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Influence of Compaction Delay on Cement Stabilized Lateritic Soil

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ABSTRACT-*Stabilization of soil is important to enhance the engineering properties of soil like strength, durability and volume stability. During such process some unavoidable delays occurs between mixing the stabilizers with the soil and compaction of the stabilizers mix which affects the properties of stabilized soil. The paper focuses on an investigation into the effect of 0 to 3 hours compaction delay with half an hour intervals on soil - cement mixes 0, 5, 10, 15, 20 and 25% cement contents by weight of dry lateritic soil. The tests carried out on the cement stabilized soil were the Atterberg Limit test, Compaction test, the Compressive Strength test and the California Bearing Ratio (CBR) test. The results obtained showed that the Liquid limit decreased from 37.00% to 30.43% while the Plastic limit increased from 19.31% to 22.57% and Plasticity index decreased from 17.69% to 7.86% with increase in the percentage of cement mix. The results obtained also indicated that the maximum dry density (MDD), optimum moisture content (OMC), compressive strength and California bearing ratio (CBR) decreased by 18%, 14%, 12% and 21% respectively at 3 hours time elapsed between mixing and compaction for 25% cement. For this form of stabilization, treatment with 25% cement and compaction delays not more than 2 hours should be allowed.*

Keywords: California bearing ratio (CBR), Cement, Compaction, delay, Lateritic soil, Stabilizatior.

1. Introduction

In countries of the tropics and subtropics, lateritic soils are encountered in various engineering projects. In the Precambrian times, Nigeria consisted of uplifted continental landmass made up of basement sediments, Kogbe (1975). This resulted in the formation of lateritic soils which are of relatively good quality for road construction works. Lateritic soils are formed under weathering systems know as laterization, the most important characteristic of which is the decomposition of ferro – alumino silicate minerals and the permanent deposition of sesquioxides (Al_2O_3 and Fe_2O_3) within the soil profile to form the material know to engineers and builders as laterite (Gidigasu, 1976). Laterite is a clayey soil rich in iron and aluminium oxides and is formed by weathering of igneous rocks in moist warm climates. It is composed mainly of iron and aluminium compounds and poor in humus and essential plant nutrients such as potassium, nitrogen and phosphorus, but may contain large amounts of quartz and kaolin.

Most lateritic soils in their natural states are at best suitable mainly as sub – base course materials where roads are expected to carry heavy wheel loads. Ola (1974) and Akoto (1987) found that failures of roads are due to the defective nature of lateritic soils which are the commonly available material for base and sub – base construction. However, the constraint in the availability of standard base course materials may be overcome by designing the road to fit the substandard site material by the application of additives which are normally mixed with soil in predetermined economical proportions to achieve favourable improvement of soil properties.

Soil improvement, generally referred to as soil stabilization can be defined as any process aimedat improving the performance of a soil as a construction material. Bell (1993) referred to soil stabilization as the process of mixing additives with soil to improve its volume stability, permeability and durability. Soil stabilization is done mechanically or chemically. The processes, which involves compacting and consolidation of soils are typical mechanical stabilization while processes such as addition of cement, lime, corn cob ash and or with other pozzolanic materials are considered as chemical stabilization. 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 thewing, wetting and drying. It also affects the particle size of fine particles (Bello, 2011). Cement can also be used for stabilization of a wide range of soils. However cement can be applied to stabilize any type of soil, except those with organic content greater than 2% or having pH lower than 5.3 (ACI, 1990).

The Portland cement Association (1959) indicated that it is possible to predict the usual range in cement requirements for mixtures of soil – cement, knowing the AASHTO group of the natural soils. However, the adaptability of that procedure is unreliable for some lateritic soils (ISSMFE, 1982/1985)). This is not unconnected with a likely broad variation in the nature of fines passing BS No. 200 sieve, degree of aggregation and chemical as well as mineralogical constitution of soils within the same AASHTO group. Studies have been conducted in the past by many researchers (Bulman, 1972; Ola, 1975; Kolias et al., 2005; Sariosseiri, 2009; Okonkwo, 2009; Bello, 2011; Bayat et al., 2013) regarding the use of cement alone or in conjunction with lime or pozzolana for improving properties of soil in any region of the world. But delay between mixing the stabilizers with soil and compaction of the soil – stabilizers mix leads to change in both strength and density properties of the soil for fixed compactive effort. Most of the time delay is unavoidable due to any one reason of the following: sudden rainfall, delaying if compacting equipments are used after mixing, poor transportation etc. these make the compaction process a delayed one. These delaying hours significantly affects the strength of stabilized soils. Hence it is necessary to study the influence of compaction delay between the mixing and compaction on the engineering properties of lateritic soil stabilized with cement.

