Influence of Compaction Delay on CBR and UCS of Cement Stabilized Lateritic Soil.

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ABSTRACT

The results of a statistical study on the influence of compaction delays on properties of cement-stabilized yellowish brown tropical soil was conducted using two-way analysis of variance and multiple regression analysis. The effects of compaction delays on California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) are statistically significant at the 5% level, for different compactions, cement contents, and curing regardless of the compactive effort employed (standard Proctor and West African Standard). The t-statistics from regression analysis show that compaction delays significantly influence the measured value of CBR and UCS. It is recommended that the findings of this study will be useful in controlling the compaction delay for cement-treated yellowish brown lateritic soil.

(Keywords: compaction delays, cement, regression analysis, California bearing ratio, unconfined compressive strength, compactive efforts)

INTRODUCTION

World climatic zones govern the regional distribution of lateritic soils. Laterites occur in the tropics and subtropical regions of the world and deposits have been identified in six main regions of the world and these are: Africa, India, South-east Asia, Australasia, Central and South America (CIRIA,1988). The formation of lateritic soils requires conditions of temperature and rainfall similar to those of the humid tropical and sub-tropical zones; regional occurrence can therefore be broadly related to these zones (CIRIA, 1988). According to Gillot (1987), laterite soils are formed in hot, wet tropical regions with annual rainfall between 750 and 3000 mm (usually in area with a significant dry season) on a variety of different types of rocks with high iron content. Laterite formation factors include climate (precipitations, leaching, capillary rise and temperature), topography (drainage), vegetation, parent rock (iron-rich rocks) and time. Of all these primary factors, climate is considered the most important (Gilliot, 1987). The location and distribution of lateritic materials have been associated with temperature and rainfall conditions that characterize the earth's surface between latitudes 35^{o}N and 35^{o}S (Gidigasu, 1976). They are the product of intensive weathering that occurs under tropical and subtropical conditions. They also have naturally stable grading with a suitable proportion of clay materials to act as binder (Ackroyd,1960). They have characteristic reddish shades, which appear to be due to the various degree of iron, titanium and manganese hydration. The shades also reflect the degree of maturity with age; ferruginous laterite soils seem to change from red to brown to black while aluminous soils become brighter in color (Maignien, 1966).

Meanwhile, laterites are used extensively as base and sub-base road materials for low cost road and those that carry low to medium traffic. They may be classified as problem and non-problem types. Problem laterites are those that have reputation of being problematic in road construction. These types of soils are easily noticed in highway and airfield pavement where they are uses as sub-bases material, resulting in pavement swelling, depression and lateral movements in the presence of water even under moderate wheel loads. These types of laterite are characterized by high natural water contents and liquid limits, low natural densities and friable and/or crumble structure (Gidigazu and Kuma, 1987). Hence, it can be stated that laterites that do not possess these properties are non-problem types. In some cases the properties of soils used for construction mat not meet the required standards. In such cases it may not be economically justifiable to import materials that meet such standards to the construction sites. The need thus arises to improve the properties of the available soils. Soil stabilization, which refers to a process whereby the physical and/or chemical properties of a soil are modified in order to suit the purpose for which a soil is meant, has been an old practice by personnel that utilize soils as construction materials.

Portland cement is the most important hydraulic cement utilized extensively in various types of cement stabilization of lateritic soils. Cement acts as a binder and provides the much desired hardening and strengthening properties. The addition of cement also increases compressive strength, the resistance of lateritic soils to freezing and thawing, wetting and drying. It also affects the particle size distribution of the soils by increasing the size of fine particles. Conventionally, Portland cement have been used to appreciably improve the properties of soils (Ola, 1975; 1983; Osula, 1989; Scullion and Harris, 1998; Berthelot *et al.*, 2005; Gadzama, 2009). Adeyemi and Abolurin (2000) also stated that cement stabilized samples exhibited the highest cured strength when compared with lime and some mixture of both. Gadzama (2009) also established that 4% cement can be recommended as an optimal content to stabilize soil from parts of Northern Nigerian.

