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Comparative Study on Basic Index Properties of Cement Stabilized Black Cotton and Lateritic Soils on Sedimentary Formation of Part of South-Western Nigeria

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Abstract: *This research investigates the impact of cement stabilization on Black Cotton Soil (BCS) and Lateritic Soil. It also examines how varying cement proportions (10%, 20%, and 30%) affect their engineering properties and compaction characteristics. Given the tendency of BCS to swell when wet and shrink when dry, along with the inconsistent strength of Lateritic Soil, this study highlights the need for effective soil stabilization methods in civil engineering, especially in areas where these soils are commonly found. In accordance with BS 1377 (1990), series of experimental tests, including particle size distribution, Atterberg limits etc., were performed to analyse the modifications in soil properties. For BCS, the Liquid Limit decreased from 63.20% in its natural state to 21.79% at 50% cement substitution, while the Plastic Limit declined from 37.78% to 15.74%. The specific gravity of black cotton soil 2.63 at its natural state and lateritic has 2.73 while that of cement at its natural state is 3.13. The results demonstrated notable enhancements of maximum dry density, shear strength, and moisture retention in both soil types, with Lateritic Soil showing better performance and needing less cement for effective stabilization. These findings are significant for road construction and civil engineering infrastructure development, offering insights into optimal cement content to improve soil performance.*

Keywords: *Cement, Stabilization, Black Cotton Soil, Lateritic Soil, Atterberg Limit Test, Compaction.*

Introduction

Soil stabilization is a critical aspect of civil engineering, particularly in regions where soil properties pose challenges to construction. Among various soil types, black cotton soil and lateritic soil exhibit distinct characteristics that impact their behaviour under stabilization treatments. Soil stabilization involves enhancing the properties of soil by incorporating appropriate stabilizers. This process is crucial, particularly in road construction projects, where a weak base can lead to unexpected road failures (Garber & Hoel, 2000). Soil stabilization is defined as modifying any soil property to enhance its engineering performance. Depending on the material being stabilized, it can be carried out manually, mechanically, or chemically (Murthy, 2012). According to Garber & Hoel (2000), soil stabilization involves treating natural soil to improve its engineering characteristics. Essentially, it is the process of creating or enhancing specific properties in soil to make it suitable for a particular application. Lime and cement have been effectively utilized for soil stabilization and improvement (Rields & Brooks, 1999). Cement-treated soil has shown significant improvements in its properties. The hydration process of Portland cement involves the reaction between anhydrous calcium silicate and aluminate phases with water, leading to the formation of hydrated compounds. These solid hydrates occupy more space than the original anhydrous particles, resulting in a rigid, interlocking structure. The porosity of this structure is determined by the water-to-cement ratio (w/c) in the initial mix. As long as the mix has enough plasticity for proper compaction, a lower w/c ratio will yield higher compressive strength in the hydrated cement paste, mortar, or concrete, and better resistance to environmental contaminants. The hydration process is complex, and it's useful to examine the reactions of the silicate phases (C3S and C2S) separately from the aluminate phases (C3A and C4AF). This process has been thoroughly reviewed by Taylor (1997).

Background Study

Based on lots of experimental studies, that has been done on the stabilization of black cotton and lateritic soil using different stabilizers. The principal goal of this section is to present a summary of the research work that was carried out by different researchers in this field. Soil materials are a vital element in all civil engineering designs. Therefore, an understanding of the origin, development and use of soil materials is a basic requirement for the field and laboratory personnel who work with them. The term 'soil' as defined by Arora (2010) is accepted to be an unconsolidated material composed of solid particles produced by the disintegration of rocks. A natural aggregate mineral particles bonded by strong permanent cohesive forces is called 'rock'. It is a hard, solid material that requires drilling, wedging or blasting for its removal from the earth surface. Soils may be classified in a general way as cohesionless or cohesive or a coarse or fine grained. As the terms are too general and cover too wide a range of physical and engineering properties, additional refinement or means of classification is necessary to determine the suitability of a soil for a specific engineering purpose and to be able to convey this information to others in an understandable way. Numerous classification systems have been proposed in the past several decades, which are helpful and guide in classifying soils. The most commonly used are the AASHTO and the Unified Classification Systems (Bowles, 1992). American Association of State Highway and Transportation Officials (AASHTO) formerly the Bureau of Public Road System is used worldwide. The AASHTO classification system started with the then U.S. Bureau of Public Roads in the years 1927-1929 and the system was revised in 1945. It classifies soils into eight groups, A1 through A-8, The Unified Classification System was originally developed for use in airfield construction and it had already been in use since about 1942, but was slightly modified in 1952 to make it apply to dams and other construction. A soil is well-graded gravel or non-uniform if there is a wide distribution of grain sizes present, if there are some grains of each possible size between the upper and the lower gradation limits. This could be ascertained by plotting the grain-size curve and either observing the shape and spread of sizes or computing the coefficient of uniformity and coefficient of curvature. A poorly graded, or uniform, if the sample is mostly of one grain size or is deficient in certain grain sizes. The unified classification system defines a soil as Coarse-grained if more than 50 percent is retained on the No.200 sieve, Fine-grained if more than 50 percent passes the No. 200 sieve. The coarse-grained soil is either: Gravel if more than half of the coarse fraction is retained on the No. 4 sieve or Sand if more than half of the coarse fraction is between the No.4 and No.200 sieve. Classification of coarse-grained soils depends primarily on the grain-size analysis and particle size distribution. Classification of fine-grained soil requires the use of plasticity chart; each soil is grouped according to the coordinates of the plasticity index and liquid limit. On this chart an empirical line (the A line) separates the inorganic clays (C) from silts (M) and organic (O) soils. Although the silty and organic soils overlapped areas, they are easily differentiated by visual examination and odour.

