of soil are not only influenced by shear strength characteristics but also by index properties (Oyelami & Van Rooy, 2016). The index properties of the geopolitical zone's soils are presented in Table 3. The natural moisture content (NMC) was within the 5 – 15 % range reported by Emmanuel et al., (2021) except for OD1, OD3 and OY1. The observed values could be a result of existing drainage conditions, the depth of the soil as well previous rainfall data (Ramamurthy & Sitharam, 2005). The specific gravity (Gs) ranged from 2.4 - 2.6, 2.3 – 2.6, 2.4 – 2.6, 2.0 – 2.8, 2.2 – 2.4 and 2.3 – 2.5 for Ekiti, Ondo, Osun, Oyo, Ogun and Lagos states respectively. The suitability of soil samples for highway subgrade materials can be preliminarily assessed by the % fines in the soil samples. FMWH (1997) adopting the AASHTO classification system recommended a maximum of 35 per cent (≤ 35%) for excellent – good subgrade material while % fines greater than 35% (> 35%) are fair – poor subgrade materials. Nine (9) soil samples - EK3, OD2, OD3, OS1, OY2, OY3, OG3, LG2 and LG3 – are rated Excellent – Good while the remaining nine (9) are Fair – Poor subgrade materials. The plasticity of the soil samples measured from the Plasticity Index (PI) showed that PI ranges are 11.3 – 24.2%, 8.1 – 13.9%, 12.2 – 15.7%, 7.3 – 20.2%, 12.0 – 16.5% and 16.8 – 20.5% for Ekiti, Ondo, Osun, Oyo, Ogun and Lagos states soils respectively. Largely, the values fell within the stipulated maximum of 20% for highway subgrade materials stipulated by FMWH (1997). EKI and OY1 soil samples were exceptions. However, only EK2, OD2, OD3, OY1, OY3, and OG3 samples met the requirement of not more than 12% (≤ 12%) for subbase and base materials.

Table 3: Index properties of the soil (Selected Southwest Nigeria) samples

Property	EKITI			ONDO			OSUN			OYO			OGUN			LAGOS		
	EK1	EK2	EK3	OD1	OD2	OD3	OS1	OS2	OS3	OY1	OY2	OY3	OG1	OG2	OG3	LG1	LG2	LG3
NMC (%)	13.7	14.7	6.5	30.3	7.1	31.8	3.3	4.7	6.7	17.9	7.4	3.8	3.2	7.4	6.5	14.6	14.3	13.0
Gs	2.6	2.4	2.4	2.3	2.6	2.3	2.6	2.4	2.6	2.0	2.8	2.3	2.2	2.4	2.2	2.3	2.5	2.3
% fines	47.0	37.5	21.0	43.6	23.9	25.3	21.6	59.2	46.5	43.0	0.7	25.6	55.5	36.0	22.9	49.6	2.7	18.9
% sand	41.2	31.8	39.0	45.4	73.1	20.7	24.4	22.8	9.5	47.0	60.3	47.4	37.5	41.0	68.1	40.4	95.8	79.1
% gravel	11.8	30.7	40.0	11.0	3.0	54.0	54.0	18.0	44.0	10.0	39.0	27.0	7.0	23.0	9.0	10.0	1.5	2.0
LL (%)	51.0	32.0	34.0	45.0	44.0	38.0	44.0	43.5	50.0	26.1	30.0	35.0	53.0	38.0	45.0	41.8	38.2	39.0
PL **(%)**	26.8	20.7	20.3	31.1	33.9	29.9	28.3	31.1	37.8	16.8	9.8	27.7	36.5	25.1	33.0	21.3	19.8	22.2
PI (%)	24.2	11.3	13.7	13.9	10.1	8.1	15.7	12.4	12.2	9.3	20.2	7.3	16.5	12.9	12.0	20.5	18.4	16.8
Soil class (AASHTO)	A-7-5	A-2-6	A-2-6	A-7-5	A-2-5	A-2-4	A-2-7	A-7-6	A-7-5	A-4	A-2-6	A-2-4	A-7-5	A-6	A-2-7	A-3	A-6	A-2-6

