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Effect of Scrap Tyre Crumb Rubber (STCR) and Lime on the California Bearing Ratio (CBR) of Non-Lateritic Soil

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Abstract

Nigeria is one of the countries generating many used tyres with only small quantity utilized for different local use and the remaining large quantity dumped in different areas as waste. In this study non – laterite soil was stabilized with 3 % Scrap Tyre Crumb Rubber (STCR) and 5.0, 7.5, 10.0, 12.5 and 15.0 % lime for use as road construction material. Atterberg limit tests, compaction (using West African Standard energy) and California Bearing Ratio (CBR) tests were carried out using standard methods, on the natural non-lateritic soil and the treated soil specimens. Preliminary test on the soil was carried out which classified the soil as A-6 (9) and CL in accordance with ASHTO and USCS classification systems respectively. Compaction and California Bearing Ratio (CBR) parameters of the treated non-lateritic showed a great improvement as the MDD increased from 1.68 Mg/m3 to 1.88 Mg/m3 while the OMC reduced from 17.1 % to 14 %. Both soaked and unsoaked CBR values equally increased to 109 % and 103 % respectively with the addition of lime up to 15% plus 3% STCR waste. Based on results obtained from the study, the use of a mixture of 15% lime and 3% STCR waste, are recommended for the treatment of non-lateritic soil for road construction purposes.

Keywords: Non-Lateritic Soil, Scrap Tyre Crumb Rubber, California Bearing Ratio, CBR Test, Lime.

Introduction

Building road in the developing nations has been a major challenge to Government and different specialists in the construction industry. The challenge facing Government is the limited resources available for the construction of roads and the high cost of road building normally put forward by the construction companies. On road construction site, the contractor is faced with the problem of non-availability of suitable road construction materials, within the vicinity of most road projects. A situation that normally results in the usage of materials imported from other locations, resulting in additional costs that does not guarantee economy in road construction. Stabilization in road construction using locally available materials within the vicinity of road projects is one of the ways of ensuring economy in the construction (Firoozi et al., 2017). One of such materials that is readily available in Nigeria is laterite (LongJohn and Ayininuola, 2021). Laterite as defined by Andrew (2023) as a highly weathered tropical soil, rich in secondary oxide of any or a combination of iron, aluminium and manganese. The major of distinguishing parameter for a laterite and non – lateriric soil is the ratio of silica to the sesquioxides (Fe_2O_3, Al_2O_3). Laterite soils have silica sesquioxide (SS) ratio value of less than 1.33 and lateritic soils have silica sesquioxide (SS) ratio value ranging between 1.33 to 2.0. Non tropical lateritics soils have silica sesquioxide (SS) ratio of greater than 2.0 (LongJohn and Ayininuola, 2021). The development of new engineering materials with regulated properties from unconventional source has the potential of providing the sustainability of many engineering projects (Aabid and Baig, 2021). In soil stabilization, lime is one of the commonly used stabilizers for stabilizing various types of granular soil (Asma and Dariusz, 2013, James, and Pandian, 2016). Using scrap tyres as a recycled material either a whole or shredded into small pieces, provide a lightweight construction material often with improved engineering properties such as strength compared with those of soils alone (Tapas and Baleshwar, 2013, Rajvinder and Dalyir, 2019, Saeed et al., 2019). More emphasis has been placed on sustainable development, hence there is need to extensively investigate various means of proper utilization/elimination of waste material from our environment (Neville, 2012). In this study, an attempt was made to stabilized lateritic soil with scrap tyre crumbs rubber and lime for possible use as road construction materials.

Problem Statement

Waste tyres in Nigeria are generated annually in large amount and this adds to the existing volume in the environment thus, create one of the major environmental challenges, especially their disposal issue. It has been reported that about 15 million scrap tyres exist in Nigeria with an annual increase of 15 % that translates to about 800,000 scrap tyres from motorcycles, cars, and trucks generated annually (Amenaghawon et al., 2013).

The increasing number of cars all over the world results in millions of tonnes of scrap tyres annually. Nigeria is also one of the countries generating many used tyres. Only small quantity of waste tyres is utilized for different application such as floor-mats, tarred roadmaking and locally to produce shoes. The remaining large quantity of these wastes is dumped illegally in different areas of Nigeria. The use of these wastes is not only to prevent the negative impact on human health and environment but also to reduce the cost of disposal, preserve and protect the environment as well as proffer solution to problems associated with the soils of low shear strength (Sumit et al., 2022).

