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RESEARCH ARTICLE

SOIL STABILIZATION AND IMPROVEMENT OF MARINE CLAYS USING CEMENT AND LIME IN A MARSHLAND

Youdeowei, P.O[a]., Nwankwoala, H.O[b]*., Ayibanimiworio, G.T[c]

[a] Institute of Geosciences and Space Technology, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria
[b] Department of Geology, University of Port Harcourt, Nigeria
[c] Department of Civil Engineering, Faculty of Engineering, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria
**Corresponding Author email: nwankwoala_ho@yahoo.com*

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ABSTRACT

This study assesses the stabilization of marine clay soil using cement and lime to improve on the subgrade material. The tests conducted include: the natural moisture content, specific gravity, sieve analysis, Atterberg limit, compaction and California Bearing Ratio (CBR). The types of stabilization used were mechanical and chemical. The results obtained were classified using AASHTO classification system and based on the results the soil corresponds to group A-6 soils. The highest CBR values of 33.24% and 424.35% were obtained at 20% cement content for unsoaked and soaked and for lime the highest CBR values were 5.07 and 10.46 for 11% lime content for both unsoaked and unsoaked. Based on the results obtained, the addition of cement and lime to clay soil in the presence of water improved the CBR values for soft clay stabilization for highway construction with low traffic volume. It is therefore concluded that the addition of cement and lime to clay soil improved the bearing capacity and the maximum dry density of the clay soil. Further research should be carried out to examine the effects of industrial by-products on effective clay soil stabilization.

KEYWORDS

Stabilization, lime, cement, subgrade, clay, construction.

1. INTRODUCTION

Soil stabilization aims at improving soil strength and increase resistance to softening by water through eliminating of voids in the soil grains, reducing the volume of the soil mass, increasing the capacity to bear load and improving impermeability. The improvement-techniques have made land at water log region useful to high way engineers. It is a way of improving the weight bearing capabilities and performance of the in-situ sub-soils in order to strengthen road surfaces. Stabilization is to improve on site materials to create a solid and strong sub-base and base courses. Improvement of sub-grade has to do with blending and mixing materials with the soil in order to stabilize the subgrade (Otoko, 2014). The process may include the use of chemicals (additives) or mechanical stabilization that may alter the gradation and improve the engineering properties of the soil, thus increasing its stability. This study seeks to improve on the sub-grade stability through the use of additives or mechanical means. Soil in marshland (soft clay) is the most challenging problem to high way engineering. Affected areas include land saturated with water, those covered with soft clay, land side and contaminated land. Although all soil types needs to be improved in order to improve the extent to which it can carry its load.

Cement is the primary stabilizing agent or hydraulic binder because it can be used alone to bring about stabilizing action required (Sherwood, 1993). Portland cement can be used either to modify and improve the quality of soil or transform the soil into a cemented mass with increased strength and durability. Lime, on the other hand provides an economical way of soil stabilization. Lime modification describes an increase in strength brought about by pozzolanic reaction (Sherwood, 1993). Lime is particularly effective at stabilizing clay or aggregates containing high proportion of the fine clay particles.

Soil layer's shear strength and stiffness can be improved by using additives and can thereby reduce the thickness of the stabilized layer and overlying layers within the pavement system (Otoko, 2014). Various techniques as well as various binders are currently used to strengthen peat. A combined surface stabilization with stabilized cement columns to support foundation loads (Hebib and Farrell, 2003). A group researcher used reinforced stone column to transfer loads to the lower firm structure (Black et al., 2007). In other study, researcher increased the shear strength of undrained peat by almost 36% using a drainage method (Rahman et al., 2004). According to a study, an effective method of soil improvement is mass stabilization (Jelisic and Leppanem, 2000).

Stabilization is commonly used for better soil gradation, reduction of the plastic index or swelling potential, and increased durability and strength, determination of working platform and high way structural support sufficiency of subgrades enhanced with Geogrides, determine working platform and high way structure stability of subgrades when enhanced with cementious materials. It also determines equivalencies of soft

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subgrades as working platforms when enhanced with different additives. This study therefore seeks to improve on the bearing capacity of soft clay in the Niger Delta region for highway subgrades by the use of various stabilization techniques.