Laterite is a residual soil formed from the weathering of igneous rock under conditions of high temperature and high rainfall such as those typically occurring in tropical regions, where decomposition process result in a soil leached of silica (SiO_2) and calcium (iv) oxide but retaining high concentration of iron and aluminum sesquioxide; which is an oxide with three atoms of oxygen and one metal atom i.e. $Fe_2O_3.Al_2O_3$. The resulting concentration of iron and aluminum oxides sharply differentiate laterization from temperature climate weathering in which the end produce is largely clay minerals. As a result of heavy rainfall during wet season, followed by the dry season high temperature and rapid evaporation of the tropics, plant draw water far below the ground, to replenish the one lost to the atmosphere; as long as the supply holds. This leads to the accumulation of iron and aluminum hydroxides which are insoluble and not re-dissolved during raining season and are therefore left at or near the surface where they form a thick red to black soil called laterite. There are identified three stages in the process of laterization, the first stage; decomposition is characterized by physio-chemical breakdown of primary minerals and the release of constituent elements, the second stage involves the leaching under appropriate drainage conditions of combined silica and bases and the relative accumulation of oxides and hydroxides of sesquioxides (mainly Al_2O_3 and Fe_2O_3, the most resistant components to leaching), the third stage (dehydration or desiccation) involves partial or complete dehydration sometimes involving hardening of the sesquioxides rich materials and secondary minerals. Under tropical condition high temperature and rainfall, these minerals tend to decompose into various conditions. The free iron oxides content and the degree of dehydration or hardening as the unique granular structure of some lateritic soil are believed to always correspond to tropical climate. The most significant proportions of irons and aluminum oxides found in lateritic soil which tends to cement the soil particles to form a coarse grained weakly bonded particulate material. The relatively high temperature of lateritic formation is a feature of tropical climate. These types of laterite are also common in many tropical regions including Nigeria where in most cases sourcing for alternative soil may prove economically unwise. The classes of lateritic soil include; Luvisols and ferruginous soils occur in the more arid extremes of lateritic soils, in areas with pronounced dry seasons. They have formed over all rock types. They display lower Atterberg limits, higher densities and CBR values than others. Ferralsols, acrisols and ferrallitic soils occur in the more humid extremes for lateritic soils and in areas with dense vegetation. These soils have also formed over all rock types. Ferralsols and ferrallitic soils may contain plinthite which hardens on exposure; however, dehydration does not normally occur because of dense vegetative cover. Nitosols, ferrisols and perhaps some carnbisols have formed over all types of rocks in intermediate to high rainfall areas where erosion has kept pace with profile development. The high degree of hydration of clay materials is responsible for the similarity of properties among these soils and ferrallitic soils.

Black Cotton Soil is also known as expansive soil, this soil is weird soil if we consider its behaviour with the moisture, when this soil comes in contact with moisture it swells and losses all its strength, whereas in summer season when atmosphere absorbs all its moisture it shrinks which forms cracks in the soil and these conditions are difficult to deal for engineers (Rajshekhar Rathod et al, 2021). When civil infrastructures are built with or on these soils, it experiences the shrinkage or swell property depending on the level of stress it is exposed to. It is therefore quite tasking to carry out design and construction involving the use of this soil due to its un-usual behaviour. These soils mostly found in the hot environment in the semi – arid areas of the temperate and tropical climate zone with defined alternating dry and wet seasons and where evaporation exceeds precipitation (Chen, 1988). They are largely located on sedimentary plains as a result continuous erosion of the clay content out of nearby hills. BCS can likewise be found on low level areas and depressions. (Paul Yohanna, Ianna M. Kanyi, et al, 2021). Historically, civilizations have used various stabilization techniques, from ancient earth roads to modern methods involving lime and cement (McDowell, 1959).

Contemporary practices have evolved to include alternative materials such as industrial by-products and agricultural waste, which offer both economic and environmental advantages (Akinwumi et al., 2012; Adesanya & Raheem, 2009a). Recent studies highlight the effectiveness of materials like rice husk ash, sugarcane bagasse ash, and corn cob ash in enhancing soil properties and reducing environmental impact (Cordeiro et al., 2008; Adama & Jimoh, 2012; Jimoh & Apampa, 2014). These alternatives not only improve soil stability but also offer cost-effective solutions and contribute to waste management (Bhaumik & Janani, 2016; Eberemu, 2015). While these advancements address many challenges, there are still gaps in understanding the long-term performance and environmental impacts of these materials. Future research should focus on optimizing stabilization techniques and evaluating the sustainability of alternative stabilizers in diverse soil conditions. The advantages of soil stabilization includes: It improves soil strength, Reduce expansiveness, Improves soil workability, improve the engineering properties of soil and make it suitable for construction, Avoid unseen settlement, Reduce dust in work environment. It is applied in Foundation, Dam and Reservoir, Road constructions.

