Asian Journal of Engineering and Technology (ISSN: 2321 – 2462)
Volume 01– Issue 05, December 2013

Effect of Oil Contamination on Lime and Cement Stabilized Laterite Soil

Ochepo J., Ibrahim M., Joseph V.

Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria

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ABSTRACT - ***This study was carried out to evaluate the effect of spent oil contamination on the strength of lime and cement stabilized soil. Laterite soil was stabilized with lime as well as with cement in percentages of 0, 2, 4, 6, and 8 % of the dry weight of soil. Specimens were prepared for UCS and CBR. The specimens for UCS were wax cured for 7, 14 and 28 days while specimens for CBR were wax cured for 4 days. Contamination of the specimen was achieved by soaking the specimen after de-waxing top and bottom in spent oil medium in a plastic bowl for 48 hours after the respective curing periods. The uncontaminated and contaminated soils were both tested for UCS and CBR values. The results obtained show that the strength of lime and cement stabilized soil decreased when contaminated with oil. The value of the UCS decreased by about 20, 14 and 9 % and 38, 22 and 14 % respectively on the average for oil contaminated cement stabilized soil as well as oil contaminated lime stabilized soil cured for 7, 14 and 28 days respectively. Similarly, the CBR of the soil- cement and soil-lime mixtures reduced by about 13 and 35 % respectively. It was also observed that the resistance to loss in strength increased with cement and lime content with curing period. This results show that for all practical purpose, cement and lime stabilized pavement structures exposed to oil contamination are susceptible to failure as a result of reduction in strength and bearing capacity due to oil contamination.***

Key words: Lime, Cement, Oil-Contamination, Unconfined Compressive Strength, California Bearing Ratio

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1. INTRODUCTION

Nigeria is one country in the world that is rich in crude oil production. It has 159 oil fields and 1481 oil wells in operation. The oil and gas export constitute the backbone of the economy of the nation, accounting for more than 98% of export earning and about 83% of federal government revenue, as well as generating more than 40% of its gross domestic product (GDP). It also provides about 95% of foreign exchange earnings, and about 65% of government budgetary revenues. All of these oil operations are concentrated in the Niger Delta area of the country spanning about 70,000 km² of wetlands which is primarily formed by sediment deposition. It makes up about 7.5% of Nigeria's total land mass. The population of the area is about 20 million people.

Oil spillage in Nigeria is a common occurrence because of the oil exploration activities. Oil drilling began in the country in 1958. From 1958 to date, an estimated 9 million to 13 million barrels of oil have been spilled. The government estimates that about 7,000 spills occurred between 1970 and 2000. Between 1976 to 1986 total of 2005 oil spill incidents were reported in Nigeria by oil companies with an estimated total quantity of oil spilled being 2,038,711 barrels [1]. [2] reported that between January and June, 1998 alone Nigeria recorded three different oil spills of approximately 60,800 barrels of crude oil and [3] reported that on 1st May 2010 a ruptured ExxonMobil pipeline in the state of Akwa Ibom spilled more than a million gallons into the delta over seven days before the leak was stopped. Causes of this spillage include corrosion of pipelines. Tankers accounts for 50% of all spills, sabotage 28%, and oil production operations 21%, with 1% of the spills being accounted for by inadequate or non-functional production equipment.