2. Materials and Methods

2.1 Laboratory Test and Analysis

All laboratory tests were conducted in accordance with BS 1377 and BS 6031 standard codes of practice (methods of testing soil for civil engineering purposes and earth works), and also with those to determine soil suitability and strength for road works. Classification was based on **ASAHTO** system. Various tests and analysis were carried out to examine the effects of cement and lime on clay soil namely natural moisture content, particles size distribution analysis, specific gravity test, atterberg limits test, compaction test and California Bearing Ratio (CBR). Tests were all carried out to investigate the effect of cement and lime on the stabilization of clay soil. The types of stabilization used are mechanical and chemical.

2.2 Particle Size Distribution Analysis

The particle size distribution expresses the size of particles in terms of percentage by weight of the soil passing each sieve. The procedure involves oven drying the clay soil sample for 24 hours allowing it to cool, and soaking also for 24 hours. The sieve 75µm was then used to wash and sieve the soil which was then oven dried and its resulting weight was recorded. The sieves were arranged according to the aperture size and the reweighed sand was poured into the set of sieves and shaken vigorously for 10minutes. The sieve was left for a while for the sample to settle, the sand retained on each sieve was weighed and recorded and the corresponding percentage retained and passing were calculated. A graph of the percentage passing was plotted against the sieve sizes.

2.3 Natural Moisture Content

This test was used to determine the amount of moisture content present in the soil as a percentage of its dry mass. The empty can was weighed to the nearest 0.1g (and represented as M_1) after which a considerable amount of wet sample was placed therein and weighed (represented as M_2). Thereafter, it was placed into the oven to dry for 24hours, removed and weighed (represented as M_3). The moisture content (MC) was calculated as a percentage of dry soil mass by using Eq. (1).

$$MC = \frac{M_2 - M_3}{M_3 - M_1} x\ 100\% \qquad (1)$$

2.4 Specific Gravity Test

The 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 of about 40^{0}C in temperature. The procedure for its determination involved emptying, drying and weighing the specific gravity bottle (to give M_1) into which soil sample was introduced and weighed (to give M_2). Water was then added to the sample in the glass jar to 1/3 of its real height and stirred vigorously till the sample particles were in suspension. After which it was filled to the glass jar brim and weighed as (m3). Thereafter, the bottle content was poured out and cleaned. The specific gravity, (Gs) was calculated by using Eq. (2).

$$Gs = \frac{M_2 - M_1}{50 - (M_3 - M_2)} \qquad (2)$$

2.5 Atterberg Limits Tests

The Atterberg limits are basic measures of the nature of fine-grained soil, depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state, the consistency, behavior and engineering properties of a soil is different. Thus, the boundary between each state can be defined based on a change in the soil's behavior. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays. The different Atterberg limits are liquid limit, shrinkages limit and plastic limit test.

The procedure for determining the liquid limit (LL) involved measuring out 200g of soil sample passing the 425µm BS test sieve, pouring it on the metallic trays, adding a little quantity of water to it and mixing thoroughly to obtain a paste that was not too thick nor too watery. It was then placed in the Casagrande's device, levelled and divided with the grooving tool. The number of blows at which the divided part became closed was recorded. A portion of this soil was put in a can to determine its moisture content. The experiment was repeated while gradually increasing the amount of distilled water added. Then, the relationship between the moisture content and the corresponding number of blows was plotted. The moisture content corresponding to 20 blows was considered as the liquid limit of the soil.

The procedure for determining the plastic limit (PL) involved moulding and rolling the already thoroughly mixed sample with the palms to a threadlike shaped stick of about 3mm diameter. The plastic limit was indicated by the moisture content corresponding to the point at which the first crumbled. Consequently, the plasticity index (PI) was calculated by using equation 3:

$$PI = LL - PL \qquad (3)$$

Determination of the linear shrinkage (LS) involved obtaining the moisture content below which no further volume changes of a mass occurs. The procedure involved mixing thoroughly a portion of the clay sample passing the 425µm BS sieve with water and placing it in a cleaned and greased shrinkage mould. The surface of the soil was levelled and the bowl was placed in an oven for 24hours. Thereafter, the corresponding reduction in the length of the sample was measured and used in calculating the linear shrinkage based on Eq. (4).

$$LS = \frac{1 - length\ of\ oven\ dried\ spacement}{initial\ length\ of\ spacement} x\ 100 \qquad (4)$$

2.6 Compaction Test

This test determines the maximum (practical) dry density (y-max) and optimum moisture content (W opt) of the soil with and without additives. The results are subsequently used in the preparation of CBR specimens. Compaction tests provide important information about the soil quality at a site which can be used to determine the most favourable building sites, the maximum load the soil can withstand and the appropriateness of the site for highway. In order to investigate the effects of cement on clay soil and the effect of lime on clay soil, the mix proportions of clay soil with cement and the mix proportion of clay with lime as shown in table 1 were used in the tests.