Methodology

In this study, experiments were carried out to evaluate the effects of cement stabilization on two soil types: black cotton soil and lateritic soil on sedimentary formation of part of South Western Nigeria (Figures 1 a, b and c). Index and engineering properties tests were carried out on the soil samples at natural state in accordance with the procedures outlined in BS 1377 (1990) and stabilized state in accordance with the procedures outlined in BS 1924 (1990). The methodology involved a series of geotechnical tests, these are: Grain Size Distribution (sieve analysis), Specific Gravity, Standard Consistency, Atterberg's Limits tests, etc. These tests were designed to assess the physical and mechanical properties of the soils in their natural (virgin) state and after stabilization with varying cement contents. Each test, except for sieve analysis, was conducted on soil samples stabilized with three different cement percentages: 10%, 20%, and 30% cement substitutions (Figures 1 a, b, and c). The Black cotton soil samples were obtained from Ilobi–Muwa along Owode-Ilaro Road, Yewa South Local Government, Ogun State, Nigeria, while lateritic soil was collected from a borrow pit within the locality of Ilaro, Ogun State, Nigeria.


a b c

Figure 1: a Lateritic soil, b Black Cotton Soil and c Ordinary Portland Cement

Figure 2: a. Sieve sizes distribution, b. Specific Gravity using Pycnometers

This test was carried out to determine the specific gravity of soil grains using the density bottle according to BS 1377-2 (1990) at the soil mechanics laboratory (Figure 2b).

Atterberg Limit Test

The Atterberg limits tests were carried out in accordance with the British Standard Methods-BS 1377 (1990) at the soil mechanics laboratory (Figure 3). The test procedures are further explained below.

Liquid Limit (LL)

This test was carried out in accordance with British Standard 1377: 1990 Part 2. A 200g oven-dried sample of soil that had passed through a 425 mm sieve was adequately saturated with water on a glass plate, covered, and left for about 24 hours. At the elapsed time, the sample was properly remixed with spatulas. The cone penetrometer was correctly set up in preparation for the exam. The mixed sample was placed in the sample cup, and the initial reading was recorded. The sample was penetrated for five seconds, and the end reading was recorded in the same manner. The soil was then removed from the cup to be measured for moisture content. The soil from the cup was returned to the glass dish. The soil was re-mixed properly, and the water content was slightly increased. The cup was also meticulously cleaned. The entire procedure was repeated five times and penetration against moisture content was obtained. M_1 = mass of an empty moisture can, M_2 = mass of can + wet soil, M_3 = mass of moisture can + dry soil, Mass of water = M_2 - M_1 and Mass of dry soil = M_3 - M_1

Plastic limit (PL)

Plastic limit test is one of the laboratory tests used internationally for the classification soil into groups. The weights and can numbers were recorded on the data sheet using the lids of the empty moisture cans. One-fourth of the initial soil sample was diluted with distilled water until the soil had the right consistency to roll without sticking to hands. After forming an ellipsoidal mass, the soil sample was rolled between the palm of the hand or the fingertips on the glass plate. The mass was rolled into a thread by applying pressure at 90 strokes per minute with a consistent diameter (From the starting position, a stroke is a continuous forward and backward hand movement). It took less than two minutes to deform the thread to a 3.2 mm diameter.

Shrinkage limit (SL)

The mixed sample was poured into the shrinkage mold and leveled to the mold's tip. The sample was first measured before being oven dried for 24 hours. The sample's ultimate length was measured after it had cooled. The shrinkage limit was calculated using the following equation:

$$Shrinkage\ Limit = weight\ of\ water\ at\ point\ when\ the\ sample\ stops\ shrinking \div the\ sample's\ \ dry\ weight$$

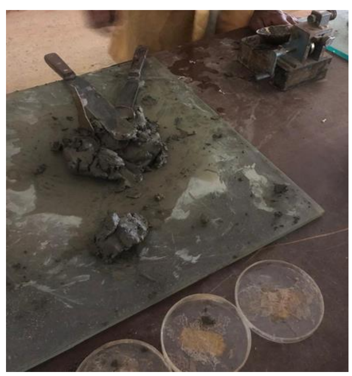

Figure 3: Atterberg Limit test apparatus

This study examines the comparative behaviour of black cotton and lateritic soil stabilized with different proportion 10%, 20% and 30% of cement added to both samples. This study is aimed at evaluating the impact of cement stabilization on black cotton soil which was obtained from Ilobi – Muwa, along Owode-Ilaro Road, Yewa South local government, Ogun State, Nigeria (6º49ʾ29ʾʾN 3º0ʾ51ʾʾE) and Lateritic soil which was obtained within the locality of Ilaro, Ogun State, Nigeria (6º53ʾ58ʾʾN 3º1ʾ07ʾʾE).

Results and Discussion

The results of the experimental work which include grain size distribution, specific gravity, Standard consistency test, Atterberg limits test for black cotton and lateritic soils on sedimentary formation of part of South-Western Nigeria are presented blow. The results of various Index Properties mentioned above are presented in Figures 4 to 8 and Tables 1 to 16.