Over the times, cement and lime are the two main materials used for stabilizing soils. These materials have rapidly increased in price due to the sharp increase in the cost of energy since 1970s (Neville, 2012, Ogochukwu and Charles, 2023) and the cost of construction of stabilized road equally continue to be high. An alternative to the use of high percentage of cement is the use of lime as a modifier to reduce the plasticity index of the soil in addition to cement for stabilization.

Objectives of the Study

The specific objectives of the study are:

i. Characterization of non-lateritic soil.
ii. Investigation of the compaction characteristics of the mixes using West African Standard (WAS) compaction energy.
iii. Determination of the California Bearing Ratio, (CBR) of the mixes.
iv. Determination of the optimal mix.

Research Questions

i. How does the addition of scrap tyre crumb rubber affect the mechanical properties of non-lateritic soil?
ii. What is the optimal dosage of scrap tyre crumb rubber for achieving the stabilization?
iii. How does the addition of lime influence the stabilization process of non-lateritic soil with scrap tyre crumb rubber?
iv. What are the long-term durability and environmental impacts of stabilizing non-lateritic soil using scrap tyre crumb rubber and lime?
v. What are the economic implications of using scrap tyre crumb rubber and lime for stabilizing non-lateritic soil compared to traditional stabilization methods?

Hypothesis

The addition of scrap tyre crump rubber (STCR) and lime to nonlateritic soil will significantly improve its Califonia Bearing Ratio (CBR) compared to untreated nonlateritic soil, due to the beneficial effects of scrap tyre crumb rubber (STCB) in enhancing soil stability and lime in providing pozzolanic reactions and soil stabilization. This hypothesis suggests that the combination of scrap tyre crumb rubber (STCR) and lime will positively impact the California Bearing Ratio (CBR) nonlateritic soil by reinforcing its strength and stability.

Methodology

Characterization of the Lateritic Soil

Soils have peculiarities, they vary in properties. In other words, no two soils can be similar in all properties but can behave alike in some cases. Therefore, it is necessary to identify a soil and properly classify it to the group it belongs. This can be achieved by conducting preliminary tests on the natural soil. The following tests were conducted on the lateritic soil in accordance with British Standard, BS 8006 (1995), which include:

Sieve Analysis

This test is done to determine the particle size distribution of soil sampled as per British standard BS 1377: part 2:1990. 200g of soil sample was weighed, wet sieved to remove clay and silt particles using sieve No. 200 (75µm). After washing, the sample was dry in an oven set to 105 oC for 24 hours. After dried, the standard BS sieves was arranged in descending order of aperture, the oven dried sample would then be poured into the sieves and shake for at least 10 minutes using mechanical shaker. After sieving, the mass of sample retained on each sieve was determined. The calculated result of percentage passing was plotted on the semi-log graph against sieve size.

Liquid Limit

Liquid limit' (LL or wL) is defined as the arbitrary limit of water content at which the soil is just about to pass from the plastic state into the liquid state.

This test was conducted using cone penetrometer method in accordance with British standard, BS 1377: part 2: 1990. The soil sample for liquid limit was air-dried and 200g of the material passing through BS sieve No.40 (425µm aperture) was obtained and mixed thoroughly with water to form a homogeneous paste on a flat glass plate. A portion of the soil mixture will then place in the cone, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the centre of the hinge. The cone will then be lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove. The number of blows at which that occurred was recorded and small quantity of the soil was taken to determine it moisture content. The values of the moisture content determined the corresponding number of blows was plotted on a semi-logarithmic graph and the liquid limit was determined for the moisture content corresponding to 25 blows.

Plastic Limit

Plastic limit (PL or wp) is the arbitrary limit of water content at which the soil tends to pass from the plastic state to the semi-solid state of consistency. The plastic limit of the soil was conducted in accordance with British standard, BS 1377: part: 1990. A portion of the soil used for the liquid limit test was retained for plastic limit determination. The ball of the soil was mould between the fingers and rolled between the palms of the hand until it dried sufficiently. The sample will then be divided into approximately four equal parts. Each of the parts was rolled into a thread between the first finger and the thumb. The thread will then be rolled between the tip of the fingers of one hand and the glass. This process continued until the diameter of the thread reduced to about 3 mm in five to ten forward and backward movement of the hand. The movement continued until the thread sheared both longitudinally and transversely. The crumbled sample will then be place in the moisture container and the moisture content determined.