Table 1: Mix Proportion used for Tests

S/No	Clay Soil (%)	Cement (%) by mass of soil	Lime (%) by mass of soil
1	100	5	0
2	100	10	2
3	100	15	5
4	100	15	8
5	100	20	11

The test procedure involved measuring 3000gs of oven dried clay soil and pouring it on a tray and breaking it down into smaller and fine particles. It was then mixed thoroughly with 150ml of distilled water, placed in the mould (in 3 layers, each 50mm thick) and subjected to 25 blows using the standard rammer (of 2.5kg falling through 30cm). The top surface of the layer was scraped before placing the subsequent layers of loose soil. After compaction of the third layer, the level of the compacted soil was slightly above the top of the mould. The collar was then removed and followed by trimming of the soil with a straightedge and determination of its mass.

Two samples were taken, one from the top and the other from the bottom of the mould, and their respective moisture contents were determined.

This was followed by extruding the sample from the mould and breaking it up into a loose state. Then 120ml of water was added and the same series of steps were repeated until the mass of the compacted soil in the mould fell. Thereafter, a graph of moisture content versus dry density was plotted and the maximum dry density (MDD) and optimum moisture content (OMC) corresponding to standard doctor compaction test were determined. The calculations under the compaction test were carried out using Eqs. (5) and (6).

$$\text{Wet Density; (y-wet) g/cc} = \frac{Weight\ of\ soil\ in\ compaction\ mould}{Volume\ of\ mould} \quad (5)$$

$$\text{Dry Density; (y-dry) g}^{\frac{cc=y-wet}{1+\frac{mc}{100}}} \quad (6)$$

2.7 California Bearing Ratio Test

The California Bearing Ratio Test (CBR Test) is a penetration test used for evaluating the bearing capacity of subgrade soil for design of pavements. It is carried out on natural or compacted soils under soaked or un-soaked conditions and the results obtained are compared with the curves of standard tests to indicate the soil strength. The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of area which is then divided by the pressure required to achieve an equal amount of penetration on a standard crushed rock material. In order to carry out this test, the same mix proportions used under the compaction test were used again in this test. 6kg of dry soil was mixed thoroughly with calculated quantity of water to obtain moist soil with the required moisture percentage.

The soil was compacted in three different CBR moulds, each in 5 layers and subjected 25 blows each using the standard rammer (4.5kg and falling through 30cm). The top surface was scraped and levelled after compacting the third layer. Sufficient surcharge mass was then placed on the soil surface to equal the actual or estimated mass of construction. The loading was applied at the rate of 1.25mm/min. Readings of the load were taken at the following penetrations for both the top and bottom layers namely 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 2.0, 3.5, 4.0, 4.5, 5.0, 5.5 and 6.0, immediately, after the penetration test, filter paper was placed on the compacted exposed surface (both at the top and bottom), closed with metallic cover to prevent direct influence of water and placed in soaking tank for 24hours. Thereafter, it was removed and the corresponding soaked readings were taken at the same penetrations used under the unsoaked condition for both the top and bottom.

The readings of load intensity were plotted against the readings of penetration and a smooth curve was drawn through the points. The values of the load at penetration of 2.5mm and 5.0mm were expressed as percentage of standard loads of 70kg/cm and 150kg/cm respectively. The higher value out of these two was considered as the CBR. The CBR values were calculated by using Eqs. (7) and (8).

$$\text{CBR at 2.5mm penetration} = \frac{Actual\ 3.\ Load\ in\ kg/mm\ taken\ by\ soil}{3.24} x\ 100 \quad (7)$$

$$\text{CBR at 5.0mm penetration} = \frac{Actual\ Load\ in\ kg/mm\ taken\ by\ soil}{19.96} x\ 100 \quad (8)$$