Ola (1977) noticed an increase in the compressive strength of lateritic soils with cement content. Curtis et al. (2009) stated that full-depth reclamation and cement stabilization enabled significant volumes of in-place granular materials to be reclaimed and strengthened while allowing for the installation of a woven geotextile and sand drainage system over a wetted-up subgrade in a more cost-effective and sustainable construction manner.

Interestingly compaction delays have been shown to affect some properties lime stabilized soil (Osinubi, 1998; Osinubi and Nwaiwu, 2006) but much have not been stated regarding the influence of compaction delays on cement-stabilized soil. It is on this basis that this research is aimed at investigating and evaluating the influence of compaction delay on CBR and UCS of cement stabilized Yellowish brown tropical soil Compaction delays have been shown to affect certain properties of lateritic soil-lime mixtures (Osinubi, 1998; Osinubi and Nwaiwu, 2006). The objective of this study is to show the effects of compaction delays on the properties of cement stabilized Yellowish brown tropical soil. Results from the study are also used to predict the compaction and strength properties of the stabilized soil based on variables that include time delay.

MATERIALS AND METHODS

Soil

The soil used in this study is a natural yellowish-brown lateritic soil obtained from a borrow pit in Ede (Latitude 7^{o}41’ N and Longitude 4^{o}35’E), in Nigeria, using the method of disturbed sampling. The soil is classified as A-7-6 according to the AASHTO Soil Classification System (AASHTO, 1986, 2002) and CL according to the Unified Soil Classification System (ASTM, 1992, 2002, 2007). Geologically, the study area lies within southwestern Nigeria basement complex. It forms part of the African crystalline shield. The basement complex is composed predominantly of folded gneisses, migmatite, schist and quartzite of the Precambrian age. There exist two distinct seasons, namely: wet and dry seasons. The wet season starts in April and ends early October while the dry season in late October and ends in early April.

Cement

Portland cement which is the most common type of cement in general use in this part of the country was used as stabilizing agent in this study.

Water

Potable water was used for the preparation of the specimens at the various moisture contents.

Clay Mineralogy

The clay mineralogy of the material of fractions passing through a British Standards-BS No. 200 sieve was assessed by x-ray diffraction (XRD) and supplemented by differential thermal analysis (DTA).

Index Properties

Laboratory tests were carried out on the natural soil to determine its index properties in accordance with BS (British Standard, 1990a) while the one for the soil-cement mixtures were carried out in accordance with BS (British Standard, 1990b).

The CBR were carried out in conformation with the recommendations of the Nigerian General Specifications for Roads and Bridges (Nigerian General Specification, 1997), which states that specimens be cured for 6 days un-soaked and immersed in water for 1 day before testing.

Compaction of Soil

The Standard Proctor (SP) and West African Standard (WAS) compaction procedures were utilized during the tests. The SP compactions utilized 3 layers applying 27 blows each of a 2.5kg rammer falling from a height of 300mm using 1000cm^3 mould. For the West African Standard, compactive effort which is the conventional energy level commonly used in the region, consist of energy level derived from a 4.5 kg rammer falling through 450 mm height onto five layers using 10 blows each.

Soil-Cement Mixtures

Samples of soil and soil-cement mixtures were prepared by mixing the desired proportions of potable water, soil and cement. Percentages of cement ranged from 0 to 9% by weight of dry soil, while percentages of moisture content ranged from 8 to 32%. The soil-cement mixtures were prepared by first thoroughly mixing dry predetermined quantities of crushed soil, cement and in a mixing tray to a uniform paste. The required amount of water determined from moisture-density relationships for soil-cement mixtures was later added to the dry soil-cement and both left for elapse times of up to 3 h (i.e., 0, 1, 2, and 3 hours) before compaction.

Strength Tests

Specimens were cured for 7, 14, and 28days in case of unconfined compression, but the CBR specimens were cured for 6 days un-soaked and immersed in water for 1 day before testing in accordance with the Nigerian General Specifications for Roads and Bridges (Nigerian General Specification, 1997).

Methods of Analysis

Laboratory findings were first presented graphically to reflect trends in the effects of cement content and compaction delays on the compaction characteristics as well as strength properties of the soil. The two-way analysis of variance (without replication) was then used to assess, in qualitative terms, the relative effects of cement content, curing age and compactive effort, as well as compaction delays on properties of stabilized soil.