The negative impact of oil spillage on the ecosystem as well as on the engineering properties of soil is enormous. This oil product released into the soil contaminates the soil subjecting it to a change in its engineering properties and making it unsuitable for use as a base material for road construction, topping layer for car parker landfill cover material and detrimental to buildings and structures standing on it due to loss of bearing capacity and excessive settlement. A study carried out by [4] on the geotechnical properties of oil contaminated soil shows that the bearing capacity of the soil decreased and compressibility increases because of the oil contamination. It was also observed that the permeability of the soil significantly decreased. Similar study carried out by [5] to evaluate the compressibility and strength properties of oil contaminated laterite soil shows increase in compressibility and decrease in unconfined compressive strength of contaminated soil relative to the uncontaminated soil. [6] conducted a series of triaxial tests on oil contaminated and uncontaminated clean sands. The results obtained showed that the friction angle drastically reduced for oil saturated loose and dense samples. On the other hand, the volumetric strain increased. These findings suggested that settlement of footing would increase as a result of oil contamination. [7] in his experimental and theoretical studies of the behaviour of strip footing on oil contaminated sand with oil content ranges from 0 to 5% in respect to weight of dry soil, reported that there is a significant decrease in bearing capacity and bearing capacity factor (N_γ) with increase in oil content as well as increase in settlement and settlement factor of the footing with increasing depth of contaminated sand. [8] investigated the effect of crude oil on geotechnical properties of sandy-soil and clay. The results showed that the Atterberg limits decreased with the increase in oil percentage. The increase of oil content in the soil samples also caused the decrease of maximum dry density, optimum water content, porosity and shear strength. [9] investigated the influence of oil contamination on the geotechnical properties of Basaltic Residual soil by artificially contaminating the soil with engine oil in step concentration of 4% of the dry weight of soil sample. It was discovered that oil contamination enhances the liquid and plastic limits of the soil. There was reduction in maximum dry density (MDD) and optimum moisture content (OMC) of the soil compare to uncontaminated soil with increase in oil content. [10] reported that the load carrying capacity of oil partially saturated sand decreased with oil content.

One of the measures aimed at improving the geotechnical properties of geotechnical deficient soil is by chemical stabilization with additives such as lime and cement [11], [12], [13], [14]. It has been reported that oil contaminated soil can similarly be stabilized by additives such as lime and cement. For example, report by [15]shows increase in unconfined compressive strength when oil contaminated soil was treated with cement and cement by-pass dust. Similarly, [16] reported stabilizing fuel contaminate soil with lime, fly ash and cement as well as admixture of lime, fly ash and cement in different combinations. It was observed that the geotechnical properties of the contaminated soil were improved by way of cation exchange, agglomeration and pozzolanic actions. The best result was obtained when 10 % lime, 5% fly ash and 5% cement was added to the contaminated soil. The improvement in the geotechnical properties of the soil was attributed to the formation of neo-formations such as calcium silicate hydrate and calcium aluminate hydrate which bind the soil particles. Formation of stable complex between oil and metallic cation was thought to reduce leachable oil.

In this study, effort is made to investigate and compare the effect of oil contamination on cement and lime stabilized laterite soil. Laterite soil was define as a soil belonging to horizon A or B of well drained profile developed under humid tropical climates with clay fraction constituted essentially of the kaolinite group and of iron or aluminium hydrate oxides [17]. There has been much report on the geotechnical and field performance of laterite soil stabilized with lime and cement, [18], [11], [12], [19], [13]. These reports confirm a general improvement in the engineering properties of the soil with cement and lime treatment.

The laterite soil was stabilized by addition of lime as well as with cement in step increment of 0, 2, 4,6 and 8 % as reported in [11], [12], [19]. The test specimen was wax cured in humidity room at 100% relative humidity and temperature of 25 ± 2 and then de-waxed top and bottom and immersed in oil contaminated medium for 48 hours before testing.

2. MATERIAL AND METHODS

2.1 Material

Soil: The soil used in this study is a natural reddish brown laterite which was collected from a borrow pit in Shika village, Zaria Local Government Area, Kaduna State in Northern part of Nigeria, (latitude $11^o\ 15'$ N and longitude $7^o\ 45'$ E), by using the method of disturbed sampling.

Spent oil: The spent oil used was collected from Oando lubrication workshop adjacent Ahmadu Bello University Main gate, Samaru Campus.

Lime: Lime was collected from National Research Institute of Chemical Technology Zaria.

Cement: The cement used was Dangote cement obtained from a major distributor in Sabon-Gari, Zaria.

2.2 Methods

2.2.1 *Preliminary tests*

The laboratory tests to determine the index properties of the natural soil were conducted in accordance with British Standard, [20]. The results are as shown in Table 1. The physical properties of the spent oil were also determined as shown in Table 2. Oxide composition of cement and lime were determined at the Centre for Energy Research and

Training (CERT), A. B. U. Zaria, using the method of Energy Dispersive X-Ray Fluorescence (EDXRF). The results are shown in Table 3.