3. Results and Discussion

The natural moisture content (average) obtained for the clay soil sample for sample points 1, 2, 3, 4 and 5 were 23.74%, 23.59%, 21.57%, 22.44% and 21.65%, respectively as shown In Table 2. The specific gravity of a clay soil sample points 1, 2, 3, 4 and 5 were determined as 2.34, 2.34, 2.22, 2.35 and 2.18, respectively as shown in Table 3. The particle size distribution (Tables 4a, 4b, 4c, 4d and 4e shows a decrease in the particle size distribution analysis with the corresponding percentage retained on and passing through each of the sieves. This analysis showed the natural soil sample (clay) for each of the samples ranging between 53.33% to 58.66% sand fraction and 41.35% to 46.67% clay content as shown in Figure 5a, 5b, 5c and 5d based on the % of fines more than 12% passes through the no.200 sieve and the plasticity index is > 7. Therefore, the soil is SC (Clayey Sand, clayey sand with gravel). According to AASHTO Soil Classification System, the soil (clay) corresponds to group A-6 with fair to poor drainage characteristics as well as fair to poor general rating as a sub-grade material, hence, the soil needs to be stabilized.

The moisture content values obtained under the Atterberg's Limit Test (comprising of the liquid limit, plastic limit and shrinkage limit results) are as shown in Tables 6a, 6b and 6c. The liquid limit, plastic limit and plasticity index of the natural soil samples were obtained as shown in Tables 6a & 6b. According to Unified Soil Classification System (ASTM D2487 and D2488, these soils (clay) falls into the major division of the fine-grained soils and a group of ML (inorganic silt) since its liquid limit falls below 50% for each of the sample points (Table 6a & 6b).

The summary of the compaction test is shown in Table 8. The compaction test results for the clay soil without the addition of cement and lime and with the addition of cement and lime when compared showed that the addition of these additives at varying quantities has a positive effect on the clay soil, as they all improve the dry density of the selected clay soil. As the percentage of the cement increases from 5% to 20%, the maximum dry density also increases from 1910kg/m3 for the control sample to 2050kg/m3 for 20% cement content. The maximum dry density (MDD) values for lime stabilized soil increases with decreasing percentage of lime. However, the best result was obtained at 2% lime with MDD 1960kg/m3. This experiment shows that the lime provides an economical way of soil stabilization.

For the California Bearing Ratio (CBR) test, Tables 9a and 9b gives a summary of the unsoaked and soaked CBR values for the control and treated samples at 2.5mm and 5.0mm. It was observed that the soaked CBR values for the control sample (0% additive) decreases from 5.74% unsoaked to 3.86% soaked, indicating that in the presence of water in a well compacted clay soil reduces its strength. It was observed that when clay soil is stabilized with cement and lime in the presence of water (soaked), it accelerate the hardening process. This makes the soaked CBR values after 24 hours to be higher than the unsoaked CBR values. For the treated samples, (i.e 5% - 20% additive), the CBR values increased with addition of cement.

As the percentage of the cement content increased, the CBR values also increased from 6.89% for 5% additive to 33.24% for 20% additive for the unsoaked and 19.07% for 5% additive to 424.35% for 20% additive for the soaked CBR. This shows that in the presence of water in cement stabilized clay soil increases the hydration process and CBR values. The expansion ratio of cement stabilized clay soil increased with increase in the percentage of cement. Based on the Indian Road Congress (IRC) recommendations for pavement design on soaked CBR values, these materials are >5%, therefore are good for sub-grade strength. These experiments show that lime stabilized with clay soil requires relaxation period to allow lime to diffuse through the soil, thus producing maximum effects on plasticity. The result obtained from the unsoaked CBR shows that at 2% lime, the CBR value is 1.8% while for the unsoaked, the CBR value is 5.66%. The lime stabilized soil for both unsoaked and soaked shows that an increase in the percentage of lime increases the CBR values. Lime stabilized soil when compared with cement stabilized soil shows that at 5% additives of lime, the CBR value is 8.46% for soaked, and for cement the CBR value is 19.07% soaked which implies that cement is more effective in clay soil stabilization.

Table 2 (a): Moisture content test results for sample point 1

Test Sample	Mass of empty can (g) (M_1)	Mass of can + wet (g) (M_2)	Mass of can + dry (g) (M_3)	Moisture Content (g)	Moisture Content (%)
1	5.5	46.2	38.6	7.6	22.96
2	5.5	49.7	41.0	8.7	24.51
Average MC %					23.74

Table 2 (b): Moisture content test results for sample point 2

Test Sample	Mass of empty can (g) (M_1)	Mass of can + wet (g) (M_2)	Mass of can + dry (g) (M_3)	Moisture Content (g)	Moisture Content (%)
1	4.3	49.0	39.9	9.1	25.56
2	5.2	47.3	39.9	7.4	21.33
Average MC %					23.45