The two-way ANOVA was carried out at 5% level of significance. Multiple regression analysis was also carried out in order to predict properties of the soil-cement mixtures from variables that include elapse times.

RESULTS AND DISCUSSION

Properties of Soil and Soil-Cement Mixtures

The particle size distribution of the natural soil is shown in Figure 1. The index properties of the soil are summarized in Table 1. The test matrix for the two-way analysis of variance is shown in Table 2. The variations of MDD with cement contents for no compaction delays as shown in Figure 2 while with OMC are shown in Figure 3.

There is increase in MDD with higher cement content up to 3% cement content and this is followed by a decrease in MDD with higher cement content up to 9% as shown in Figure 2. In all, the maximum dry density increased with an increase in compaction effort, while the optimum moisture content decreases with increase in compaction effort. This has been found to be true in all soils (Braja, 1998).

OMC values decreased up to 3% cement content and increased with higher cement content up to 9% cement content as shown in Figure 3. OMC values decrease with increase in cement content up to 5% and invariably increase at the energy level of standard Proctor.

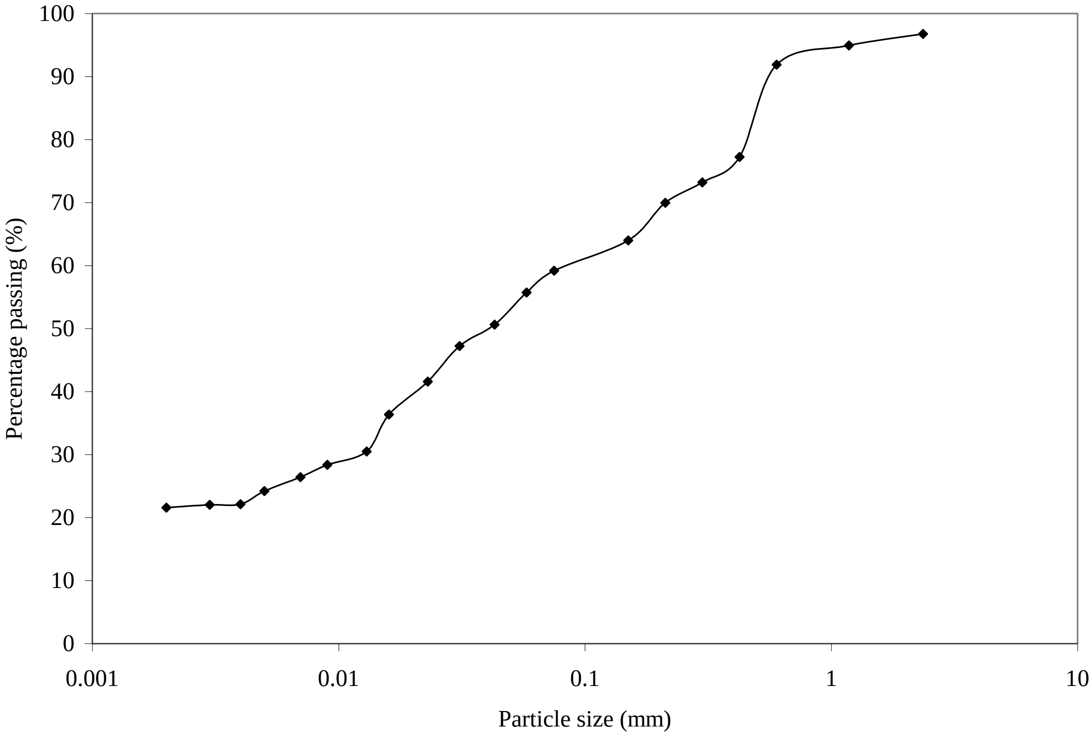

Figure 1: Particle Size Analysis of the Soil Sample.

Table 1: Index Properties of Soil Samples.