2. Experimental Procedure

2.1 Collection and preparation of lateritic samples

The soil used in this study is a natural reddish – brown lateritic soil obtained from a borrow pit in Awo, Egbedore Local Government Area of Osun State, Nigeria, using the method of distributed sampling. Disturbed samples were collected at 1.0m depth from the natural earth surface to avoid organic matter influence. The soil samples were later air – dried for five days in a cool, dry place. Air drying was necessary to enhance grinding and sieving of the soil. After drying, grinding was carried out using a hammer to break the lumps present in the soil. Sieving was then done to remove over size materials from the soil samples using a wire mesh screen with aperture of about 6mm in diameter as recommended by Oshodi (2004). Fine materials passing through the sieve were collected for use while those retained were discarded away.

Determination of the properties of the natural soil summarized in Table 1 was carried out in accordance with BS 1377 (1990) while its particle size distribution is shown in Figure 1.

2.2 Cement

Portland cement (Elephant 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.

2.3 Water

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

2.4 Equipment and Test Procedures

The tests that were implemented (specific gravity, sieve analysis, atterberg limit, compaction, California bearing ratio and strength tests) were carried out with the basic equipment used to perform these tests. The test procedures are as follows:

1. Preparation of soil samples:
   (a) Soil samples dried
   (b) Soil samples were sieved appropriately
2. Mixing of soil samples:
   (a) Soil samples mixing with Portland cement (with the defined percentage)
   (b) Water added to act as a medium for the reaction process
   (c) Soil samples mixing with Portland cement (with the defined percentage) and water left for elapse times of up to 3 hours.
3. Testing of soil samples:
   (a) determination of natural moisture content
   (b) sieve analysis
   (c) specific gravity
   (d) atterberg limit
   (e) soil compaction
   (f) california bearing ratio (CBR)
   (g) strength

The last five tests (i.e. specific gravity, compaction, atterberg limit, California bearing ratio and strength tests) were then repeated with various percentages of Portland cement.

3. Test Results

The lateritic soil without mixing with cement was tested to examine its physical properties. These properties and grading curve are shown in Table 1 and Figure 1 respectively. The results of the Atterberg limits test for the soil sample mixing with different percentages of cement are shown in Figure 2 while Table 2 shows the compaction test results with different percentages of cement at no compaction delay. The results of compaction tests with different percentages of cement at compaction delay are shown in Figures 3 and 4. The results of compressive strength of stabilized lateritic blocks at no compaction delay are shown in Figure 5 while the results of the compressive strength of stabilized lateritic blocks with compaction delay are shown in Figure 6. The results of California bearing ratio (CBR) with different percentages of cement at no compaction delay are presented in Table 3 while the results of California bearing ratio (CBR) with different percentages of cement with compaction delay are shown in Figure 7.

4. Discussion of Results

4.1 Atterberg Limits

The Atterberg limits of soil samples found in the natural state and mixed with different percentages of cement are shown in Figure 2. There is a strong limit liquidity passing 37.00% to 30.43% decrease. This decrease is due to the variation of water content with increasing cement content. This observation is in good agreement with the results in Bell, 1993; Al - Rawas et al, 2005; Reyes, 2007). The implication of this reduction in soil plasticity, with an increasing amount of cement is attributed to the process of exchange of cations between the soil and stabilizers (Rawas et al., 2005). In contrast, an increase in liquid limit when increasing the percentage of cement has been shown in (Yong and Ouhadi, 2007). We can say that this difference depends on the nature of the soil: namely an increase can occur for kaolinitic clay soils and a decrease may occur for clay montmori - llonite (Attoh – Okine, 1995).