Table 2 (c): Moisture content test results for sample point 3

Test Sample	Mass of empty can (g) (M_1)	Mass of can + wet (g) (M_2)	Mass of can + dry (g) (M_3)	Moisture Content (g)	Moisture Content (%)
1	3.1	52.2	43.2	9.0	22.78
2	4.4	52.9	44.0	8.9	22.47
Average MC %					22.63

Table 2 (d): Moisture content test results for sample point 4

Test Sample	Mass of empty can (g) (M_1)	Mass of can + wet (g) (M_2)	Mass of can + dry (g) (M_3)	Moisture Content (g)	Moisture Content (%)
1	3.9	50.8	42.9	7.9	20.26
2	3.9	51.5	42.1	9.4	24.61
Average MC %					22.44

Table 2 (e): Moisture content test results for sample point 5

Test Sample	Mass of empty can (g) (M_1)	Mass of can + wet (g) (M_2)	Mass of can + dry (g) (M_3)	Moisture Content (g)	Moisture Content (%)
1	4.5	52.2	43.5	8.7	22.31
2	4.3	51.0	42.9	8.1	20.98
Average MC %					21.65

Table 3 (a): Specific Gravity Test Result for sample point 1

Masses (g)	Test 1	Test 2	Test 3
Mass of density bottle (M_1)	25.5	25.5	25.5
Mass of bottle & dry sample (M_2)	55.5	52.0	52.0
Mass of bottle + sample + water (M_3)	93.0	90.5	90.6
Specific gravity = $\frac{M_2-M_1}{50-(M_3-M_3)}$	2.40	2.30	2.32
Average Gs	2.34		

Table 3 (b): Specific Gravity Test Result for sample point 2

Masses (g)	Test 1	Test 2	Test 3
Mass of density bottle (M_1)	25.5	25.5	25.5
Mass of bottle & dry sample (M_2)	51.3	50.0	49.9
Mass of bottle + sample + water (M_3)	90.3	89.90	89.0
Specific gravity = $\frac{M_2-M_1}{50-(M_3-M_3)}$	2.35	2.45	2.24
Average Gs	2.34		

Table 3(c): Specific Gravity Test Result for sample point 3

Masses (g)	Test 1	Test 2	Test 3
Mass of density bottle (M_1)	25.5	25.5	25.5
Mass of bottle & dry sample (M_2)	52.9	55.1	50.0
Mass of bottle + sample + water (M_3)	90.2	92.0	89.0
Specific gravity = $\frac{M_2-M_1}{50-(M_3-M_3)}$	2.16	2.26	2.23
Average Gs	2.22		

Table 3 (d): Specific Gravity Test Result for sample point 4

Masses (g)	Test 1	Test 2	Test 3
Mass of density bottle (M_1)	25.5	25.5	25.5
Mass of bottle & dry sample (M_2)	51.3	55.9	53.5
Mass of bottle + sample + water (M_3)	90.3	93.0	91.5
Specific gravity = $\frac{M_2-M_1}{50-(M_3-M_3)}$	2.35	2.36	2.33
Average Gs	2.35		

Table 3 (e): Specific Gravity Test Result for sample point 5

Masses (g)	Test 1	Test 2	Test 3
Mass of density bottle (M_1)	25.5	25.5	25.5
Mass of bottle & dry sample (M_2)	56.9	55.0	52.9
Mass of bottle + sample + water (M_3)	92.9	91.3	90.2
Specific gravity = $\frac{M_2-M_1}{50-(M_3-M_3)}$	2.24	2.15	2.16
Average Gs	2.18		

Table 4 (a): Particle Size Distribution Analysis for Point 1

Sieve Diameter (mm)	Mass Retained	% on sieve	% Retained	% Passing
4.75	0	0	0	100.00
2.36	0	0	0	100.00
1.18	5	1.67	1.67	98.33
0.600	32	10.67	12.34	87.66
0.300	74	24.67	37.01	62.99
0.150	44	14.67	51.68	48.32
0.075	20	6.67	58.35	41.65
Pan	0	0.00	0.00	0.00

Table 4 (b): Particle Size Distribution Analysis for Point 2

Sieve Diameter (mm)	Mass Retained	% on sieve	% Retained	% Passing
4.75	0	0	0	100.00
2.36	0	0	0	100.00
1.18	4	1.33	1.33	98.57
0.600	30	10.0	11.33	88.67
0.300	52	17.33	28.66	71.34
0.150	56	18.67	47.33	52.67
0.075	18	6.00	53.33	46.67
Pan	0	0.00	0.00	0.00