Properties	**Quantity**
Natural moisture content, %	6.9
Specific gravity	2.62
Liquid limit, %	48
Plastic limit, %	30
Plasticity index, %	18
Linear shrinkage, %	7.8
% Passing BS No. 40 sieve	77.25
% Passing BS No. 200 sieve	59.2
% < 2 µm	21.57
AASHTO Classification	A-7-6
USCS Classification	CL
Group Index	8
MDD (standard Proctor), Mg/m^3	1.87
MDD (West African Standard), Mg/m^3	1.93
OMC (standard Proctor), %	20.2
OMC (West African Standard), %	16.4
UCS (standard Proctor), kN/m^2	390
UCS (West African Standard), kN/m^2	480
CBR (standard Proctor), %	9
CBR (West African Standard), %	15

Table 2:Test Matrix for Analysis of Variance.

Variables	Compaction Procedure	
	Standard Proctor	**West African Standard**
Cement Content	0, 3, 5, 7, 9	0, 3, 5, 7, 9
Compaction Delays (h)	0, 1, 2, 3 (0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 for MDD)	0, 1, 2, 3 (0, 0.5, 1.0), 2.0, 2.5, 3.0 for MDD
Curing Ages (days)	7, 14, 28	7, 14, 28

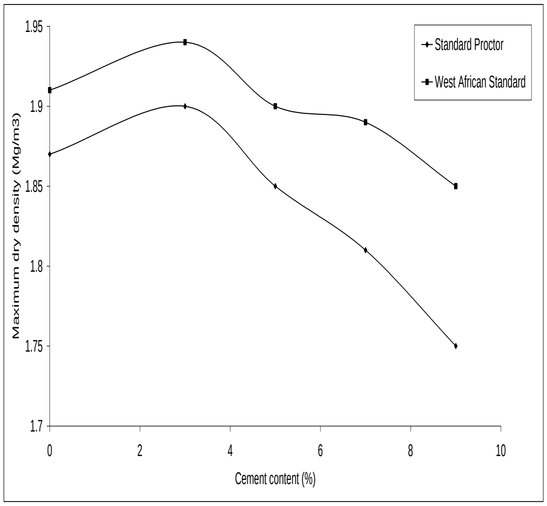

Figure 2: Variation of Maximum Dry Density with Cement Content.

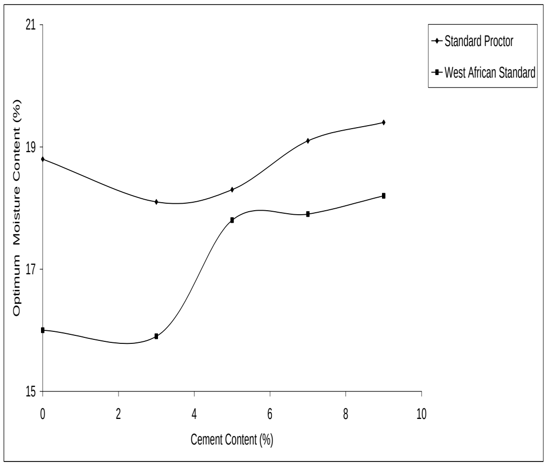

Figure 3: Variation of Optimum Moisture Content with Cement Content.

Strength Characteristics at No Compaction Delay

UCS for all the samples cured for various ages generally increased at no compaction delay with higher cement as shown in Figure 4. All samples exhibit a decrease in UCS values when cement content was in excess of 7% except for the one cured for 7 and 28 days compacted at West African Standard effort.

Excess cement contents in soil act as low strength fillers, which then result in lower values of UCS (Gillot, 1987). CBR values generally increased with higher cement content as shown in Figure 5.

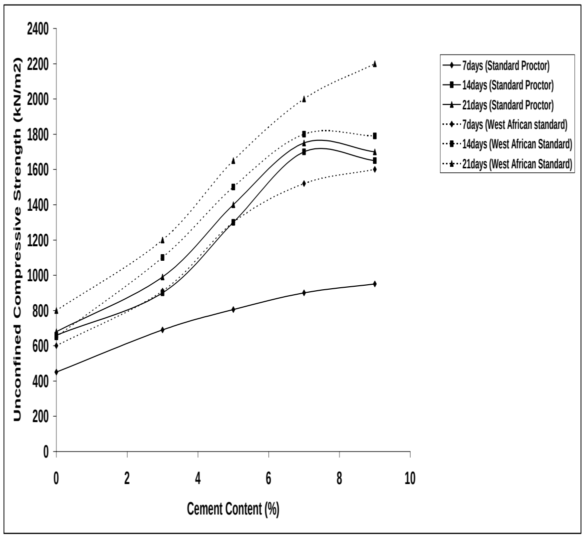

Figure 4: Variation Unconfined Compressive Strength with Cement Content.