2.2.2 Compaction and strength tests

The moisture-density relationship of the soil, soil-cement and the soil-lime mixture were determined by compaction test in accordance with [20], [21] using the British Standard light (BSL, standard Proctor), compactive effort. This is equivalent to 592.5kJ/m^3 of energy.

The samples of soil-cement and soil-lime mixtures were prepared by mixing the desired proportions of potable water, soil and cement as well as the soil and lime. The soil-cement and soil-lime mixtures were thoroughly mixed in a tray to obtain uniformity. The British Standard light compactive energy used for the compaction consists of energy derived from 2.5 kg rammer falling through 30 cm on three layers each receiving 27 blows. A minimum of five determinations was conducted within which the maximum dry density, MDD and optimum moisture content, OMC, was obtained.

The unconfined compression test was carried out in accordance with [20] Part 7. They require amount of water determined from moisture-density relationships for soil – cement as well as soil-lime mixtures was used to prepare the specimen which was wax cured for 7, 14 and 28 days.

The CBR tests were carried out in accordance with [20] part 8. After compaction, the specimen was wax cured for 4 days in the humidity room before immersing in the contaminated medium.

The contamination process involved de-waxing the UCS specimen top and bottom after curing for 7, 14 and 28 days respectively and immersing in plastic container filled with the oil for 48 hours. The CBR specimen was similarly contaminated by immersing in oil for 48 hours after the 4 days curing. The specimens were then removed at the end of 48 hours, wiped clean and tested for UCS and CBR values.

3. RESULTS AND DISCUSSION

3.1 Material properties

The index properties of the natural soil are summarized in Table 1 and Figure 1 shows the particle size distribution of the natural soil. The soil has liquid limit of 46 % and plasticity index of 14 %. The percentage passing sieve No 200 is 63.6 %. From the combine results of the Atteberg limits and the sieve analysis, the soil was classified as A-7-6 and CL in accordance with AASHTO and the Unified Soil Classification System (USCS) respectively.

Table 1: Basic properties of Soil Sample

Properties	Natural Soil.
Natural Moisture Content, %	5.8
Liquid Limit, %	46.60
Plastic Limit, %	32.4
Plasticity Index, %	14.20
Percentage Passing BS.No.200 sieve	63.55
Specific gravity	2.63
AASHTO classification	A-7-6
USCS Classification	CL
MDD (BSL)(Mg/m^3)	1.70
OMC (BSL)(%)	18.00
pH Value	6.7
Colour	Reddish Brown
Dominant Clay mineral	Kaolinite

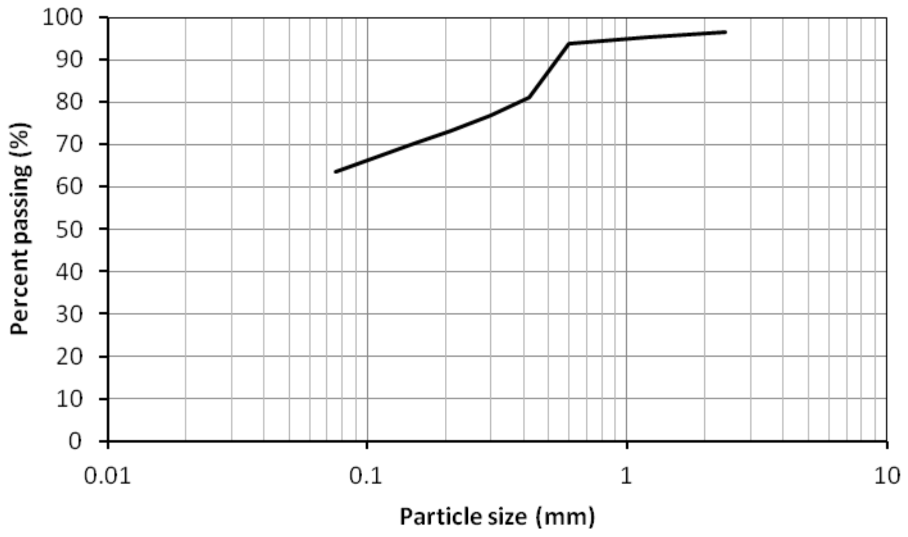

Fig 1: Particle size distribution of the laterite soil

Tables 2 and 3 respectively show the properties of the spent petroleum oil and oxide composition of the lime and cement used in this study.