Table 4 (c): Particle Size Distribution Analysis for Point 3

Sieve Diameter (mm)	Mass Retained	% on sieve	% Retained	% Passing
4.75	0	0	0	100.00
2.36	0	0	0	100.00
1.18	4	1.33	1.33	98.67
0.600	30	10.0	11.33	88.67
0.300	52	17.33	28.66	71.34
0.150	56	18.67	50.33	49.67
0.075	17	5.67	56.00	44.0
Pan	0	0.00	0.00	0.00

Table 4 (d): Particle Size Distribution Analysis for Point 4

Sieve Diameter (mm)	Mass Retained	% on sieve	% Retained	% Passing
4.75	0	0	0	100.00
2.36	0	0	0	100.00
1.18	4	1.33	1.33	98.67
0.600	32	10.67	12.00	88.00
0.300	67	22.33	34.33	65.67
0.150	54	18.00	52.33	47.67
0.075	19	6.33	58.66	41.34
Pan	0	0.00	0.00	0.00

Table 4 (e): Particle Size Distribution Analysis for Point 5

Sieve Diameter (mm)	Mass Retained	% on sieve	% Retained	% Passing
4.75	0	0	0	100.00
2.36	0	0	0	100.00
1.18	3	1.00	1.00	99.00
0.600	33	11.00	12.00	88.00
0.300	72	24.00	36.00	64.00
0.150	37	12.33	48.33	51.67
0.075	18	6.00	54.33	45.67
Pan	0	0.00	0.00	0.00

Sample point 1

Table 5 (a): Liquid Limit test result

Test	No of Blows	Mass of wet soil + can	Mass of dry soil + can	Mass of can (g)	Mass of moisture (g)	Mass of dry soil (g)	Moisture Content (g)
1	40	55.4	47.6	5.2	7.8	42.4	18.40
2	37	45.6	36.6	3.9	9.0	32.7	27.52
3	30	49.1	39.2	4.3	9.9	34.9	28.37
Average MC (%)							24.76

Sample point 2

Table 5 (b): Liquid Limit Test result

Test	No of Blows	Mass of wet soil + can	Mass of dry soil + can	Mass of can (g)	Mass of moisture (g)	Mass of dry soil (g)	Moisture Content (g)
1	39	39.5	32.6	3.9	6.9	28.7	24.04
2	34	48.2	39.5	5.2	8.7	34.3	25.36
3	26	51.1	40.3	4.3	10.8	36.0	30.0
Average MC (%)							24.47

Sample point 3

Table 5 (c): Liquid Limit Test result

Test	No of Blows	Mass of wet soil + can	Mass of dry soil + can	Mass of can (g)	Mass of moisture (g)	Mass of dry soil (g)	Moisture Content (g)
1	50	32.4	26.1	4.5	6.3	21.6	29.17
2	34	39.1	30.5	5.5	8.6	25.0	34.40
3	23	42.5	31.9	4.2	10.6	27.7	38.27
Average MC (%)							33.95

Sample point 4

Table 5 (d): Liquid Limit Test result

Test	No of Blows	Mass of wet soil + can	Mass of dry soil + can	Mass of can (g)	Mass of moisture (g)	Mass of dry soil (g)	Moisture Content (g)
1	42	34.0	28.8	5.2	6.2	23.6	26.27
2	33	38.3	34.4	3.9	8.7	30.5	28.52
3	26	43.6	39.3	4.3	10.3	35.0	29.43
Average MC (%)							28.07

Sample point 5

Table 5 (e): Liquid Limit Test result

Test	No of Blows	Mass of wet soil + can	Mass of dry soil + can	Mass of can (g)	Mass of moisture (g)	Mass of dry soil (g)	Moisture Content (g)
1	35	43.0	34.9	5.5	8.1	29.4	27.55
2	30	46.1	37.2	5.5	8.9	31.7	28.08
3	20	44.9	35.3	4.3	9.6	25.7	37.35
Average MC (%)							30.99

Table 6 (a): summary of unsoaked CBR values for the clay samples (with additives and without additives)