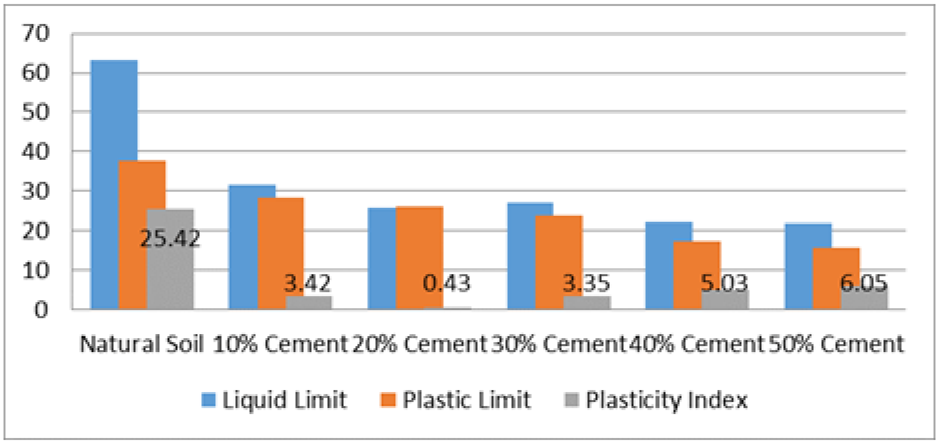

Figure 4: Results of Atterberg limit test for black cotton soil

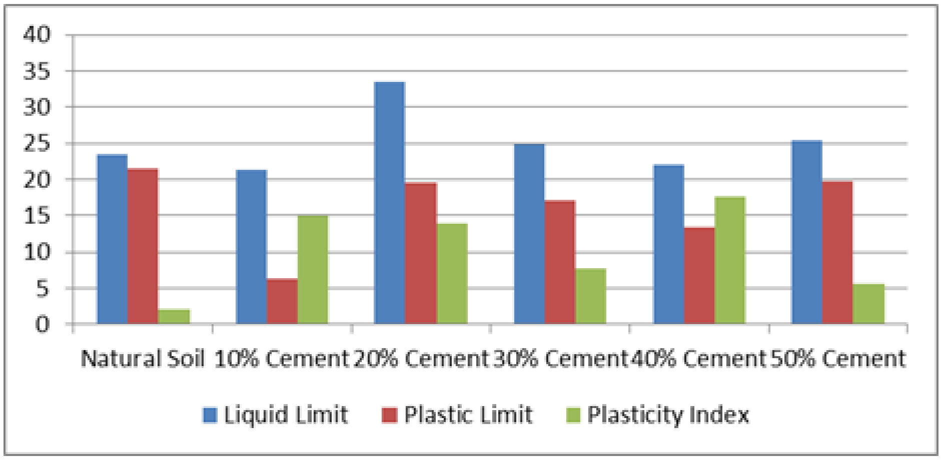

Figure 5: Atterberg Limit test for Laterite soil.

Figures 4 and 5 shows the value obtained from liquid, plastic and shrinkage limit test, for varying percentage of cement, at natural state the laterite soil is more stable than black cotton soil having lower liquid, plastic, shrinkage limit and plasticity index compared to laterite soil, has the proportion of cement increases, the liquid, plastic, shrinkage limit and plasticity index reduces which indicates the increase in the stability and load bearing capacity of the soils. These results shows that with increase in cement proportion, laterite becomes more stable than black cotton soil.