Plasticity Index

Plasticity index' (PI or Ip) is the range of water content within which the soil exhibits plastic properties; that is, it is the difference between liquid and plastic limits. The plasticity index was computed in accordance with British standard, BS 8006: 1995. Plasticity index is the difference between the liquid limit and the plastic limit expressed mathematically as in equation below.

PI=LL-PL

Where; P1 = plasticity index (%)

LL = Liquid limit (%)

PL = Plastic limit (%)

Compaction Test

This test is to determine the maximum dry density and the optimum moisture content with a given compactive effort. This test established the optimum moisture content to be used for some other performance test like California bearing ratio and the unconfined compressive strength, which requires compaction. As specified by BS 1377: 1990 West African Standard (WAS) was adopted. A cylindrical metal mould (Proctor mould) of about 1000cm3 volume and a rammer of 2.5kg weight with a height drop of 300mm was used as the given compactive effort. Twenty-five (25) blows were given on each layer of three (3) and moisture content samples was taken from the top and bottom of the mould. The optimum moisture content was taken as the moisture content at which the maximum dry density was attained.

California Bearing Ratio

The California bearing ratio (CBR) test is an empirical test developed by the California State Highway Department for the evaluation of sub grade strengths. In the test as given in BS 1377: Part 2: 1990, a specimen which is 127mm in height and 152mm in diameter was compacted into the CBR mould. The specimens were prepared in 5 (five) layers and heavy rammer was used to give sixty – two (62) blows onto each layer. The load required to causes a circular plate, 50mm in diameter, to penetrate the specimen at a specified rate of 1.25mm per minute was then measured. From the test results, the CBR value was calculated. This is done by expressing the corrected values of forces on the plunger for a given penetration as a percentage of a standard force. The 2.5mm and 5.0mm penetration caused by 13.24KN and 19.96KN loads was used to compare the loads that caused the same penetration on the specimens. Mathematically the CBR is expressed as in Equation below.

$$CBR = (P_t/P_s) \times 100$$

Where P_t = Corrected unit (or total) test load Corresponding to the chosen penetration curve.

P_s = corrected unit (for total) standard load for the same depth of penetration as for P_s taken from standard code.

Table 1. Experimentation plan

		Lime Content (%)						Total
Lime		0	5	7.5	10	12.5	15	
	Compaction	2	2	2	2	2	2	12
CBR	Soaked	2	2	2	2	2	2	12
	Unsoaked	2	2	2	2	2	2	12
	Total	6	6	6	6	6	6	36

Discussion of Results

Characterization of the Soil

The physical properties of the soil showed that the soil is light brown in colour with specific gravity of 2.43; percentage passing No.200 sieve size was 84.4 % and free swell was 27% and sand content was found to be 15.6%, thus making the soil sandy clay. The Atterberg limit test results also showed that the untreated soil has liquid limit (W_L) of 43.4%; plastic limit (W_P) of 24.6% and plasticity index (I_P) of 18% with linear shrinkage value of 9%. Sandy clay soil was found to be slightly good materials for construction purposes. Although it may be improved by stabilization based on specific requirement.

From the sieve analysis and Atterberg limit (W_L &I_P) test results, the soil was classified as A – 6 (11) according to AASHTO D3282 - 09 (2003) classification system; and a clayey soil of low plasticity (CL) according to ASTM D 2487, 2011 classification system.

Table 2. Physical properties of the soil

Soil Properties	Value
Colour	Light brown
Natural Moisture Content w (%)	5.8
Specific Gravity (Gs)	2.43
Fine Fraction (%)	84.4
Sand Fraction (%)	15.6
Liquid Limit (%)	43.4
Plastic Limit (%)	24.6
Plasticity Index (%)	18
Linear Shrinkage (%)	9
Group Index (GI)	11
AASHTO Classification	A-6 (11)
USCS Classification	CL
Maximum Dry Density (Mg/m^3)	1.68
Optimum Moisture Content (%)	17.1

Source: Soil Mechanics Laboratory Abubakar Tafawa Balewa University, Bauchi.