	Control (0%)		2% lime		5% lime		8% lime		11% lime	
Penetration (mm)	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0
Top (%)	5.14	5.16	1.81	1.85	2.49	2.40	2.64	2.86	4.31	4.21
Bottom (%)	6.34	6.16	1.66	1.75	2.64	2.96	3.63	3.41	5.82	5.51
Average (%)	5.74	5.66	1.74	1.80	2.57	2.68	3.14	3.14	5.07	4.86
CBR Value	5.74		1.80		2.68		3.14		5.07	

Table 6 (b): summary of soaked CBR values for the clay soil sample (with additives and without additives)

	Control (0%)		2% lime		5% lime		8% lime		11% lime	
Penetration (mm)	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0
Top (%)	2.34	3.86	5.66	4.96	8.61	7.26	14.95	11.57	14.95	12.32
Bottom (%)	4.31	3.86	5.66	5.16	8.31	8.17	5.29	4.96	5.97	5.41
Average (%)	3.33	3.86	5.66	5.06	8.46	7.72	10.12	8.27	10.46	8.87
CBR Value	3.86		5.66		8.46		10.12		10.46	
Expansion ratio	2.10		5.90		5.30		2.60		1.90	

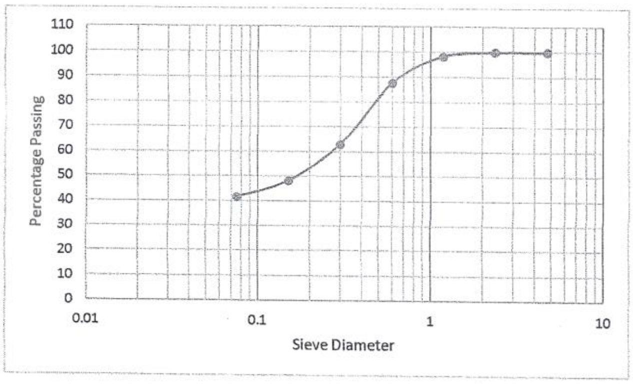

Figure 1: Particle Size Distribution Chart for Point 1

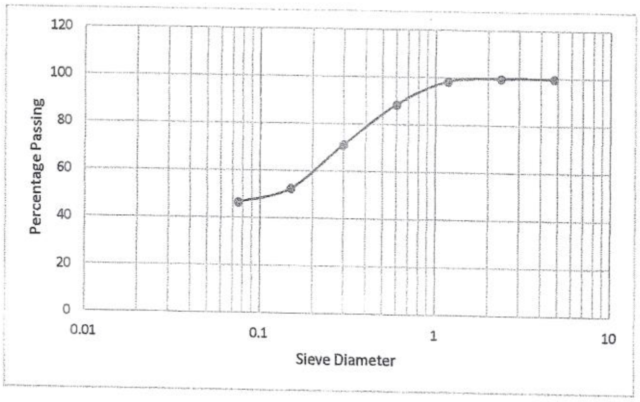

Figure 2: Particle Size Distribution Chart for Point 2

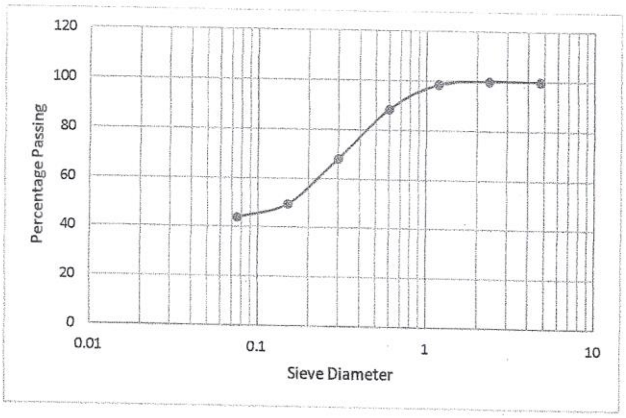

Figure 3: Particle Size Distribution Chart for Point 3

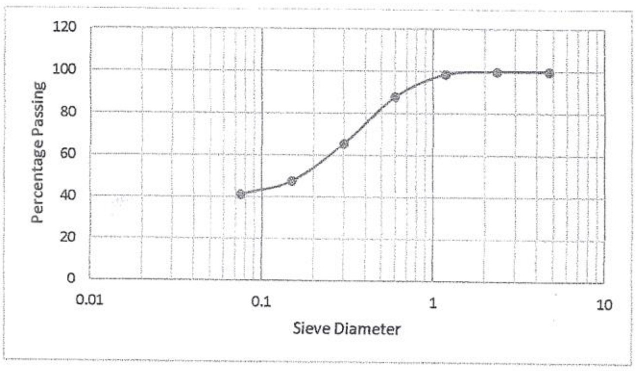

Figure 4: Particle Size Distribution Chart for Point 4

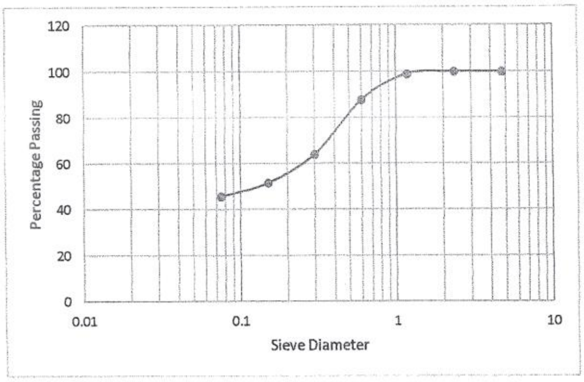

Figure 5: Particle Size Distribution Chart for Point 5

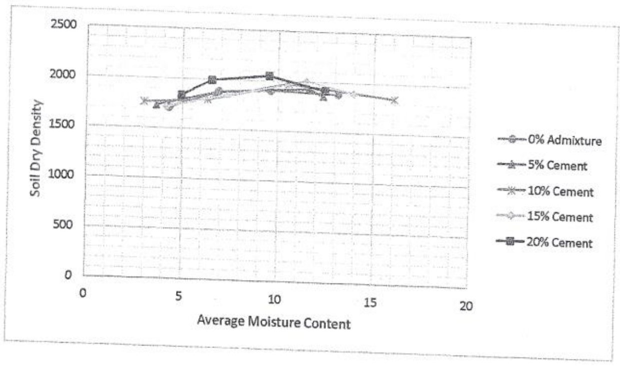

Figure 6: Graph of Dry Density against Average Moisture Content for Percentage addition of Lime

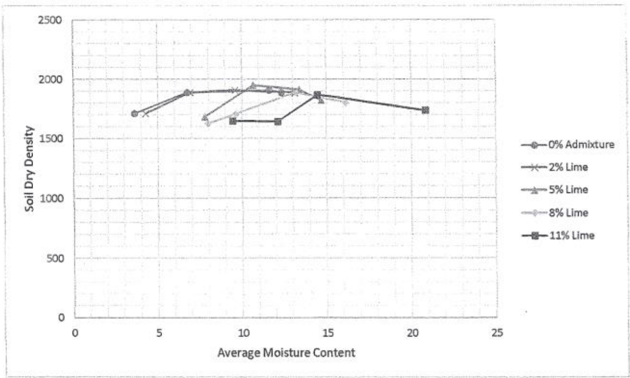

Figure 7: Graph of Dry Density against Average Moisture Content for Percentage addition of Lime

4. CONCLUSION