3.3 Effect of lime addition on the MDD of the stabilized soil samples

Figures 1 and 2 present the findings of compaction tests on lime-stabilized soil samples. There was an increase in the MDD values for the selected soil samples increased until they reached 6% but fell thereafter, whereas a contrasting behaviour was observed with the OMC values which increased until they reached 10%. Ekiti stabilized soils had values of 1764 to 2127 kg/m^3 and 10.2 to 21.9% for MDD and OMC respectively while Ondo stabilized soils had values of 1416 to 2033 kg/m^3 and 14.9 to 28.7 % for MDD and OMC respectively. The ranges of MDD and OMC are1686 to 1948 kg/m^3 and 12.6 to 18.4% for Osun stabilized soils while Oyo stabilized soils also had 1805 to 2412 kg/m^3 and 11.00 to 19.7% for MDD and OMC respectively. MDD and OMC values of Ogun stabilized soil ranges are 1650 to 1970 kg/m^3 and 10.0 to 18.5% respectively while Lagos stabilized soil samples had their MDD and OMC values ranging from 1189 to 1995 kg/m^3 and 7.5 to 15.1%, respectively.

In general, increasing the lime content up to 6% results in an increase in the MDD values of all stabilized soil samples before a decline is observed. The statistical range of the percentage gain observed with optimal 6% lime addition across the six (6) states showed the followed trend: Oyo (20.99 %) > Ondo (16.42 %) > Ogun (14.89 %) > Lagos (11.7 %) > Osun (7.84 %) > Ekiti (3.63 %). The improvement of the MDD with 6% lime addition was felt best on Oyo state and the least was observed on Ekiti soils. The general increase is caused by the lime coating of soil particles, whereas the decrease is due to the lime fine particles replacing the lower specific gravity soil sample fine particles (Ugwu & Famuyibo, 2014; Adetoro & Faluyi, 2015; Osinubi et al., 2017). As the lime content increases, so does the OMC. This is due to the addition of lime, which reduced the quality of coarse materials, clay fraction and silt with large surface areas. According to Adetoro & Dada (2015), more water is required to compact the soil-lime mixture. After stabilization with 6% lime content, nine (9) of ten (10) soil samples (OD1, OD2, OD3, OS2, OS3, OG1, OG2, LG2, and LG3) that were not initially suitable as sub-grade material became suitable i.e. ≥ 1760 kg/m^3. On the other hand, six (6) soil samples (EK2, EK3, OD3, OY1, OY2, and OY3) were found suitable as sub-base and base material after 6% lime addition (FMWH,1997).