Table 2: Summary of the petroleum oil used in the study

Properties	**Specific gravity**	**Flash point (^0C)**	**Fire point (^0C)**	**Viscosity (cP)**	**Density (g/cm^3)**
Values	**0.7**	**168**	**220**	**1.17**	**0.76**

Table 3: Oxide Composition of Lime and Cement

Oxide Composition	**CaO**	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**Mn_2O_3**	**K_2O**	**TiO_2**	**LOI**
Lime (% Concentration)	43.93	37.71	11.61	0.17	0.11	0.18	0.93	
Cement (% Concentration)	66.07	20.2	6.14	2.25	-	0.72	-	1.14

3.2 Compaction characteristics

The effect of cement and lime treatment on the compaction variables i.e. maximum dry density (MDD) and optimum moisture content (OMC) of the soil was investigated. Figures 2 and 3 show the plot of the maximum dry density and optimum moisture content of cement and lime stabilized soil. From these figures, it was observed that the MDD for cement and lime stabilized soil decreased with increasing cement and lime contents. OMC increased with increasing cement and lime contents. The decrease in MDD and increase in OMC with increasing lime and cement content is in agreement with the results of [22], [23], [24]. The drop in MDD with cement and lime treatment is thought to be due to the flocculation and agglomeration of clay particles due to cation exchange leading to corresponding decrease in dry density.

The increase in OMC with cement and lime treatment is as a result of the increased surface area of particles caused by cement and lime thereby attracting more water in addition to water required for hydration reaction.