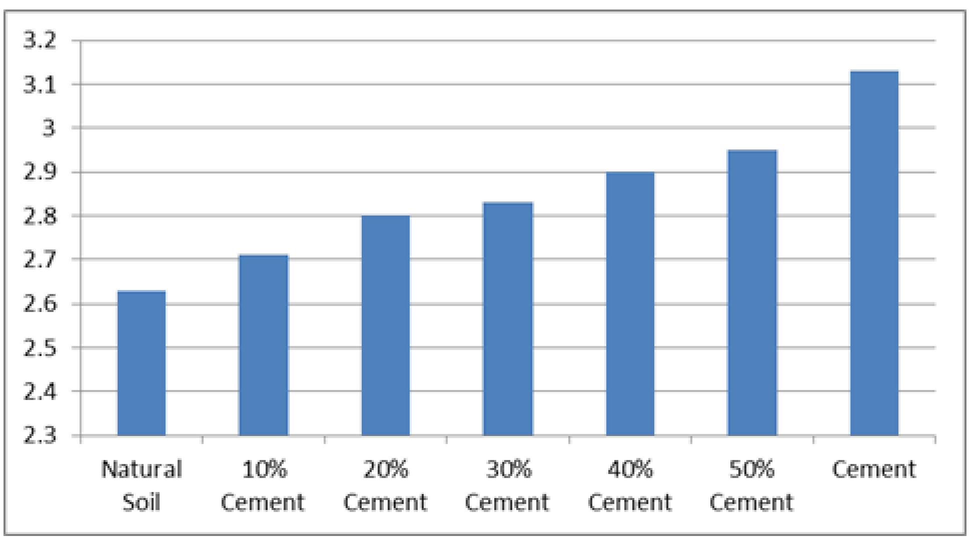

Figure 5: Results of Specific Gravity Test for Black cotton soil

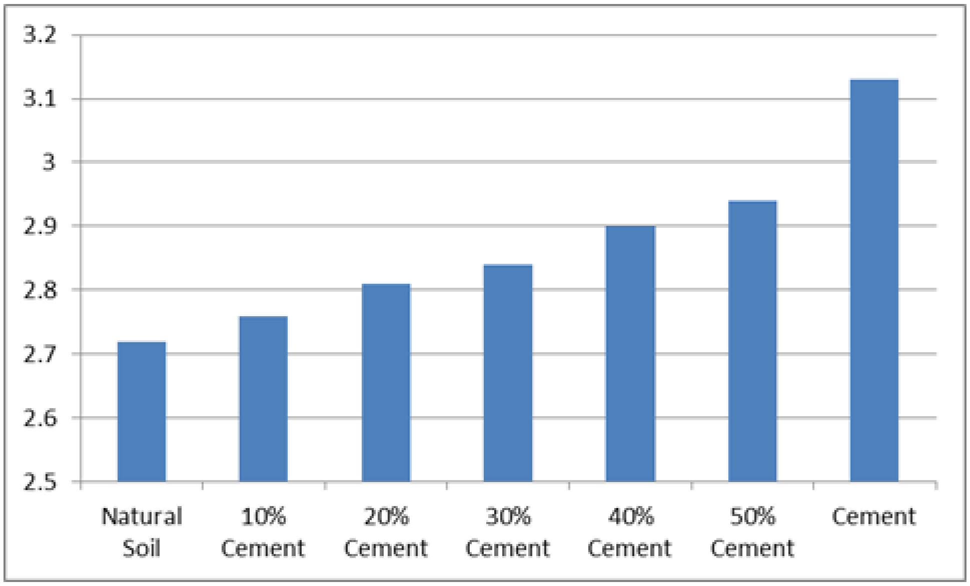

Figure 6: Specific gravity result for lateritic soil

Specific Gravity of a soil sample can be defined as the weight in air of a given volume of soil particles to the weight in air of an equal volume of distilled water at the same temperature (4ºC) (Adekanmi & Popoola, 2018). The specific gravity of a substance is determined by comparing its mass per unit volume to that of a specified volume of distilled water free of gas at a given temperature. Figures 4 and 5 shows the specific gravity test results for both soil compared. At natural state, Black cotton has value of 2.63 and lateritic soil has a value of 2.72, which induces that the lateritic soil is more stable and stronger, also having denser particles when compared to black cotton soil, the specific gravity raised significantly when 40% and 50% of cement was added to both soil, which makes the lateritic soil still more stable than black cotton soil. Grain Size Analysis can determine particle sizes ranging from 0.075 mm to 100 mm. Any grain categorization above 100 mm is done visually, particles with a diameter of less than 0.075 mm can be distributed using the Hydrometer analysis. The sieve analysis was assessed to know the distribution of the coarse, larger-sized particles (Figures 7 and 8).

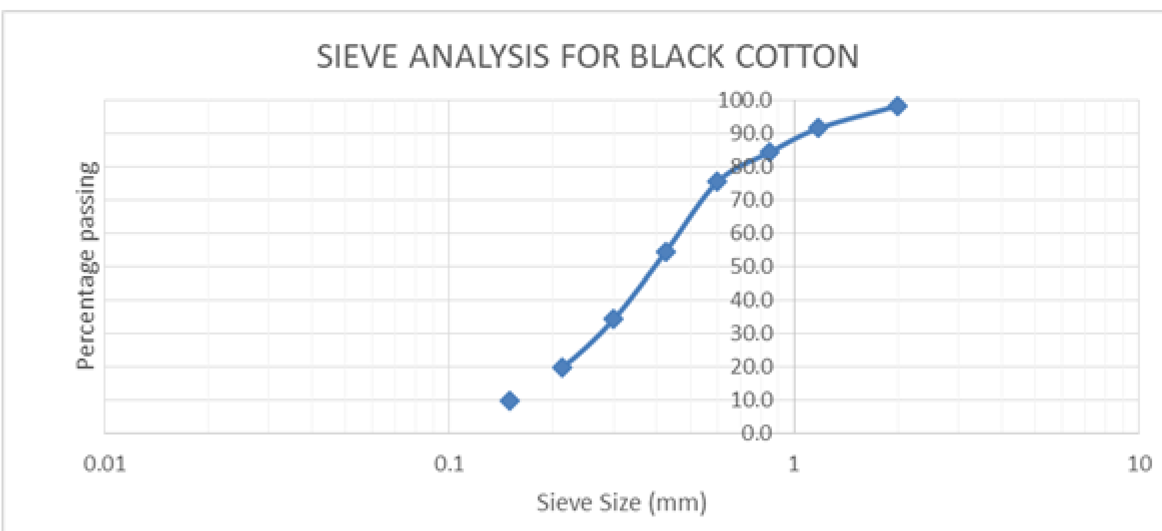

Figure 7: Graph of Grain distribution for Black cotton soil

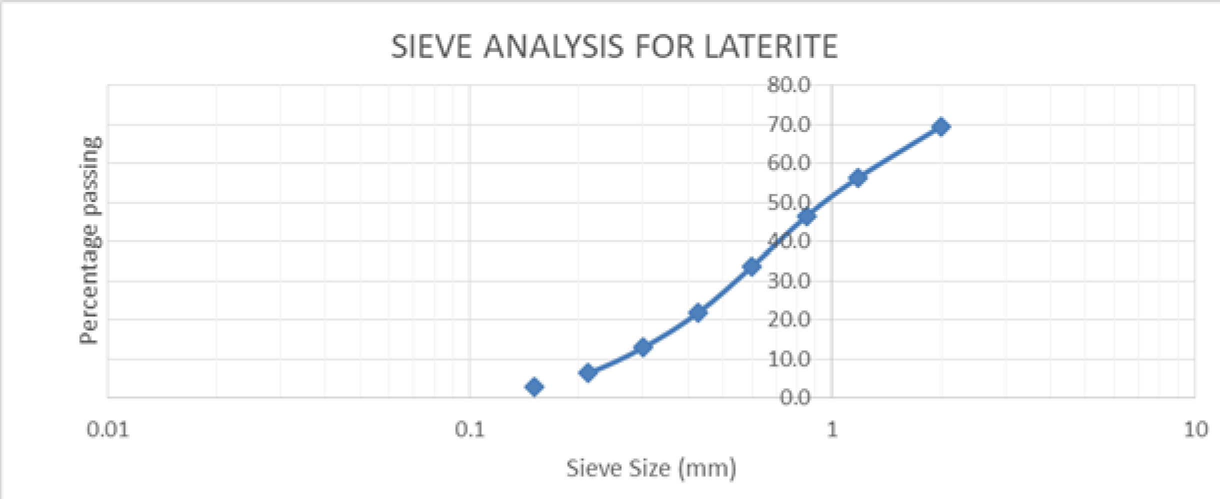

Figure 8: Graph of Grain size distribution for lateritic soil

Figures 7 and 8 shows the graph of grain size distribution for both black cotton and laterite, these shows that black cotton soil is dominated by clay particles, with limited silt and almost negligible sand, It is very fine-grained, while, Lateritic soil has balanced distribution of sand, silt, and clay.