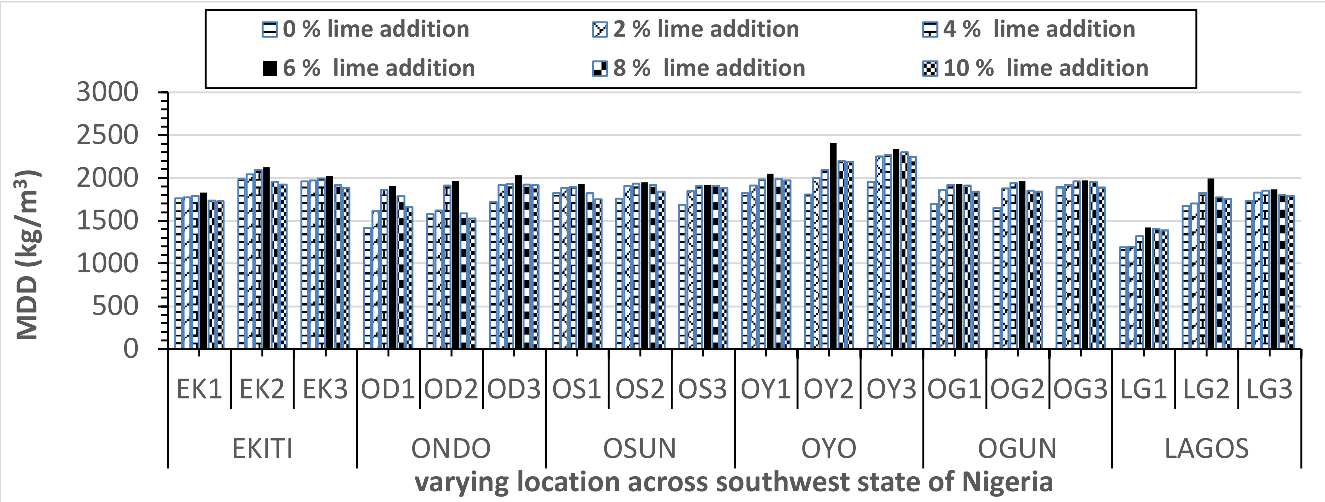

Figure 1. MDD characteristics of the unstabilized and stabilized soil

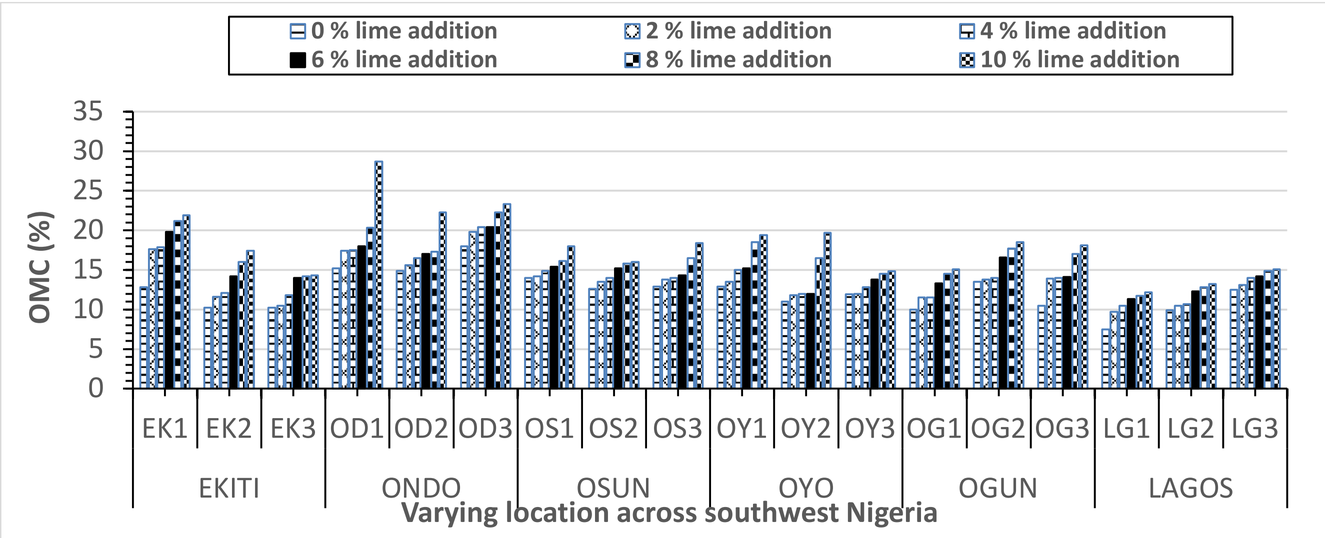

Figure 2. OMC characteristics of the unstabilized and stabilized soil

3.4 Effect of lime addition on the CBR of the stabilized soil samples

The CBR values (soaked) of all the samples are shown in Figure 3. Ekiti soils range from 11.0 to 34.0% whereas Ondo soils range from 2.4 to 7.2%. On the other hand, the Osun soil ranges from 2.3 to 20.4%, while the Oyo soil ranges from 1.3 to 52%. Further, Ogun soils have ranges to be from 2.0 to 19.9%, while Lagos soils range from 3.7 to 7.4 %. There was an improvement in the CBR of the soils up to 6% lime addition before a decrease was observed as the lime addition increased. The statistical range of the percentage gain observed with optimal 6% lime addition across the six (6) states showed the followed trend: Oyo (1861.54 %) > Osun (708.01 %) > Ogun (525.88 %) > Ondo (145.83 %) > Ekiti (72.79 %) > Lagos (53.96 %). The improvement of the CBR with 6% lime addition was felt best on Oyo state and the least was observed on Lagos soils.

The increase in CBR value up to 6% is due to the gradual development of cementitious compound between the Calcium Hydroxide ($Ca(OH)_2$) present in the soil and the lime. However, the significant decrease in CBR values in the stabilized soil samples with 8 and 10% lime addition can be attributed to excess lime content that was not mobilized in the reaction and hence filled spaces within the soil sample, limiting bonding in the soil-lime mixes (Adetoro & Dada, 2015; Ugwu & Famuyibo, 2014). The improvement potential of lime on the stabilized soil mixtures is evident. There were initially twelve (12) soil samples unsuitable for subgrade application (< 5%) but later improved to become suitable (> 5%) with the addition of 6% lime. EK1, EK2, EK3, OY2 and OY3, were found to be suitable sub-base applications with 6% lime addition as they were more than 30% (FMWH, 1997). According to studies by Amu et al. (2011a, b, and c); Adetoro & Faluyi (2015), soil samples improved as a result of stabilization.