From the results of this study, natural moisture content, specific gravity, grain size analysis and atterberg limit test shows that these materials fall into the same class. According to the Unified Soil Classification System, these materials fall into SC (Clayey sand) which according to general soil rating is fair to poor drainage characteristic, therefore, the soil needs to be stabilized. The maximum dry density for clay soil stabilization ranges between 1910kg/m3 for the control sample up to 2050kg/m3 for sample containing 20% cement content. Also, for lime stabilized soil however, the best result was obtained at 2% lime with maximum dry density value 1960kg/m3 after which it decreases to 1870kg/m3 at 11% lime. The highest values obtained in the California Bearing Ratio (CBR) test is 33.24% for unsoaked and 424.35% for soaked CBR with 20% cement content while for lime, the highest CBR values obtained are 5.07% for the unsoaked and 10.46% for the soaked CBR with 11% lime content.

Based on the result obtained for the soaked CBR treated sample at 5% cement content, the CBR value is 19.07% which according to British Standard (BS 594) specification for sub-base, base course and wearing course thickness is 100mm, 40 – 75mm and 25 – 40mm respectively. The result obtained for soaked CBR using cement as an additive showed that soft clay stabilized with cement can be used as a sub-grade material for highway construction. Also, the lime stabilized (soaked CBR) at 11% showed that lime can be effectively used as subgrade material for construction of flexible pavements in rural roads with load traffic volume. It is therefore concluded that the addition of cement and lime to clay soil improved the bearing capacity and the maximum dry density of the clay soil. It is recommended that further research should be carried out to examine the effects of industrial by-products on effective clay soil stabilization.

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