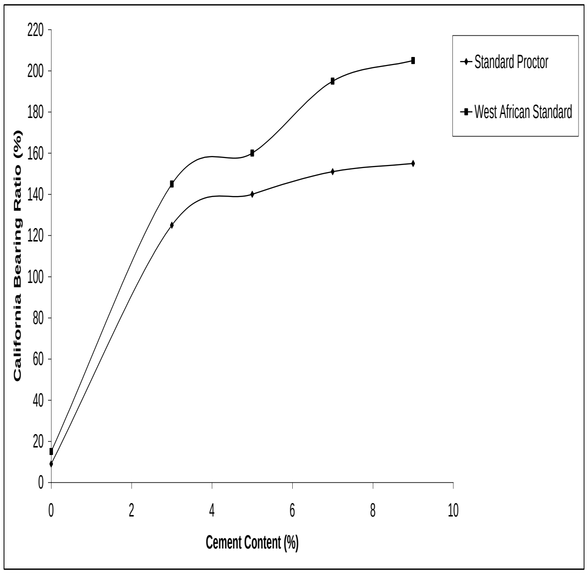

Figure 5: Variation California Bearing Ratio with Cement Content.

Strength Characteristics at Compaction Delays

Compaction delays resulted in reductions in MDD values (Figure 6) for cement content. In the same vein, UCS (Figure 7) and CBR (Figure 8) values also reduced due to compaction delays for soil-cement mixture. The strength characteristics decreased with higher elapse times up to 3h irrespective of the cement content and compactive efforts. The highest UCS values were recorded for specimen containing 9% cement and cured for 28 days under the influence of West African Standard at zero 0h compaction delay. Meanwhile, the lowest UCS values were recorded for specimens containing 3% cement when cured for 7 days as shown in Figure 7.

Statistical Analysis

Two-way analysis of variance (ANOVA) without replication at 5% level of significance was employed to check the contributions of cement and compactive efforts to variations in UCS and CBR. The contributions of compaction delay and curing ages to variations in UCS at different percentages of cement were also evaluated using ANOVA. The relative contributions of compaction delay and cement content to variations in UCS at different curing ages were also evaluated using ANOVA.

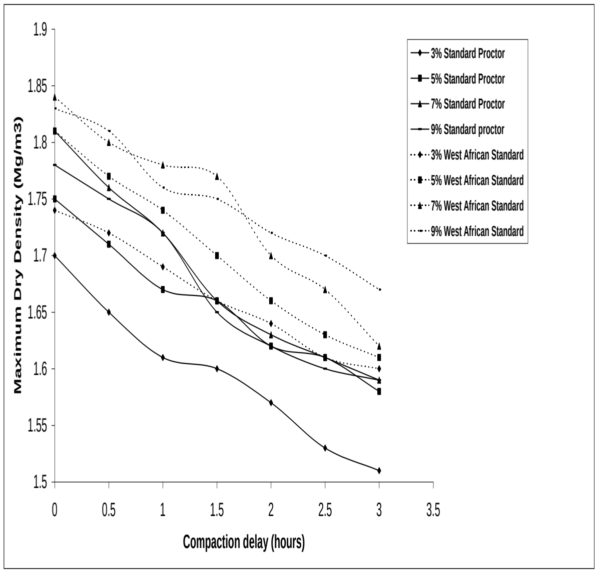

Figure 6: Variation of Maximum Dry Density with Compaction Delays (Cement Content).