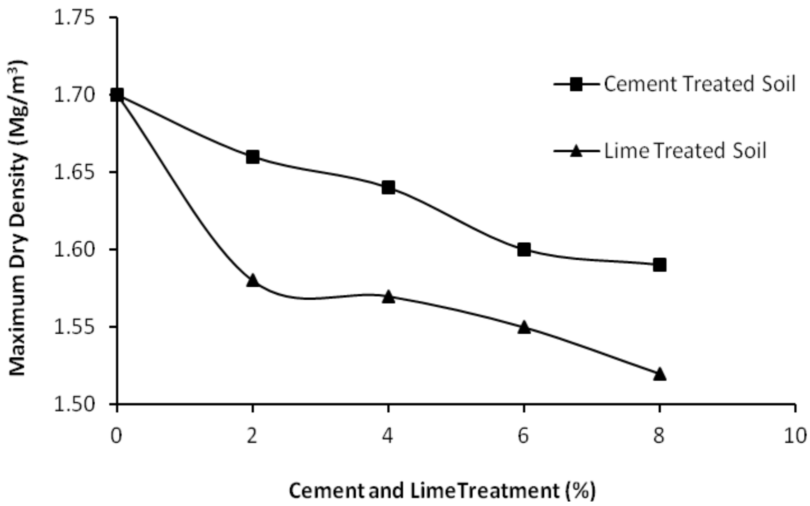

Fig. 2: Maximum dry density of oil, cement and lime treated soil

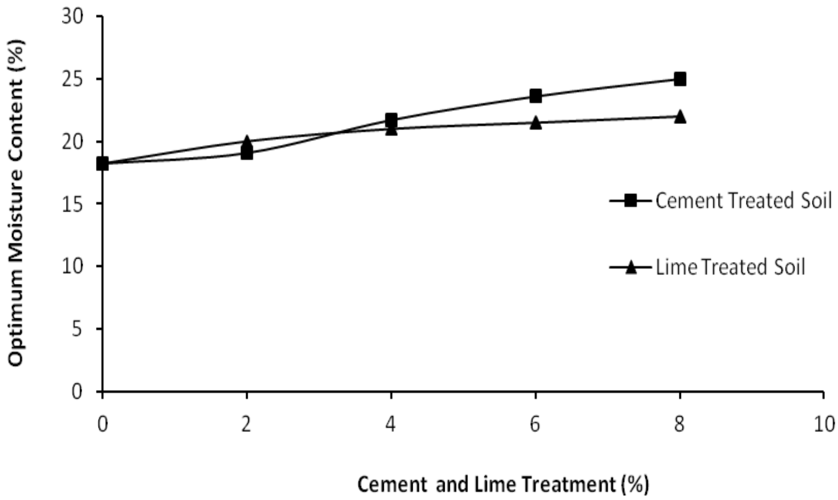

Fig. 3: Optimum moisture content of oil, cement and lime treated soil

3.3 Effect of Oil contamination on UCS of Cement and Lime Treated Soil

Figures 4, 5 and 6 show the plot of UCS of cement and lime treated uncontaminated soil as well as cement and lime treated oil contaminated soil after 7, 14 and 28 days wax curing. It was observed that UCS increased with cement and lime treatment for the uncontaminated soil at all curing periods. This is as a result of reaction between the soil mineral, cement and lime which results in formation of cementitious compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes forming a tough water insoluble gel of calcium silicate, which cemented the soil particles. This results in strength increase as recorded in this study. These results are in agreement with the report of [25]. The effect of oil contamination on the treated soil can be seen also in the plot. It was observed that contaminating the cement and lime treated soil with spent petroleum oil results in reduction of UCS values of the treated soil. The reduction in strength was observed to be on the average of about 20, 14 and 9 % and 38, 22 and 14 % respectively for cement and lime stabilized soil cured for 7, 14 and 28 days before contamination. The reduction in strength of the treated soil may be due to the penetration of the liquid oil into the fabric of the treated soil and possible reactions between the hydrocarbon compounds in the oil with the calcium silicate gel. This may have disrupted the stability of the gel and resulted in a lesser strength.

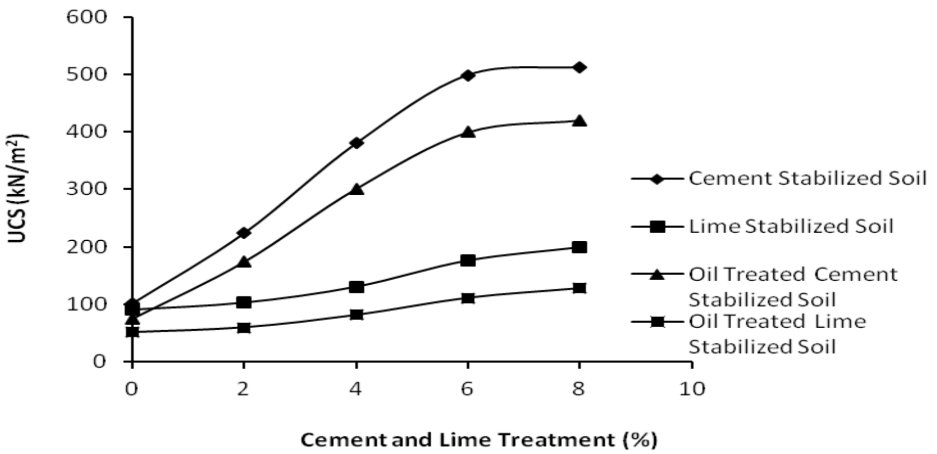

Fig. 4: Variation of UCS with Cement and lime Treatment for contaminated and uncontaminated stabilized soil (7 days curing)

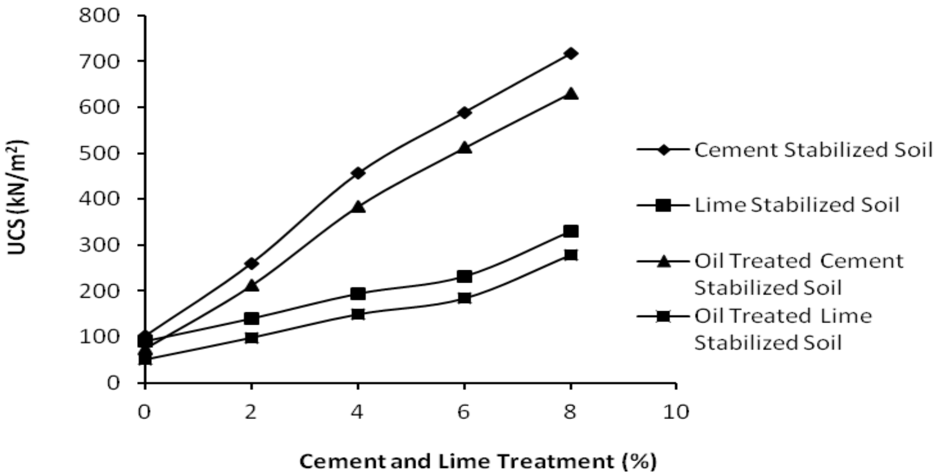

Fig. 5: Variation of UCS with Cement and lime Treatment for contaminated and uncontaminated stabilized soil (14 days curing)