Regarding the plastic limit, the treated samples showed an increase of the limit with the increase of the amount of cement (Figure 2). This limit increased from 19.31% to 22.57%. The same trends have been observed on materials treated with lime (Bell, 1996) and on materials treated with limestone (Okagbue and Yakubu, 2000). It has been shown that the addition of fly ash at low calcium soil swelling causes an increase in the plasticity limit, this is due to the replacement of the fine particles by the larger particles (Goswami and Singh, 2005). However, some authors have shown a decrease in the plastic limit; when the material is treated with a mixture of lime - pozzolana with a high content of lime more than 10% (Mujedu and Ayelabola, 2011; Bairwa R. et. al., 2013).

The plasticity index of the treated samples decreased from 17.69% to 7.86% with increase in cement content from 0% to 25% as shown in Figure 2. This means an improvement in the behavior of the plastic material. The same trend was observed in (Parsons and Kneebone, 2005).

Table 1: Physical Properties of Lateritic Soil

Physical Properties	**Test Result**
Natural moisture content, w, %	23.97
Specific gravity, Gs	2.65
Liquid Limit, LL, %	46.50
Plastic Limit, PL, %	34.48
Plasticity Index, PI, %	12.02
Shrinkage Limit, SL, %	1.80
Maximum Dry Density, γ_d, Kg/m^3	2020
Optimum Moisture Content, %	23.65
AASHTO Classification	A – 7 – 6
Group Index	12
Colour	Reddish Brown

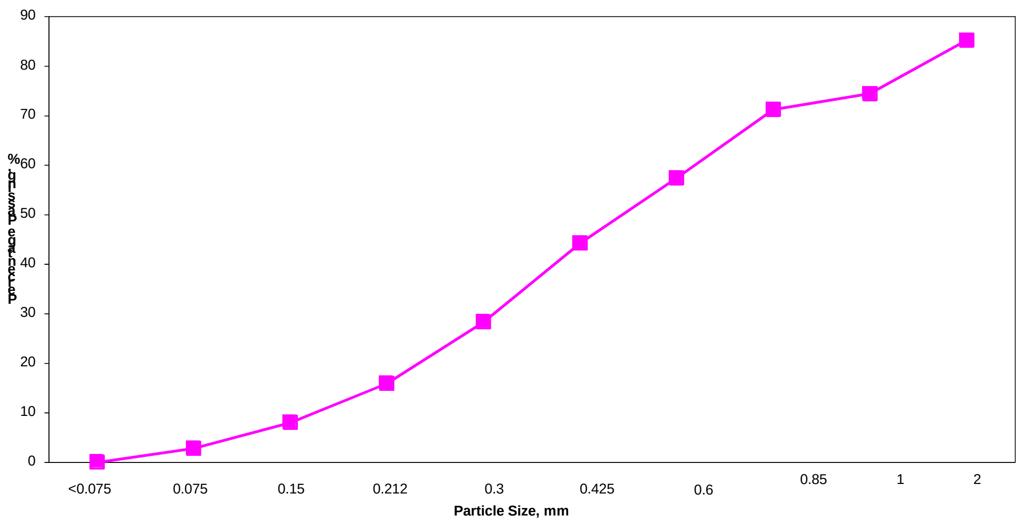

Figure1: Particle Size Distribution of Natural Soil

4.2 Compaction Characteristics

Maximum Dry Density (MDD)

The results of MDD with cement content for the treated soil at no compaction delay are shown in Table 2. The MDD decreased from 2.02Mg/m^3 for no cement to a minimum value of 1.88Mg/m^3 at 5% cement and subsequently gradually increased with higher cement content. The decrease in MDD up to 5% cement was due to the reaction between cement and the fine fraction during which coarse aggregates were formed. The aggregates occupied larger spaces thus increasing their volume and consequently decreasing the dry densities. Above 5% cement, the MDD increased because the coarse aggregates formed were firmly bonded as a result of the excess cement present in the system that plugged the voids to produce denser mixes.Figure 3 shows the effect of compaction delays on the cement stabilized lateritic soil. It was observed that MDD decreased with increase in elapse time after mixing. When compaction is delayed calcium silicate hydrates (CSH) and hydrated lime from the tricacium and dicalcium silicate compounds of the cement begin to bond particles in a loose state and distruption of these aggregates is required to densify the soil. Therefore, a portion of the compactive energy is utilized in overcoming the cementation and maximum densities are reduced with increased compaction delays (Osinubi, 1998). Results obtained show that the amount of reduction is dependent on the rate of hydration which decreases with time as well as cement content. With increase in cement content, the reduction in MDD becomes pronounced.