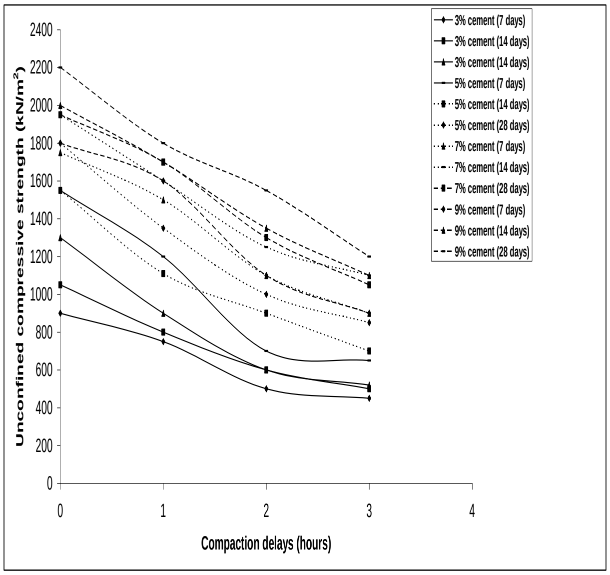

Figure 7: Unconfined Compressive Strength with Compaction Delays for Soil-Cement using West African Standard Energy.

The relative contributions of compactions delay and cement content to variations in CBR were also evaluated. All these were also carried out with respect to cement content.

The results of the contributions of compaction delay and curing age to variations in UCS at specified cement contents were summarized in Table 3. The P-value is the tail probability for a given distribution. The P-Value will be less than 0.05 (for 5% level of significance) whenever the calculated F-value is greater than the critical F-value which is an indicative of the existence of statistical significance in relation to the contributions of a given variable.

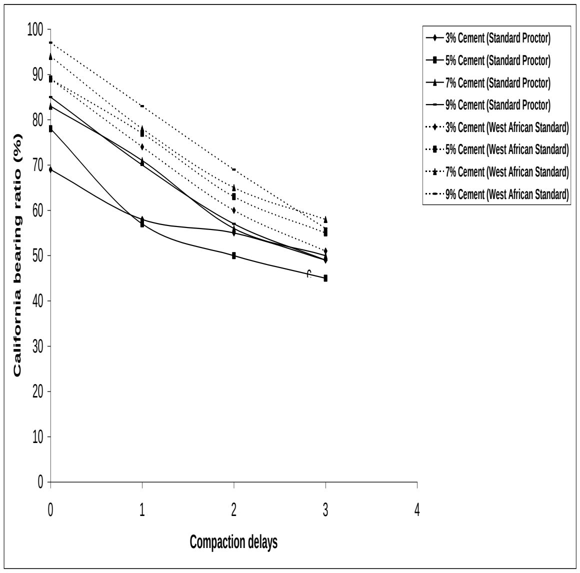

Figure 8: Variation of California bearing Ratio with Compaction Delays for Soil-Cement Mixture.

Properties of Soil-Cement Mixtures at No Compaction Delay

The relative effects of cement content and curing age to variations in UCS and CBR are shown in Table 3. With respect to the contribution of cement content, it could be seen that its contribution to the variation in UCS are statistically significant at $p < 0.05$, regardless of the compactive effort used. The values of calculated F-value (14.32) obtained at the effort of BS compaction suggest that the contributions of cement content and curing age to variations in UCS values are more significant for this soil. Also, the variations in CBR values due to variations in cement content and differences in compactive efforts are statistically significant at 5% levels since all the p-values are less than 0.05. The F-value calculated for the contribution of cement content (i.e., F = 118.65) is more than seven times the F-value for the contribution of compactive effort to variations in CBR of the soil-cement mixture.

Properties of Soil-Cement mixtures at Compaction Delay

The contributions of compaction delay and curing age to variations in UCS were assessed at the specified cement contents and for each of the compactive efforts used. The results of these analyses are summarized in Table 4. Considering the effect of the cement content and compactive effort used, the effects of both compaction delay and curing age on UCS values were statistically significant ($p<0.05$) since Calculate F-values are higher than the corresponding critical F-values. The highest calculated F-values were obtained at 7% cement content with respect to compaction delay and curing age for specimen compacted at both energy levels while the least values were obtained at 3% cement content for both compactive efforts.

Table 3: ANOVA for Cement Stabilized Soil with No Compaction Delay.