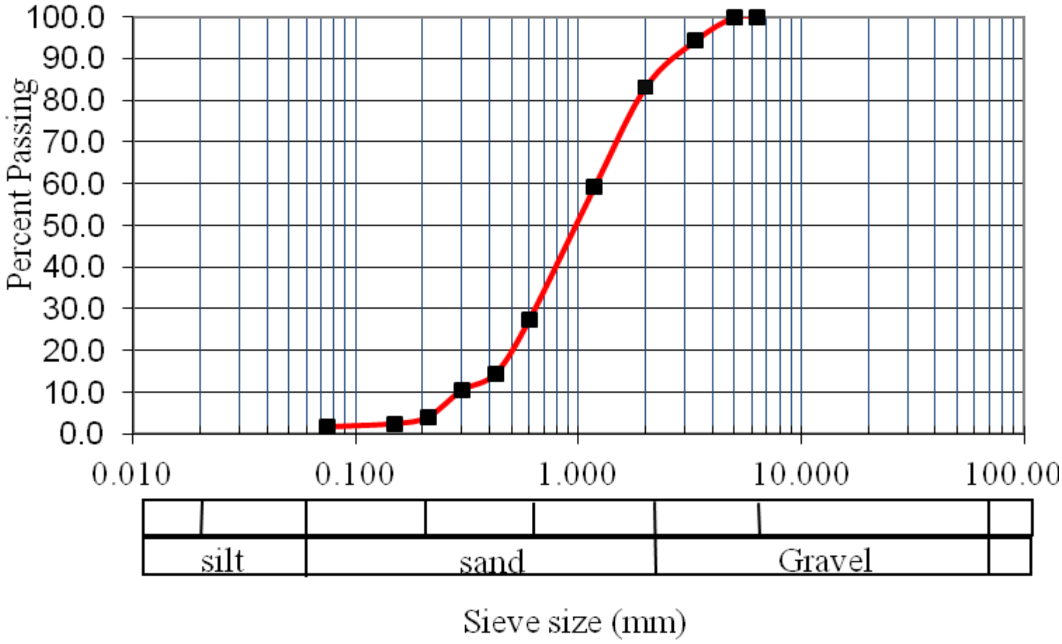

Figure 1. Particle size distribution curve

Table 3: Compaction Characteristics of the Stabilized Soil

Crumb Rubber (%)	Lime (%)	Soil (%)	Compaction Characteristics	
			OMC	MDD (Mg/m³)
0	0.0	100	17.1	1.68
3	5.0	100	16.9	1.69
3	7.5	100	16.3	1.75
3	10.0	100	15.6	1.78
3	12.5	100	15.0	1.83
3	15.0	100	14.0	1.87

Source: Soil Mechanics Laboratory Abubakar Tafawa Balewa University, Bauchi.

Compaction Characteristics

The variation of compaction characteristic with lime content of the soil specimen compacted using the standard proctor compaction energy is presented in Table 3. The maximum dry density (MDD) and the optimum moisture content (OMC) of the natural and stabilized laterite soil at varying percentages of replacements of the soil with crumb rubber and lime are presented in table 3 above.

The trends observed showed an improvement in compaction characteristic with increase in lime content in the soil sample. From Table 3, the optimum moisture content (OMC) and maximum dry density (MDD) values for the non-lateritic soil specimens considered in this study recorded expected trends with MDD results increasing appreciably while, the OMC values decreased with increase in lime content. The maximum dry density (MDD) of the soil sample with 0% lime content was 1.68 Mg/m^3 with corresponding optimum moisture content (OMC) of 17.1 %. Subsequently with addition of lime at 5, 7.5, 10, 12.5 and 15 % in the soil sample, the MDD values increased to 1.70, 1.75, 1.78, 1.83 and 1.89 Mg/m^3 respectively while the OMC values decrease from 17.1% to 16.9, 16.3, 15.6, 15 and to 14%. An increase in dry density was observed with increase in lime content as earlier investigated by (Asma & Dariusz, 2013, France et al., 2013, Firoozi et al., 2017). Generally, lime content improved the compaction characteristics of the soil by increasing the MDD and decreasing the OMC. As presented in figure 2 and 3 below