Table 1 (a – f): 0% Cement (Control) Substitution in Black Cotton Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	13.2	7.04

b.

Can No	1	2	3	4
Weight of wet soil + can (g)	84.00	78.00	72.00	66.90
Weight of dry soil + can (g)	70.40	66.04	62.83	59.79
Weight of can (g)	49.60	49.60	48.20	48.20
Weight of dry soil (g)	20.08	18.44	14.63	11.59
Weight of water (g)	13.60	11.96	9.17	7.11
Percentage Moisture content (m) %	67.73	64.86	62.68	61.35
No of Blows	10	15	28	35

Liquid Limit = 63.2%

c. PLASTIC LIMIT TEST

Can No	1	2

Weight of wet soil + can (g)	66.00	61.00
Weight of dry soil + can (g)	59.65	56.36
Weight of can (g)	42.67	44.20
Weight of dry soil (g)	16.98	12.16
Weight of water (g)	6.35	4.64
Percentage Moisture content (m) %	37.40	38.16

PLASTIC LIMIT = 37.40 + 38.16 /2 = 37.78%
PLASTICITY INDEX = LIQUID LIMIT – PLASTIC LIMIT
= 63.20 – 37.78 = 25.42%

Table 2 (a-c)10% Cement Substitution in Black Cotton Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	13.8	2.82

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	116.77	111.81	109.67	106.69	97.91
Weight of dry soil + can (g)	99.35	94.75	93.55	91.46	84.20
Weight of can (g)	45.11	43.86	43.46	43.47	43.81
Weight of dry soil (g)	54.24	50.89	50.09	47.99	40.39
Weight of water (g)	17.42	17.06	16.12	15.23	13.71
Percentage Moisture content (m) %	32.12	33.52	32.18	31.74	33.94
No of Blows	11	17	22	26	36

Liquid Limit = 31.64%

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	72.83	70.28
Weight of dry soil + can (g)	66.77	64.61
Weight of can (g)	45.15	44.65

Weight of dry soil (g)	21.62	19.96
Weight of water (g)	6.06	5.67
Percentage Moisture content (m) %	28.03	28.41

PLASTIC LIMIT = 28.03+28.41 /2 = 28.22%
PLASTICITY INDEX = LIQUID LIMIT – PLASTIC LIMIT
= 31.20 – 28.22 = 2.98%

Table 3 (a-c): 20% Cement Substitution in Black Cotton Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	13.90	2.11

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	100.92	95.19	109.40	102.72	106.26
Weight of dry soil + can (g)	88.72	84.80	95.62	90.50	93.83
Weight of can (g)	43.46	46.23	41.75	42.73	44.62
Weight of dry soil (g)	45.26	38.57	53.87	47.77	49.21
Weight of water (g)	12.20	10.39	13.78	12.22	12.43
Percentage Moisture content (m) %	26.96	26.94	25.58	25.58	25.26
No of Blows	12	15	20	25	32

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	74.83	67.15
Weight of dry soil + can (g)	68.67	62.05
Weight of can (g)	45.15	42.30
Weight of dry soil (g)	23.52	19.75
Weight of water (g)	6.16	5.10
Percentage Moisture content (m) %	26.19	25.82

Table 4 (a-c): 30% Cement Substitution in Black Cotton Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	13.90	2.11

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	93.04	104.02	101.70	93.88	96.28
Weight of dry soil + can (g)	83.54	92.30	89.30	83.80	85.91
Weight of can (g)	44.13	44.87	43.80	46.23	43.12
Weight of dry soil (g)	39.41	47.83	45.50	37.57	42.79
Weight of water (g)	9.5	11.72	12.40	10.08	10.37
Percentage Moisture content (m) %	24.11	24.50	27.25	26.83	24.23
No of Blows	15	19	23	28	35

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	74.83	73.21
Weight of dry soil + can (g)	68.67	68.20
Weight of can (g)	45.15	44.65
Weight of dry soil (g)	23.52	23.55
Weight of water (g)	6.16	5.01
Percentage Moisture content (m) %	26.19	21.27

Table 5 (a-c): 40% Cement Substitution in Black Cotton Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.20	13.90	2.11

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5

Weight of wet soil + can (g)	98.25	96.30	96.60	93.52	98.00
Weight of dry soil + can (g)	87.97	86.94	86.72	85.80	87.78
Weight of can (g)	44.47	44.33	44.80	45.16	45.11
Weight of dry soil (g)	43.50	42.61	41.92	40.64	42.67
Weight of water (g)	10.28	9.36	9.88	7.72	10.22
Percentage Moisture content (m) %	23.63	21.97	23.57	18.99	23.95
No of Blows	15	22	29	34	41

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	72.64	67.94
Weight of dry soil + can (g)	68.50	64.53
Weight of can (g)	44.75	44.30
Weight of dry soil (g)	23.75	20.23
Weight of water (g)	4.14	3.41
Percentage Moisture content (m) %	17.43	16.90

Table 6 (a-c): 50% Cement Substitution in Black Cotton Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	13.90	2.11

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	101.92	91.17	94.66	90.70	89.07
Weight of dry soil + can (g)	90.30	81.04	83.77	81.11	80.15
Weight of can (g)	44.13	44.87	43.80	46.23	43.12
Weight of dry soil (g)	46.17	36.17	49.97	34.88	37.03
Weight of water (g)	11.62	10.13	10.89	9.59	8.92

Percentage Moisture content (m) %	25.17	28.01	21.79	27.49	24.09
No of Blows	12	18	25	30	36