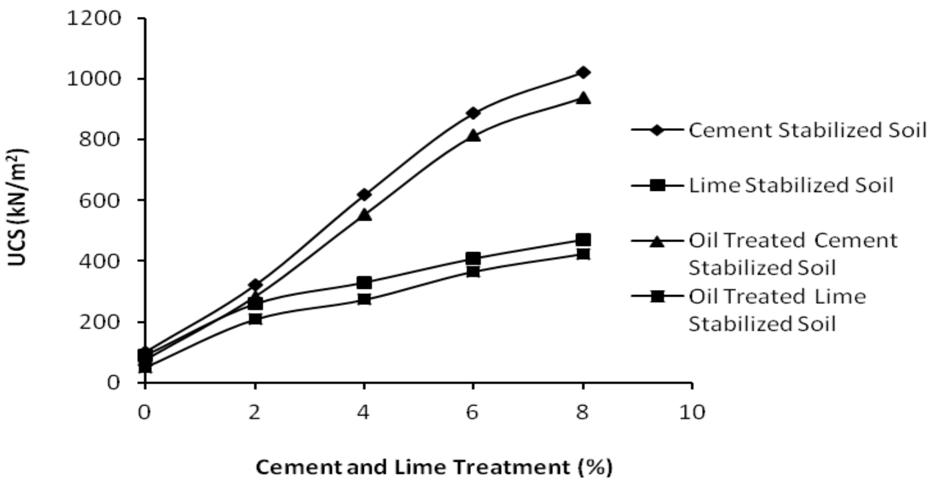

Fig. 6: Variation of UCS with Cement and lime Treatment for contaminated and uncontaminated stabilized soil (28 days curing)

3.4 Percent loss in strength (PLS)

The Percentage Loss in Strength, PLS of each of the treated contaminated soil was obtained using equation 1.

$$PLS = \left(\frac{\Delta q_{uc}}{q_u} \right) 100 \quad \ldots\ldots 1$$

Where Δq_{uc} is the difference between uncontaminated UCS, q_u and oil contaminated UCS, q_c value.

Fig 7 and 8 show the plot of PLS against curing period for cement and lime stabilized soil. It can be observed that the strength loss of the contaminated soil decreased with curing period. The decrease in strength loss with curing period as observed in this result may be attributed to degree of strength development with time which is a function of the extent of reaction between cement, lime and soil mineral. This reaction is time dependent and results in the formation of tough water insoluble gel of calcium silicate, which cemented the soil particles. Under favorable conditions, this reaction continues with time producing more cementing materials resulting in a stronger soil matrix. It appears thus that the contaminated liquid medium would find it more difficult to penetrate the matrix to disrupt the bond of the stabilized soil which has been cured for a longer period of time due to the stronger matrix formed.

Fig. 9 shows the plot of PLS against percent treatment for cement and lime treated soil. From the figure, PLS decreased with percent cement and lime treatment. This is due to formation of more cementing material at higher cement and lime content because more cement and lime were available for reactions to take place.

It is also observed that lime treated soil have higher PLS compare to cement treated soil especially at 7 days curing. This can be explain from understanding of the mechanism of reaction of soil cement and soil lime. The mechanism of soil-cement reaction has been reported to produce primary cementitious materials which are calcium silicate hydrate and calcium aluminate hydrate which is accompanied by the flocculation and coagulation of the soil particles into lager sized aggregates or grains as a result of the dissociation of the bivalent calcium ion Ca^{2+} from the hydrated lime during hydrolysis of cement. The secondary reaction is pozzolanic which results in further strength gain with time. For soil-lime, the primary reaction is cation exchange which has the immediate effect of promoting flocculation of the soil particles and a change in soil texture. This is followed by pozzolanic reaction results in the formation of cementitious product that have long term effects on the strength, volume stability and finally Carbonation [26], [27]. The initial strength gain of cement treated soil compare to lime treated soil reduces the ingress of the contaminant into the fabric of the cement treated specimen to disrupt the strength of the soil at the early and subsequent curing periods as compare to lime treated soil.