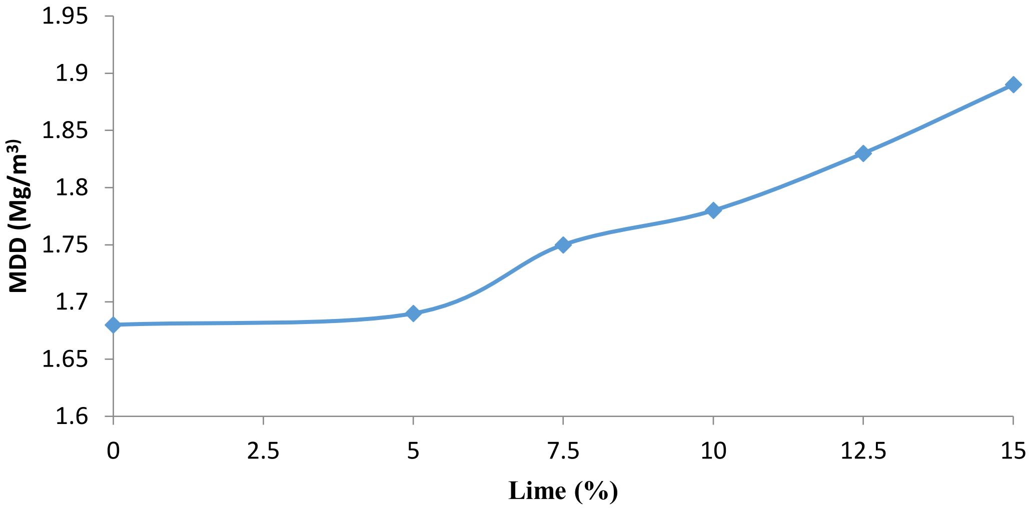

Figure 2. Variation of MDD with lime content (%)

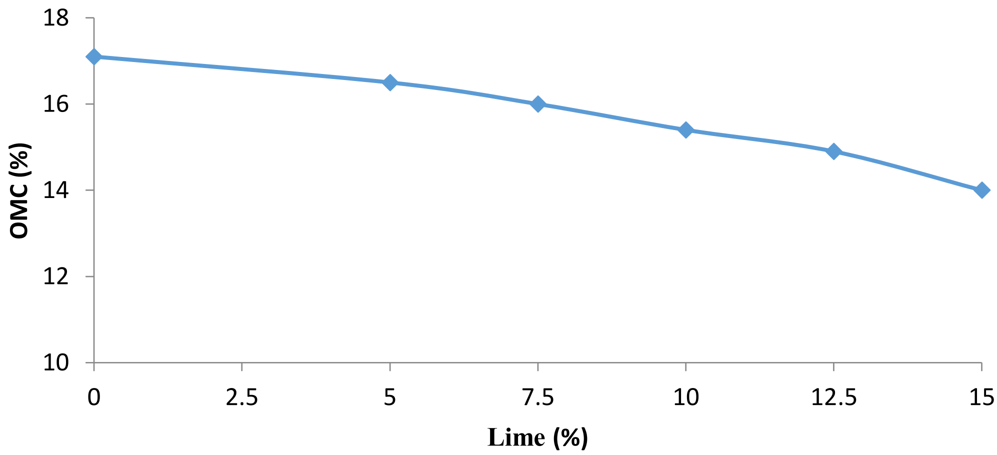

Figure 3. Variation of OMC with lime content (%)

California Bearing Ratio (CBR) Results

The average result of California bearing ratio (CBR) values, both soaked and unsoaked conditions, for crumb rubber/ lime treated non-lateritic soil compacted using the West African Standard (WAS) energy level is summarized in Table 4 below.

Table 4. California bearing ratio results

Lime (%)	CBR Unsoaked (%)	CBR Soaked (%)
0.0	31	28
5.0	48	43
7.5	61	56
10.0	89	87
12.5	112	110
15.0	156	149

Source: Soil Mechanics Laboratory Abubakar Tafawa Balewa University, Bauchi.