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	71.70	71.10
Weight of dry soil + can (g)	67.60	67.61
Weight of can (g)	42.17	44.87
Weight of dry soil (g)	25.43	22.74
Weight of water (g)	4.10	3.49
Percentage Moisture content (m) %	16.12	15.35

Table 7: Specific Gravity of Cement Substitution in Black Cotton Soil

% Substitution of Cement	Specific Gravity (Gs)
0% (Control)	2.63
10%	2.71
20%	2.80
30%	2.83
40%	2.90
50%	2.95

Table 8: Sieve Analysis of Black Cotton Soil

Sieve Size (mm)	Mass Retained (g)	Percentage Mass Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
2.00	18.5	1.60	1.60	98.40
1.18	78.0	6.75	8.35	91.65
0.850	84.0	7.27	15.67	84.38
0.600	102.5	8.87	24.49	75.51
0.425	242.0	20.95	45.44	54.56
0.300	235.0	20.35	65.79	34.21
0.212	169.0	14.63	80.42	19.58
0.150	112.0	9.70	90.12	9.88
Receiver	109.5	9.48	99.60	0.40
Total	1150.5			

Soil Sample = 1155g

Table 9 (a-c): 0% Cement Substitution (Control) in Lateritic Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
1	14.2	13.9	2.11

b. LIQUID LIMIT TEST

Can No	1	2	3	4
Weight of wet soil + can (g)	112.11	107.86	98.10	87.79
Weight of dry soil + can (g)	101.75	96.85	88.38	81.69
Weight of can (g)	49.60	49.60	49.60	49.60
Weight of dry soil (g)	52.15	47.25	38.78	32.09
Weight of water (g)	10.36	11.01	9.72	6.10
Percentage Moisture content (m) %	19.87	23.30	25.06	19.01
No of Blows	14	21	30	43

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	67.84	62.13
Weight of dry soil + can (g)	63.64	60.69
Weight of can (g)	49.60	49.60
Weight of dry soil (g)	14.04	11.09
Weight of water (g)	4.20	1.44
Percentage Moisture content (m) %	29.91	12.98

Table 10 (a-c): 10% Cement Substitution in Lateritic Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	13.9	2.11

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	105.55	97.80	94.35	89.21	84.80
Weight of dry soil + can (g)	94.84	87.43	85.69	81.35	76.92
Weight of can (g)	43.46	41.75	44.62	42.73	46.23
Weight of dry soil (g)	51.38	45.68	41.07	38.62	30.69
Weight of water (g)	10.71	10.37	8.66	7.86	7.88
Percentage Moisture content (m) %	20.84	22.70	21.09	20.35	25.68
No of Blows	11	17	24	31	40

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	66.19	70.42
Weight of dry soil + can (g)	65.16	68.60
Weight of can (g)	44.75	44.86
Weight of dry soil (g)	20.41	23.74
Weight of water (g)	1.03	1.82
Percentage Moisture content (m) %	5.05	7.67

Table 11 (a-c): 20% Cement Substitution in Lateritic Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.20	14.00	1.41

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	109.05	89.50	88.23	78.44	75.03
Weight of dry soil + can (g)	96.24	80.32	75.65	72.53	67.61
Weight of can (g)	44.13	44.87	43.80	46.23	43.12
Weight of dry soil (g)	52.11	35.45	31.85	26.30	24.49

Weight of water (g)	12.81	9.18	12.58	5.91	7.42
Percentage Moisture content (m) %	24.58	25.90	39.50	22.47	30.30
No of Blows	14	17	23	28	35

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	68.20	66.40
Weight of dry soil + can (g)	64.66	62.64
Weight of can (g)	45.15	44.65
Weight of dry soil (g)	19.51	17.99
Weight of water (g)	3.54	3.76
Percentage Moisture content (m) %	18.14	20.90

Table 12 (a-c): 30% Cement Substitution in Lateritic Soil

a. LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	14.00	1.41

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	77.90	77.45	83.55	94.20	80.44
Weight of dry soil + can (g)	71.23	71.94	75.80	85.30	74.83
Weight of can (g)	44.47	44.33	44.80	45.16	45.11
Weight of dry soil (g)	26.76	27.61	31.00	40.14	29.72
Weight of water (g)	6.67	5.51	7.75	8.90	5.61
Percentage Moisture content (m) %	24.93	19.96	25.00	22.17	18.88
No of Blows	11	18	24	32	37

c. PLASTIC LIMIT TEST

Can No	1	2

Weight of wet soil + can (g)	63.57	67.50
Weight of dry soil + can (g)	61.00	63.67
Weight of can (g)	42.17	44.87
Weight of dry soil (g)	18.83	18.80
Weight of water (g)	2.57	3.83
Percentage Moisture content (m) %	13.65	20.36

Table 13 (a-c): 40% Cement Substitution in Lateritic Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	13.90	2.11

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	97.99	108.33	110.98	108.55	94.25
Weight of dry soil + can (g)	88.69	95.72	98.84	96.71	84.51
Weight of can (g)	43.46	41.75	44.62	42.73	46.23
Weight of dry soil (g)	45.23	53.97	54.22	53.98	38.28
Weight of water (g)	9.3	12.61	12.14	11.84	9.74
Percentage Moisture content (m) %	20.56	23.36	22.39	21.93	25.44
No of Blows	12	19	23	28	34

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	73.54	70.40
Weight of dry soil + can (g)	70.00	67.53
Weight of can (g)	44.75	44.86
Weight of dry soil (g)	25.25	22.67
Weight of water (g)	3.54	2.87