Properties	Source of variation	Degree of Freedom	F-Cal	F-Critical	P-Value
UCS (standard Proctor)	Cement content	3	14.32	4.67	4.47E-03
	Curing age	2	9.25	5.23	1.11E-02
UCS (West African Standard)	Cement content	3	15.77	4.67	3.55E-03
	Curing age	2	9.39	5.23	2.15E-03
CBR	Cement content	3	118.65	9.76	2.17E-03
	Compactive effort	1	14.13	10.23	1.21E-02

Table 4: ANOVA for UCS with Different Percentages of Cement and with Compaction Delay.

Properties	Source of variation	Degree of Freedom	F-Cal	F-Critical	P-Value
UCS (standard Proctor)					
3% cement	Compaction delay	3	10.2	4.76	2.34E-04
	Curing	2	14.2	5.14	4.53E-03
5% cement	Compaction delay	3	45.56	4.76	1.21E-05
	Curing	2	68.34	5.14	5.65E-05
7% cement	Compaction delay	3	98.23	4.76	9.11E-04
	Curing	2	102.4	5.14	2.21E-05
9% cement	Compaction delay	3	24.51	4.76	7.23E-06
	Curing	2	31.12	5.14	6.25E-06
UCS (West African Standard)					
3% cement	Compaction delay	3	45.64	4.76	9.17E-05
	Curing	2	45.21	5.14	2.45E-05
5% cement	Compaction delay	3	125.24	4.76	1.45E-06
	Curing	2	137.54	5.14	9.24E-06
7% cement	Compaction delay	3	130.23	4.76	2.89E-06
	Curing	2	168.24	5.14	2.34E-05
9% cement	Compaction delay	3	89.45	4.76	1.11E-06
	Curing	2	100.12	5.14	1.98E-06

The combined effects of compaction delay and cement content on UCS values were evaluated statistically for each curing age and at each compaction energy level. The results of the two-way analysis of variance in these cases are summarized in Table 5.

The contributions of compaction delay and cement content to variations in UCS values are found to be statistically significant at the two energy levels utilized. The compaction delay effects on UCS values at 28 day curing age were lower at the energy level of the standard Proctor with F=79.52 than at the WAS effort with F=107.36 for cement stabilized soil (Table 5).

The F-values obtained at the two energy levels utilized show that the effect of cement content on UCS values decreased with higher curing age The F-values for the effect of cement content at the energy level of standard Proctor effort decreased from 92.51 to 45.56 as the curing age increased from 7 to 28 days. This trend is also the same for WAS compactive effort which decreased from 94.23 to 52.31. From the fore-going, it is certain that compaction energy, compaction delay, curing age, cement content are variables that significantly affect measured UCS values

Also, the difference in compaction delays had significant effects on the variations in CBR values. The F-calculated values at the efforts considered were greater than the F-critical. This is for cement stabilized soil (Table 6). It can thus be satisfactorily stated that the effects of compaction delays had significant effects on UCS and CBR. Hence, compaction delay is an important factor which should be given great consideration when stabilizing yellowish brown lateritic soil with cement constructional processes. This is so because of the decrease in UCS and CBR values associated with higher compaction delays.

Multiple regression analysis procedure was utilized to establish relationships for predicting UCS and CBR. The independent variables in the relationships are compaction delay, cement content, compaction energy. The results of the analyses are presented in Table 7. An index that is essentially an integer categorical value was used to represent the compactive effort. The value of 1 was assigned to the energy of the standard Proctor compaction while -1 value was assigned for the WAS energy effort.

Table 5: ANOVA for UCS of Soil-Cement with Different Curing Times and with Compaction Delay.

Properties	Source of variation	Degree of Freedom	F-Cal	F-Critical	P-Value
UCS (Standard Proctor)					
7 days	Compaction delay	3	92.3	4.76	1.12E-05
	Curing	2	92.51	5.14	9.22E-05
14 days	Compaction delay	3	78.65	4.76	1.33E-05
	Curing	2	34.59	5.14	4.44E-05
28 days	Compaction delay	3	79.52	4.76	4.12E-05
	Curing	2	45.56	5.14	1.44E-05
UCS (West African Standard)					
7 days	Compaction delay	3	98.33	4.76	2.33E-06
	Curing	2	94.23	5.14	9.34E-06
14 days	Compaction delay	3	78.34	4.76	3.22E-06
	Curing	2	82.93	5.14	2.11E-05
28 days	Compaction delay	3	107.36	4.76	2.99E-06
	Curing	2	52.31	5.14	1.99E-06

Table 6: ANOVA for CBR of Cement Stabilized Soil with Compaction Delays.