Effect of Crumb Rubber/Lime Content on the California Bearing Ratio (CBR) of Lateritic Soil

The California Bearing Ratio (CBR) of the soil is presented in Figures 4. The trends showed that with increase in lime, the CBR values also increased. The CBR values increases from 31 % to 156 for unsoaked condition and from 28 to 149 for soaked condition. Therefore, the variation in the CBR values is of increasing order for both unsoaked and soaked condition. This may be due to the effect of lime content in the soil which, in soaked condition, gains hydration. With increase in lime, the clay particle sizes in the soil increase (probably due to swelling) and hence minimize the point of contact between the solid particles in the soil mass. This minimizes the angle of internal friction and hence increases the CBR value of the soil sample. The treated soil with up to 15 % lime content showed an adequate improvement in the CBR values as compared to the untreated soil samples. This was also observed by researchers such as France et al., 2013, Jagmohan et al., 2014 and Asrif, 2016. However, with 10 – 15 % lime content, the CBR values for both unsoaked and soaked conditions were observed to be adequate for base course in road constructions. This is presented in figure 4 below.

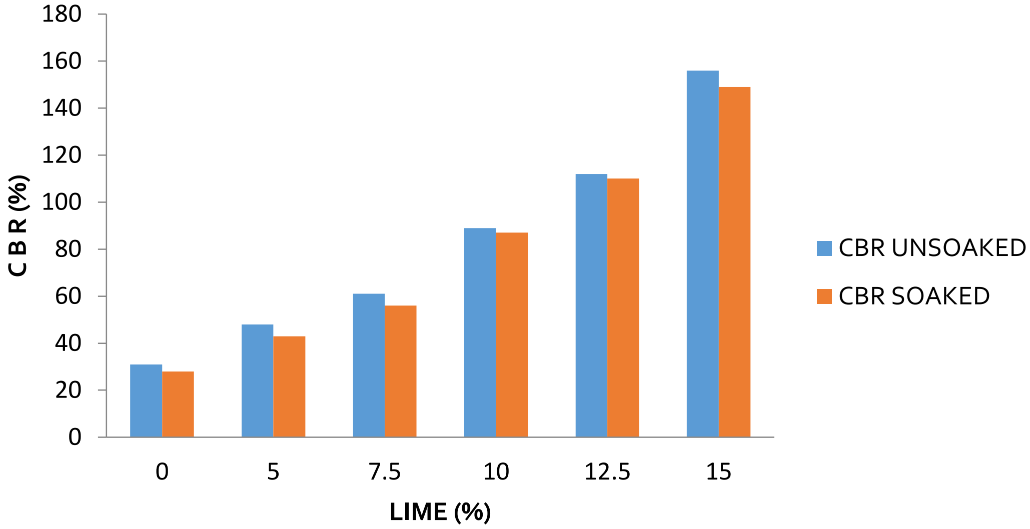

Figure 4. Variation of CBR with lime content (%)

Conclusion and Recommendation

Conclusion

Based on the findings of this research work, the following conclusions are hereby drawn;

i. From the Atterberg limit and sieve analysis tests results, the soil is said to be A-6 (11) and CL in accordance with ASHTO and USCS classification systems respectively (ASTM D 2487-2011).
ii. For the compactive effort used, there is an increase in the MDD values with corresponding decrease in OMC when the soil is treated with up to 15 % lime and 3 % crumb rubber.
iii. The California Bearing Ratio (CBR) of the soil sample increases with increase in lime content. Samples with 10 – 15 % lime and 3 % crumb rubber content, compacted using WAS attained minimum CBR values recommended for base course in road constructions.
iv. The compaction characteristic of the soil is significantly affected by the addition of 3% crumb rubber and 10 – 15 % lime content. Specimen compacted using WAS gave a compaction characteristic value of 1.89 Mg/m^3 and appreciable California bearing ratio (CBR) value, thus the optimal mix of 3% crumb rubber and 15% lime is adopted for stabilization of non – lateritic soils.

Recommendations

Lime was found to be an effective and economical chemical stabilizer of non-lateritic soil with 3 % crumb rubber that can be used to improve the CBR value for road construction purpose with WAS compaction energy. The following recommendations for further research are hereby given:

i. The unconfined compressive strength (UCS) and the durability performance of non-lateritic stabilized with crumb rubber and lime should be investigated.
ii. Also, the use of other chemical additives in non-lateritic soil stabilized with crumb rubber and lime should be investigated as they might improve on the engineering properties of the soil mix.
iii. Performance of non-lateritic soil stabilized with crumb rubber and lime using other compaction energy levels (British Standard Light and British Standard Heavy) may be checked.

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