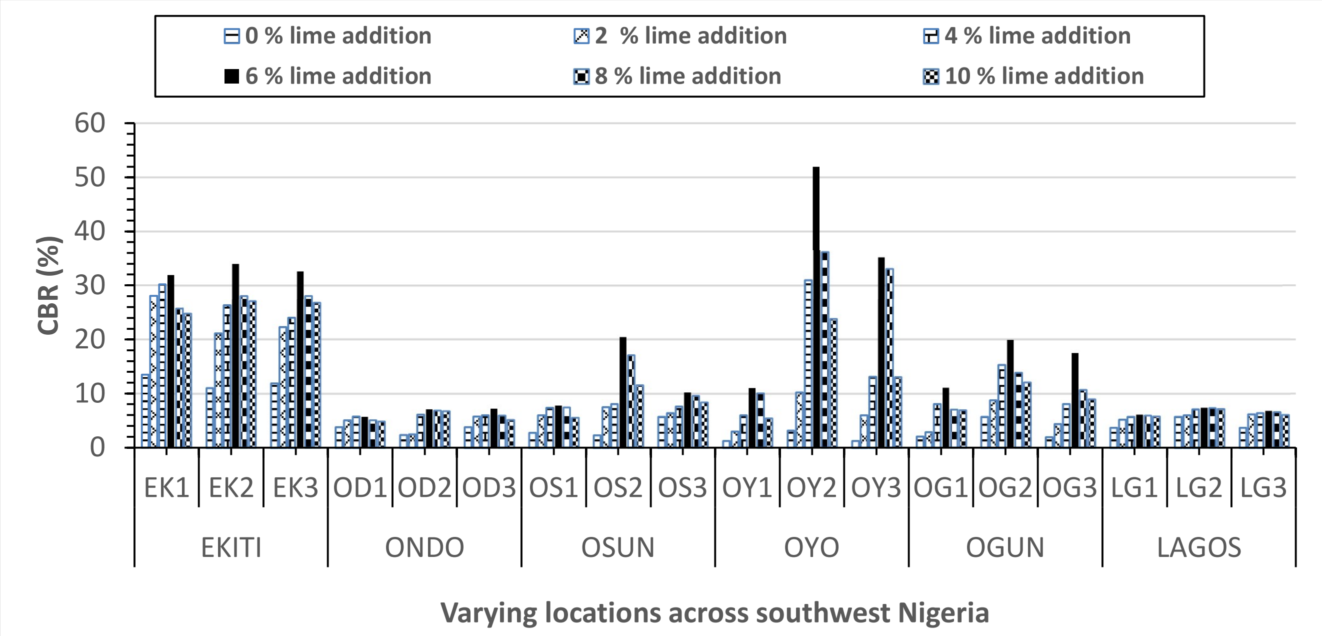

Figure 3. CBR behaviour of the unstabilized and stabilized soil

3.5 Effect of lime addition on the UCS characteristics of the stabilized soil samples

Figure 4 shows the result of the UCS behaviour of lime-stabilized soil samples. With an increase in lime content, the UCS values for the stabilized samples increased by up to 6% before declining. UCS values ranged between 123.2 and 937.4 kN/m^2 for Ekiti-stabilized soil samples and it also ranged from 44.9 to 255.7 kN/m^2 for Ondo-stabilized soil samples. For Osun and Oyo Stabilized soil samples, the ranges of UCS values are 115.1 to 588.8 kN/m^2 and 82 to 279 kN/m^2 respectively. The values of UCS ranges are 136 to 241 kN/m^2 and 47.68 to 322.80 kN/m^2 for Ogun and Lagos stabilized soil samples respectively. UCS values in all the stabilized soil samples increased with increasing lime content up to 6%, then decreased. According to Oyediran and Okosun (2013), the addition of around 6% lime increased the UCS of the soil significantly, resulting in a more than 100% increase in the UCS of the soil samples. The statistical range of the percentage gain observed with optimal 6% lime addition across the six (6) states showed the followed trend: Osun (305.41 %) > Ekiti (208.14 %) > Ondo (132.12 %) > Lagos (95.62 %) > Oyo (43.38 %) > Ogun (25.02 %). The improvement of the MDD with 6% lime addition was felt best on Osun state and the least was observed on Ogun soils.