Percentage Moisture content (m) %	14.02	12.66

Table 14 (a-c): 50% Cement Substitution in Lateritic Soil

a. SHRINKAGE LIMIT TEST

Test No	Length of wet soil sample (cm)	Length of dry soil sample (cm)	Percentage Shrinkage limit (%)
Water Content (%)	14.2	14.00	1.41

b. LIQUID LIMIT TEST

Can No	1	2	3	4	5
Weight of wet soil + can (g)	77.00	83.68	87.46	98.65	95.16
Weight of dry soil + can (g)	70.11	76.09	78.67	90.00	85.42
Weight of can (g)	44.47	44.33	44.80	45.16	45.11
Weight of dry soil (g)	25.64	31.76	33.87	44.84	40.31
Weight of water (g)	6.89	7.59	8.79	8.65	9.74
Percentage Moisture content (m) %	26.87	23.90	25.95	19.29	24.16
No of Blows	13	19	26	31	38

c. PLASTIC LIMIT TEST

Can No	1	2
Weight of wet soil + can (g)	72.37	68.53
Weight of dry soil + can (g)	67.50	64.53
Weight of can (g)	42.17	44.87
Weight of dry soil (g)	25.33	19.66
Weight of water (g)	4.87	4.00
Percentage Moisture content (m) %	19.23	20.35

Table 15: Specific Gravity of Cement Substitution in Lateritic Soil

% Substitution of Cement	Specific Gravity (Gs)
0% (Control)	2.72
10%	2.76
20%	2.81
30%	2.84
40%	2.90
50%	2.94

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Table 16: SIEVE ANALYSIS of Lateritic Soil

Sieve Size (mm)	Mass Retained (g)	Percentage Mass Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
2.00	410.0	30.48	30.48	69.52
1.18	177.0	13.16	43.64	56.36
0.850	132.0	9.81	53.45	46.55
0.600	173.0	12.86	66.31	33.69
0.425	160.0	11.90	78.21	21.79
0.300	119.0	8.85	87.06	12.94
0.212	87.0	6.47	93.53	6.47
0.150	48.0	3.57	97.10	2.90
Receiver	36.0	2.68	99.78	0.22
Total	1342.0			

Soil Sample = 1345g

The tests under Atterberg limit are classified into three tests which are; liquid limit, plastic limit and shrinkage limit. These tests (i.e. Liquid Limits (LL), Plastic Limit (PL) and Shrinkage limit (SL) was carried out on the soil sample(s) and helped in assessing the samples natural reactions to water. The liquid limit is the water content at which the soil begins to behave like a liquid. Below this moisture level, the soil behaves like a plastic substance. Plastic Limit (PL) is the water content at which fine-grained soil can no longer be remoulded without cracking. The shrinkage limit (SL) is the moisture content in which the soil transitions from semi-solid to solid. At this moisture content, the volume of the soil mass does not change as the material dries further. Shrinkage limit is required when studying the swelling and shrinkage properties of cohesive soil; however, it is not as widely used as the liquid and plastic limits. This study aimed to evaluate the effectiveness of cement stabilization on Black Cotton Soil and Lateritic Soil, with a focus on understanding the impact of various cement percentages on soil properties and characteristics. The results from the experimental tests conducted provided valuable insights into the behavior of these soils under different stabilization conditions. The addition of cement significantly improved the compaction characteristics of both Black Cotton Soil and Lateritic Soil. Cement-treated soils demonstrated increased maximum dry density (MDD) and reduced optimum moisture content (OMC) compared to untreated soils. The Liquid Limit (LL) test results indicated that the soil's ability to retain moisture increased with higher cement content, reflecting improved soil cohesion and stability. The Plastic Limit (PL) and Shrinkage Limit (SL) tests further highlighted the enhanced workability and reduced shrinkage behavior of cement-stabilized soils. Cement stabilization effectively enhanced the shear strength and load-bearing capacity of both soil types. The increase in shear strength was consistent with the increase in cement content, which contributed to the soil's improved performance under load. The results also showed a reduction in the soil's plasticity index with higher cement percentages, indicating a more stable soil structure less prone to deformation and moisture variation. Between the two soil types, Lateritic. Soil generally exhibited better performance in terms of compaction and strength characteristics compared to Black Cotton Soil. This difference can be attributed to the inherent properties of the soils, such as grain size distribution and mineral composition, which influence their response to cement stabilization. The findings of this study have practical implications for road construction and other civil engineering applications. Cement stabilization proves to be an effective method for enhancing the geotechnical properties of problematic soils like Black Cotton Soil and Lateritic Soil. The improved compaction and strength characteristics of stabilized soils can lead to more durable and cost-effective construction solutions.

Conclusion

In conclusion, cement stabilization is a viable method for improving the engineering properties of Black Cotton Soil and Lateritic Soil. The study demonstrates that varying cement percentages significantly influence the compaction behaviour, moisture retention, and strength characteristics of these soils. The insights gained from this research contribute to the development of more effective soil stabilization practices, enhancing the performance and sustainability of road construction and other civil engineering projects. Further research could explore the long-term performance of cement-stabilized soils under varying environmental conditions and loading scenarios. Long-term durability studies could provide insights into the sustainability of cement stabilization methods. Investigating the use of alternative stabilizing agents, such as geopolymers or industrial by-products, could offer additional benefits in terms of cost and environmental impact. Comparative studies involving these materials could expand the scope of soil stabilization technologies. Field trials and case studies of cement-stabilized soils in actual construction projects would help validate laboratory findings and assess the practical challenges and benefits of these stabilization methods. Future research directions could include studies on long-term durability and the use of alternative stabilizers, which may further advance soil stabilization techniques and support sustainable construction practices.

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