Table 2: Compaction Test Results for the Lateritic Soil Sample with Different Percentages of Cement at no Compaction Delay.

Cement Content (%)	**OMC (%)**	**MDD, (Mg/m^3)**
0	23.65	2.02
5	18.57	1.88
10	24.01	1.98
15	21.05	1.83
20	20.23	1.75
25	20.06	1.69

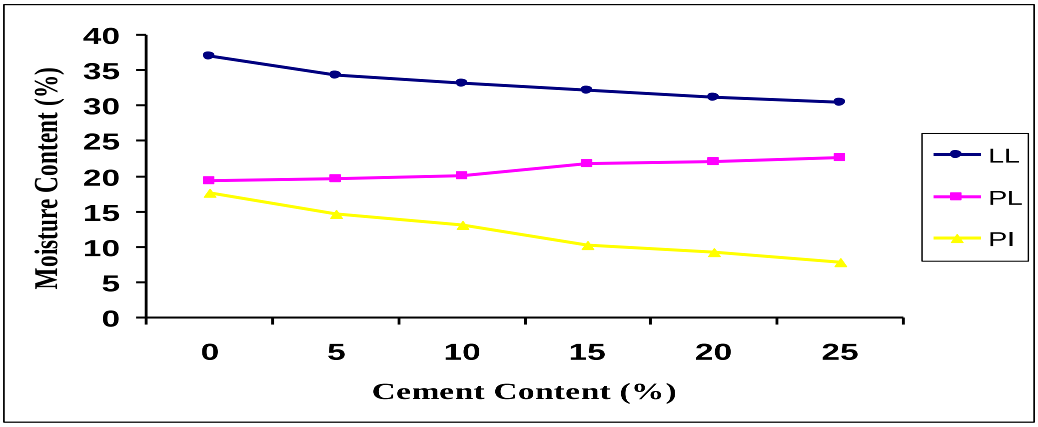

Figure 2: Influence of Portland Cement on the Atterberg Limits

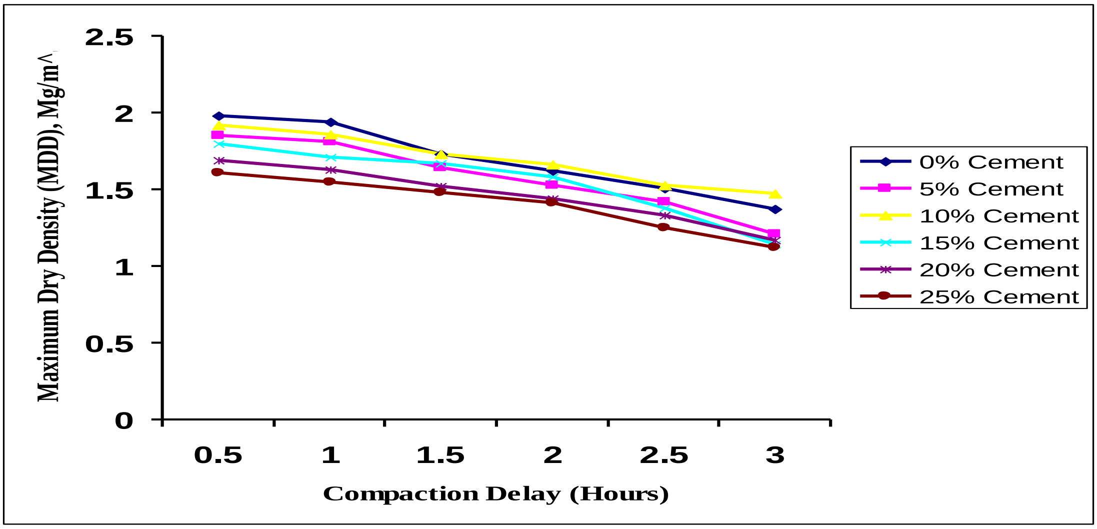

Figure 3: Variation of Maximum Dry Density (MDD) of Stabilized Lateritic Soil with Compaction Delay