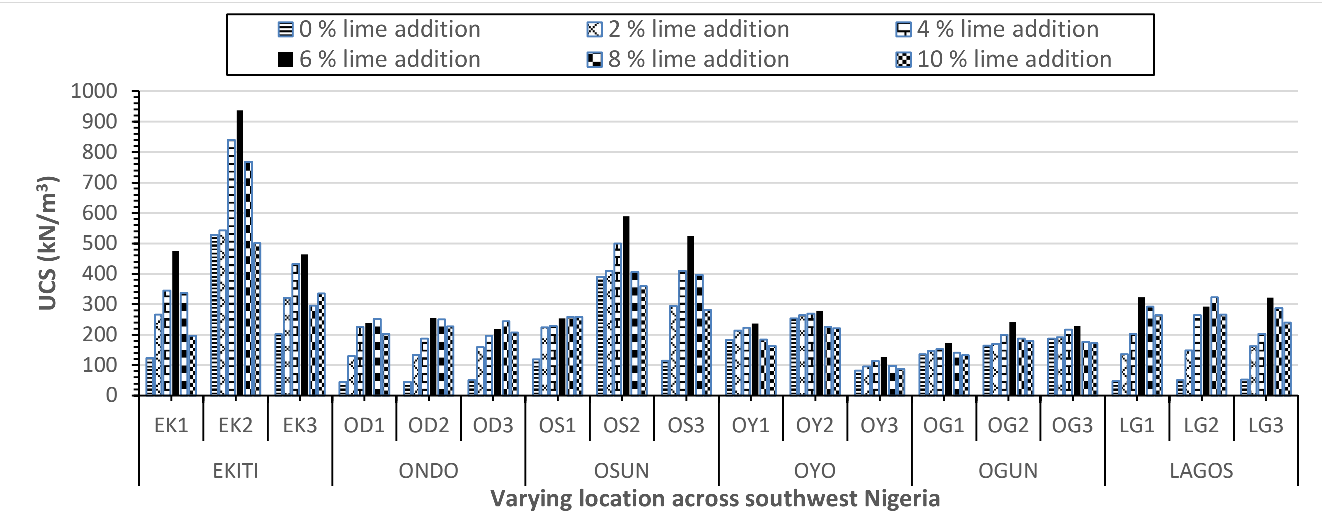

Figure 4. UCS behaviour of the unstabilized and stabilized soil

3.6 Statistical analysis

The Two-way ANOVA was performed to understand the relationship between the independent variables (varied lime content and location) and dependent variables (MDD, OMC, Soaked CBR and UCS). The effect of the varied lime addition as well as the varied location is presented in Table 4. The two-way ANOVA showed that there was a statistically significant relationship between the effects of lime content and location on MDD, OMC, Soaked CBR and UCS of the soil samples. The p – values of 0.000 which portrayed high relationship was obtained. A R-Squared of 0.922, 0.943, 0.83, and 0.868 were obtained for the ANOVA analysis for MDD, OMC Soaked CBR and UCS respectively. The R-Squared values showed the variation in the dependent variable as explained by the independent variables. Also, the adjusted R-Squared - a modified version of R-Squared - which adjusts for the independent variables were 0.891, 0.920,0.772 and 0.815 for MDD, OMC, Soaked CBR, UCS respectively. Also, the multiple comparison (LSD) test (supplementary table) showed that 0% lime addition expectedly has significant relationship with 2%,4%,6%,8% and 10% lime addition in the behaviour of the engineering parameters except with 2% lime content for Soaked CBR. 2% lime addition, also is statistically significant in the engineering performance of the stabilized soil with 0%, 4% and 6% for MDD, 0%, 6%, 8% and 10% for OMC, 6% and 8% for Soaked CBR and 0%, 4% and 6% for UCS. For 4% lime addition, there is statistically significance with 0%, 2% and 10% for MDD, 0%, 8% and 10% for OMC, 0%, 6% for Soaked CBR and 0% and 2% for UCS. For the optimum lime addition of 6%, there exist a statistical significance with 0%, 2%,8% and 10% for both the compaction characteristics (MDD and OMC). There was also statistical significance with 0%,2% and 10% for both Soaked CBR and UCS as well as with 4% for Soaked CBR.