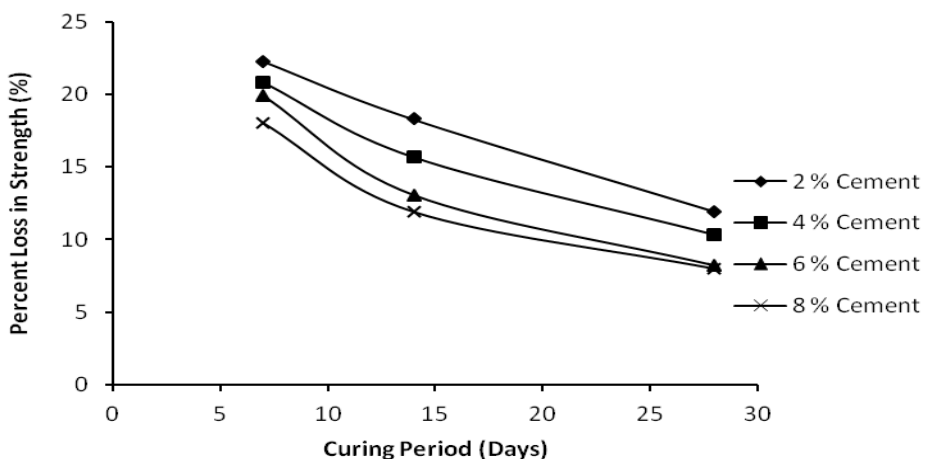

Fig. 7: Variation of PLS with Curing Period for Cement Stabilized Soil

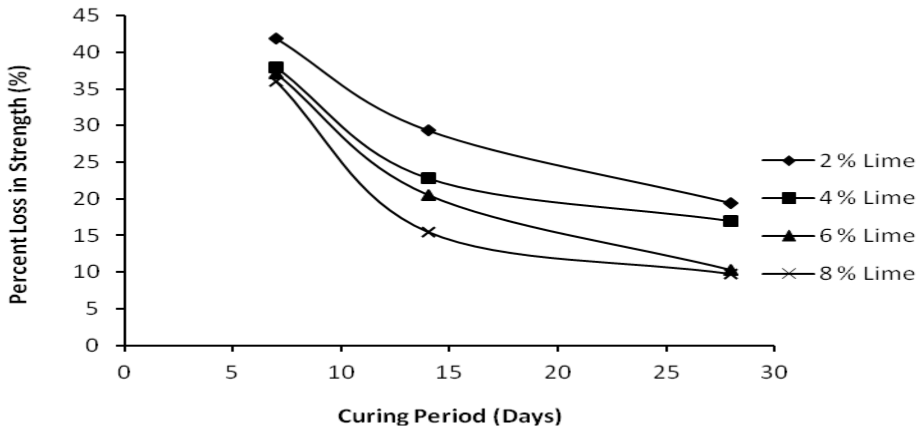

Fig. 8: Variation of PLS with Curing Period for Lime Stabilized Soil

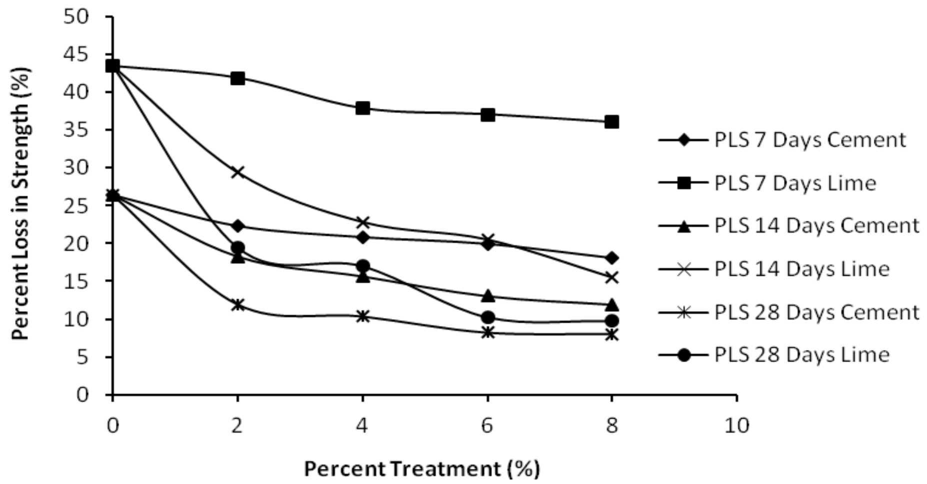

Fig. 9: Variation of PLS with Percent Treatment

3.5 Effect of spent oil contamination on CBR

The California bearing ratio (CBR) value of a soil is an important parameter used to indicate its strength and bearing capacity. It is widely used in design and to assess the suitability of soil or otherwise for base and sub-base. The CBR is therefore a familiar test used to evaluate the strength of soils for these applications.

Figure 10 shows the plot of CBR values for both contaminated and un-contaminated treated soil cured for four days. It can be seen from the plot that the CBR values increased with cement and lime content but decrease when the soil-cement and soil-lime mixture was contaminated with spent oil for 48 hours. This result shows about 13 and 35 % reduction in CBR of the contaminated soil-cement and soil-lime mixture respectively. This reduction in strength rendered unsuitable for use the stabilized material as it means when the soil-cement and soil-lime mixture are subjected to the contaminated environment for a prolonged period of time, the strength will deteriorate further. The observations in the CBR values are consistent with those of UCS.