4.3 Optimum Moisture Content (OMC)

The results of the OMC of cement stabilized lateritic soil at no compaction delay are shown in Table 2. The OMC decreased from 23.65% for no cement to a minimum value of 18.57% at 5% cement. The result obtained does not conform with the usual trend of increasing OMC/decreasing MDD for cement – treated soils. The decrease observed in the 0 – 5% cement range may be as a result of insufficiency of water in the system which led to self – dessication and consequently lower hydration. It is know that if no water movement to or from cement paste is permitted, the reaction of hydration use up the water until too little is left to saturate the soil surfaces and the relative humidity within the paste decreases (Osinubi, 1998).

The effect of compaction delays on the OMC of soil – cement mixes are shown in Figure 4. It was observed that the OMC of 5% cement – treated soil was greatly affected by the compaction delays. This is not unconnected with the lower hydration produced in the 0 – 5% cement range for no compaction delay. Since hydration decreases continuously and due to the self –desiccation observed at 5% cement, the effect of compaction delay is pronounced.

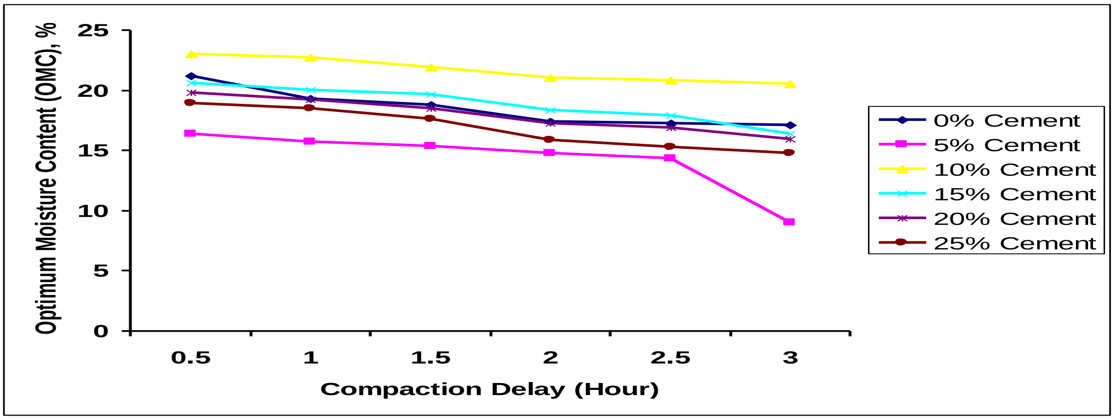

Figure 4: Variation of Optimum Moisture Content (OMC) of Cement Stabilized Lateritic Soil with Compaction Delay

4.4 Strength Characteristics

Cement – stabilized soils harden quite rapidly, particularly at high ambient temperatures which are common in tropical regions. The result of soil – cement reaction is the improvement of the engineering properties of the soils. The effects of cement on the compressive strength and California bearing ratio (CBR) values are presented in Figure 5 and Table 3 respectively for no compaction delay.

It can be observed from Figure 5 that the compressive strength of cement stabilized lateritic blocks increases as the percentage of stabilization increases. With an addition of cement (0%, 5%, 10%, 15%, 20% and 25%), the compressive strength increased from 0.33N/mm^2 to 1.45N/mm^2, 0.67N/mm^2 to 1.62N/mm^2, 1.17N/mm^2 to 2.70N/mm^2, 1.23N/mm^2 to 2.75N/mm^2, 1.55N/mm^2 to 2.84N/mm^2 and 1.96N/mm^2 to 3.15N/mm^2 for cement stabilize lateritic blocks cured for 3, 7, 14, 21 and 28 days respectively.