For 8% lime addition, there is statistically significance with 0% and 6% for MDD, 0%, 2%, 4%, 6% and 10% for OMC, 0% and 2% for Soaked CBR and 0% only for UCS. There was also statistical significance between 10% lime addition and 0%, 4%, 6% for MDD, 0%, 2%,4%, 6% and 8% for OMC, 0% and 6% for both Soaked CBR and UCS.

Table 4. ANOVA summary table

Dependent Variable: MDD					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	919752.448[a]	10	91975.245	29.657	.000
Intercept	124823415.554	1	124823415.554	40249.411	.000
Lime content	215655.228	5	43131.046	13.908	.000
Location	704097.221	5	140819.444	45.407	.000
Error	77531.206	25	3101.248		
Total	125820699.208	36			
Corrected Total	997283.654	35			
a. R Squared = .922 (Adjusted R Squared = .891)					
Dependent Variable: OMC					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	299.265[a]	10	29.926	41.395	.000
Intercept	8034.134	1	8034.134	11112.930	.000
Lime content	135.703	5	27.141	37.541	.000
Location	163.562	5	32.712	45.248	.000
Error	18.074	25	.723		
Total	8351.473	36			
Corrected Total	317.339	35			
a. R Squared = .943 (Adjusted R Squared = .920)					
Dependent Variable: Soaked CBR					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2339.351[a]	10	233.935	12.884	.000
Intercept	4913.075	1	4913.075	270.585	.000
Lime content	633.021	5	126.604	6.973	.000
Location	1706.330	5	341.266	18.795	.000
Error	453.931	25	18.157		
Total	7706.357	36			

Corrected Total	2793.282	35			
a. R Squared = .837 (Adjusted R Squared = .772)					
Dependent Variable: UCS					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	477292.978[a]	10	47729.298	16.441	.000
Intercept	2349082.438	1	2349082.438	809.194	.000
Lime content	127893.958	5	25578.792	8.811	.000
Location	349399.020	5	69879.804	24.072	.000
Error	72574.772	25	2902.991		
Total	2898950.189	36			
Corrected Total	549867.751	35			
a. R Squared = .868 (Adjusted R Squared = .815)					

4. Conclusion

The parameters of the lime-stabilized soil (CBR, MDD, OMC, and UCS) were assessed. With an increase in lime content, all of the strength parameters improved, especially at the optimal addition of 6%. At the optimal addition of 6% lime, there was a percentage gain ranging from 3.42 – 7.05 %, 18.40 – 34.82 %,6.04 – 13.88 %, 12.64 – 33.63 %, 3.96 – 18.85 % and 7.73 – 19.43 % for MDDs of Ekiti, Ondo, Osun, Oyo, Ogun and Lagos state soil samples respectively. Also, with the addition of 6% lime (the optimal), the percentage gain range from 136.30 – 209.09 %, 50.00 – 195.83 %, 78.95 – 786.96 %, 746.15 – 2607.69 %, 249.12 – 775.00 % and 29.82 – 83.78% for CBR of Ekiti, Ondo, Osun, Oyo, Ogun and Lagos state soil samples respectively. Further, UCS gains ranging from 77.57 – 285.71 %, 327.40 – 430.07 %, 50.63 – 356.04 %, 10.28 – 53.66 %, 21.93 – 46.95 %, 481.11 – 576.73 % were observed for Ekiti, Ondo, Osun, Oyo, Ogun and Lagos states soil respectively. Generally, the engineering properties of the soil improved; as nearly all of the unsuitable soil samples became suitable for subgrade and subbase materials. Comparatively, the effect of the optimal 6 % lime addition on soil was prominent in Oyo state soils Based on the foregoing, lime particularly at an optimal level of 6% is a suitable stabilizing agent for soils in Nigeria's southwestern region and should be used to stabilize soil samples in the region, especially for subgrade application. However, due to the need for a thorough evaluation and the need to lower construction costs, lime addition dosage at 1 % rather than 2 % should be evaluated on the previously evaluated engineering properties as well as others such as triaxial shear test, consolidation, and durability.

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