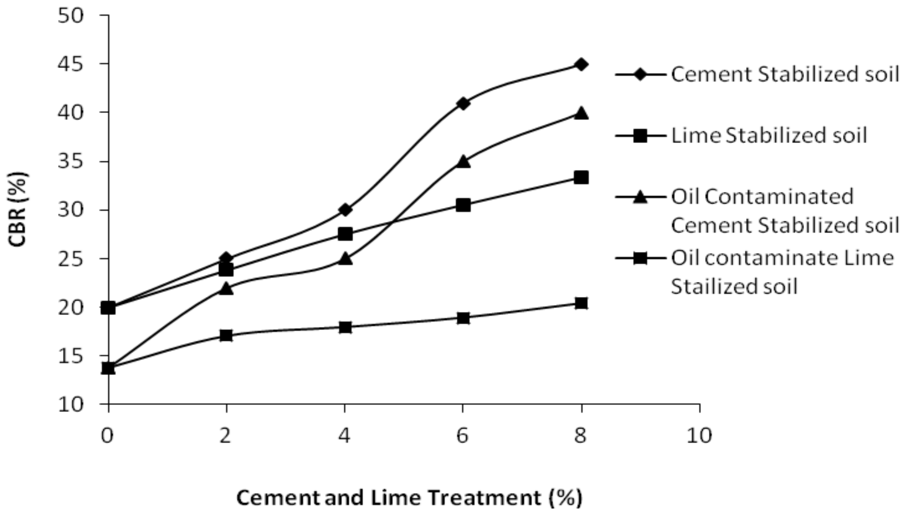

Fig. 10: Variation of CBR with Cement and lime Treatment for contaminated and uncontaminated stabilized soil

4. CONCLUSION

Evaluation of the effect of spent oil contamination on the strength of cement and lime stabilized soil was carried out in this study. The results obtained show that:

The MDD for cement and lime stabilized soil decreased with increasing cement and lime treatment while OMC decrease with both cement, lime treatment.

The unconfined compressive strength as well as the CBR of cement and lime stabilized soil increased with increasing cement and lime content. However, when contaminated with oil, after curing for 7, 14 and 28 days, the values of UCS decreased by about 20, 14 and 9 % and 38, 22 and 14 % respectively on the average for contaminated cement stabilized soil and contaminated lime stabilized soil. Similarly, the CBR of the soil-cement and soil-lime mixture reduced by about 13 and 35 % respectively.

This results show for all practical purpose that a cement and lime stabilized pavement structure if exposed to oil contamination is prone to deterioration and subsequent failure as a result of reduction in strength and bearing capacity.

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