Properties	Source of variation	Degree of Freedom	F-Cal	F-Critical	P-Value
CBR (standard Proctor)	Compaction delay	3	15.07	5.66	5.23E-04
	Cement content	2	1.77	6.12	8.80E-01
CBR (West African Standard)	Compaction delay	3	15.19	5.66	5.03E-04
	Cement content	2	4.03	6.12	3.10E-01

Table 7: Results of Regression Analysis for Cement-Soil Mixture.

Property	Variables	Coefficients	Standard error	t-statistic	P-value
UCS	Intercept	133.437	112.332	1.01	0.27
	Compaction delay	-100.123	12.67	-3.12	3.42E-06
	Compactive effort	-120.423	15.82	-1.09	1.27E-03
	Cement content	249.034	129.213	3.98	9.12E-02
	Curing age	-99.87	23.81	-1.97	3.29E-02
CBR	Intercept	55.489	3.225	0.96	1.10E-01
	Compaction delay	-14.98	2.101	-2.18	3.13E-03
	Compactive effort	-21.22	0.945	-5.48	4.73E-06
	Cement content	-3.081	0.453	-2.14	9.00E-02
	Optimum moisture content	2.013	1.012	1.08	1.30E-01

Table 8: Statistical Properties from Regression Analysis for Cement-Soil Mixture.

Property	Coefficient of determination, R^2	Adjusted R^2	Standard error of estimate	Overall F-statistic
UCS	0.53	0.5	196.55	13.33
CBR	0.81	0.78	5.67	21.34

Benson and Trast (1996) used integer categorical values to represent compactive effort when a regression model was developed for predicting hydraulic conductivity. It is also conventional to employ such indices in response surface analysis (Miller and Freund, 1985; O'Connor, 1991).

The independent variables used in the prediction of UCS were statistically significant at 95% confidence limit. The following order of importance of the variables was confirmed based on the values of t-statistics obtained, namely compaction delay, compactive effort, cement content, and curing age (Table 7). Considering the prediction of CBR, it could be seen that compaction delay and compactive effort since $p<0.005$ as shown below. The following order of importance of the variables was confirmed based on the values of t-statistics obtained, namely compaction delay, compactive effort, cement content and optimum moisture content (Table 7).

The regression parameters were obtained as shown in Table 9. For cement stabilized soil, $R^2=0.53$; adjusted $R^2=0.5$, standard error of estimate =196.55, and overall F-statistics=13.33. The value of R^2 was extremely low. The low value of R^2 suggests that some other factors are still contribute to the variations in UCS, though the standard error of estimate of UCS is high. The regression parameters for CBR were obtained as shown in Table 8. For cement stabilized soil, $R^2=0.81$; adjusted $R^2=0.78$, standard error of estimate =5.67, and overall F-statistics=21.34.

Studies have been carried out on the influence of compaction delay on the properties, specifically UCS and CBR of the cement stabilized reddish brown tropical which was statistically analyzed using two-way analysis of variance (ANOVA) and regression analysis. At no compaction delay, cement content and compactive effort significantly contribute to variations in CBR. Also, curing age had significant effects on variations in UCS values at the two energy levels used in this study.

The effects of compaction delays on UCS are also statistically significant at both the compaction energies used for various cement content and curing ages. UCS values decreased upon increments in the cement as a result of compaction delay. The highest calculated F-values were obtained at 7% cement content with respect to compaction delay and curing age for specimen compacted at both energy levels while the least values were obtained at 3% cement content for both compactive efforts. The effects of compaction delays on CBR values are also significant at 5% level for both compaction energies. The t-statistics from regression analysis show that compaction delays significantly influence the measured value of CBR and UCS. It is recommended that the findings of this study will be useful in controlling the compaction delay for cement-treated Yellowish brown lateritic soil.

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