The minimum 7 days dry compressive strength for 5% cement stabilized blocks of not less than 1.60N/mm^2 as recommended by National Building Code (2006) could not be satisfied. Beyond 5% cement stabilization however, all the blocks satisfied the minimum 28 days dry compressive strength of not less than 2.0N/mm^2 as recommended by NBRRI (2006).

The CBR value for cement – treated soil was found to increase from 12% for no cement to 223% at 25% cement. This result shows that this form of stabilization is uneconomical based on the Nigeria General Specifications (NGS, 1970), which recommends a CBR value of 180% to be attained in the laboratory for cement – stabilized material to be constructed by the mix – in – place method and only 20% and 25% of cement content meet this recommendation.

The low gain in strength may be due to the hydration of tricalcium aluminate, which is one of the main components of Portland cement, is retarded by the hydrated lime librated by the hydrolysis of tricalcium silicate. This could have occurred due to the fact that hydrated lime reacted with tricalcium aluminate and water to form tetracalcium aluminate which hydrate and formed a protective coating on the surface of unhydrated grains of tricalcium aluminate (Osinubi, 1998).

Table 3: California Bearing Ratio (CBR) of Cement Stabilized Lateritic Soil at no Compaction Delay

Cement Content (%)	0	5	10	15	20	25
CBR (%)	12	90	120	160	185	223

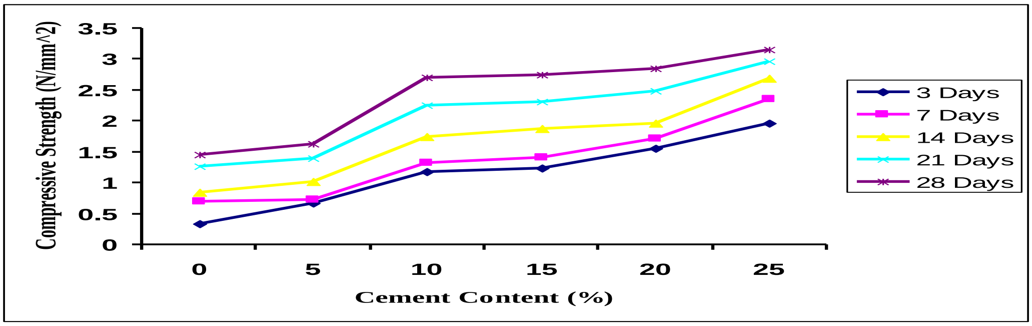

Figure 5: Variation of Compressive Strength of Cement Stabilized Lateritic Blocks at no Compaction Delay

Figure 6 showed that compressive strength decreased with increased in compaction delays. Though the values of compressive strength of the cement stabilized lateritic blocks satisfied the minimum values recommended by NBRRI, (2006) which should not be less that 2.0N/mm^2 at 28 days for 10% and above cement stabilization, the values obtained were still reduced when compared it to the values obtained at no compaction delay.

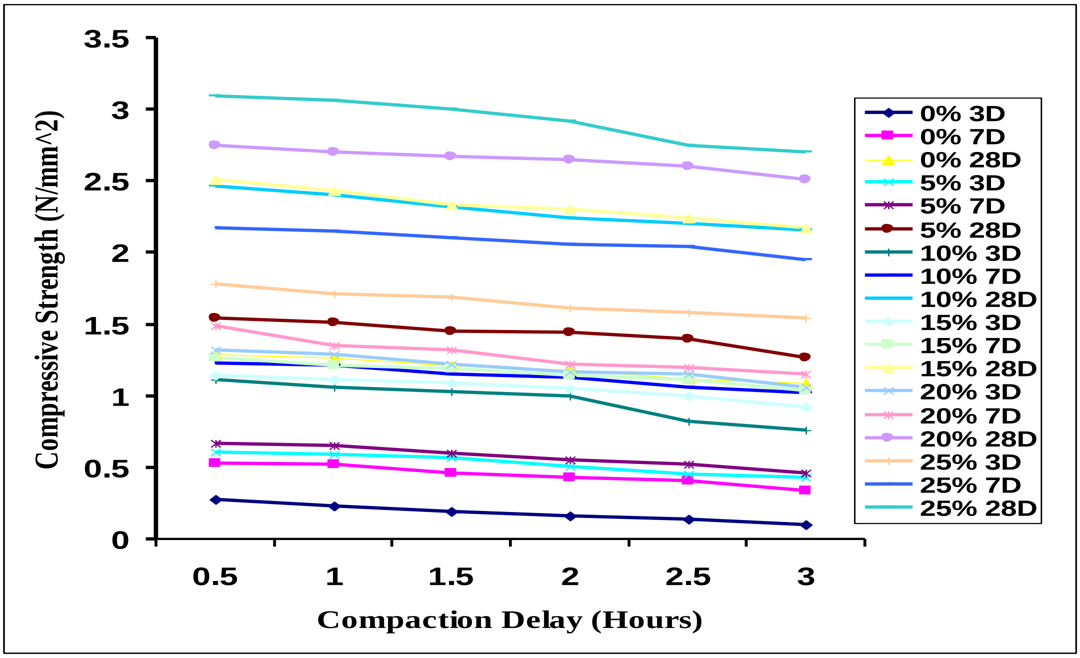

Figure 6: Variation of Compressive Strength of Cement Stabilized Lateritic Blocks with Compaction Delay

Figure 7 shows the variation of California bearing ratio (CBR) of cement stabilized lateritic soil with compaction delay. The results showed that CBR values decreased with increased in compaction delay. The reason for this is that as soon as water was added to the soil – cement mix, the cement began to hydrate and it is therefore desirable to compact as soon as mixing is completed. When this is not done, not only that some of the hardening effects of the cement would be lost but in addition extra compactive effort will be required to break down the cemented bonds that have been formed. Both of these effects together will lead to serious loss in strength (Okonkwo, 2009).

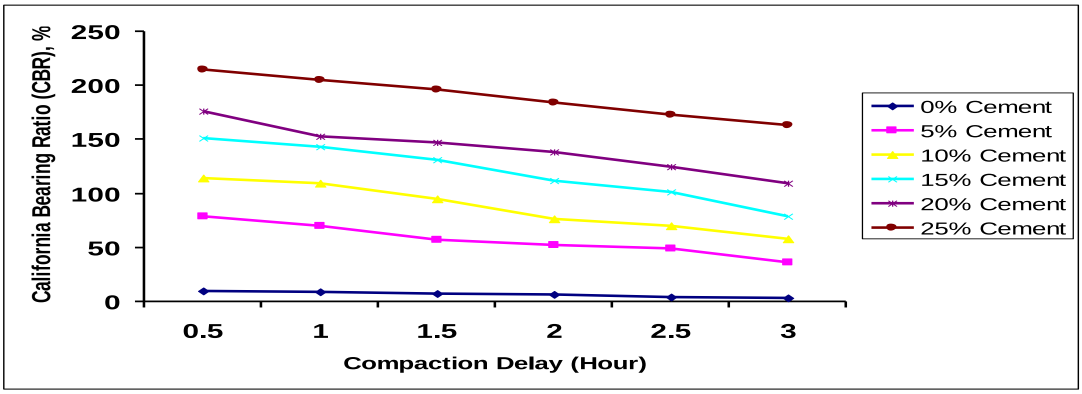

Figure 7: Variation of California Bearing Ratio (CBR) of Cement Stabilized Lateritic Soil with Compaction Delay

Conclusions

The following conclusions may be drawn from the study:

1. The liquid limit and plasticity index decreased while the plastic limit increased as the percentage of cement content increases.
2. Judging from 185% CBR value obtained at 20% cement for no compaction delay, the material can be used as base for roads.

3. The compaction and strength characteristics of the cement stabilized lateritic soil decreased with increase in compaction delays.
4. At 25% cement content for the soil, not more than 2 hours compaction delay should be allowed.
5. At 25% cement and a maximum of 3 hours time elapsed between mixing and compaction MDD, OMC, compressive strength and CBR values reduced by 18%, 14%, 12% and 21% respectively.

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