Expansive Soils Volumetric Control Using Composite Stabilizers

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ABSTRACT

Highly plastic soils of the Niger Delta region has been seen as the major causes of highway roads failure due to their unique characteristic of volume change seasonally. The soils are very sensitive to manipulations and less matured for its application in road embankment and other forms of civil engineering construction as specified by (FMW, 1998). The study evaluated the applications of composite materials of cement + plantain rachis fibre and lime + plantain rachis fibre and their performance characteristics for the modification of expansive clay soils. The soils classified as A-7-6/CH on the AASHTO classification schemes / Unified Soil Classification System as shown in table 3.1. Statistical percentile evaluation results of maximum dry density (MDD) and optimum moisture content (OMC) from compaction test at natural condition of clay soils from sampled sites are, Ebiriba, 1.005% and 1.034%, Ochigba, 1.015% and 1.030%, Eneka 1.011% and 1.020%, Isiokpo 1.014% and 1.018%, respectively of MDD and OMC. California bearing ratio (CBR) test of unsoaked parameters are 5.243%, 581%, 4.812%,4.306% and soaked, 5.581%, 5.199%, 5.717%, 4.540%, of Ebiriba, Ochigba, Eneka, and Isiokpo respectively at preliminary test of clay soils at natural condition. Results of unconfined compressive strength test of sampled roads are; Ebiriba 1.569%, Ochigba 1.638%,1.616%, Eneka 1.703%, and Isiokpo 1.551%, respectively at 100% natural clay soils. Preliminary test of clay soils at 100% consistency limits (Plastic index) are Ebiriba 0.989%, Ochigba 1.131%, Eneka 0.996% and Isiokpo 0.990%. Comparative results shown in tables 3.2 – 3.16 and figure 3.1 – 3.5 of clay soils at natural condition and composite stabilized clay soils compaction test results of maximum dry density (MDD) and optimum moisture content (OMC) possessed incremental percentile values with respect to rate of percentages ratio increase to soils Results from figures 3.2 and 3.3 demonstrated strength variance of cement and lime with PRF composition with in higher performance. Entire results of California bearing ratio (CBR) of unsoaked and soaked stabilized soils with composite materials at combined state possessed incremental percentile values as indicated in figures 3.4 with peak mix ratio of 91.75+0.75+7.5%. Formation of cracks and reduction in percentile values were observed beyond peak mix Comparatively, higher values recorded in cement to lime samples. Comparative results of unconfined compressive strength test of cementitious materials combined actions showed incremental percentile values accordingly to percentage rise of composite materials to soils ratio with cement performance in higher values to lime.. Results showed the inclusion of cementitious materials with PRF decreases the plastic index properties of stabilized soils to corresponding percentages ratio. Entire comparative results showed best performance in both cement and lime hybridized composite materials as soil stabilizers.

Key Words: Clay soils, Plantain Rachis Fibre, Cement, Lime,CBR, UCS, Consistency, Compaction

1.0 Introduction

Lime, cement and fly-ash, fibre bagasse ash and compositions of theses possesses pozzolanic properties which can quickly slat the soils condition during construction and can add long term improvement to key soil properties such as reducing the soil moisture content, reducing soil plasticity, aiding compaction. Radhakrishnan *et al.*, [1] studied the combined effect of (class-F) fly ash - Magnesium chloride and fly ash-Aluminum chloride on swelling pressure (Ps),

swelling potential (Sp) and differential free swell (DFS) of expansive soil and found that the swelling properties decreases substantially with increase in percentage of stabilizer but remain stable after certain percentage of the stabilizers.

Otoko and Blessing [2] studied the engineering behavior of stabilized marine clay with cement and lime. The authors show that the strength characteristics of the marine clay was improved as unconfined compressive strength and maximum dry density increased with increase in cement and lime content with of coarse, a corresponding decrease in the optimum moisture content

Gopala *et al*., [3] studied the effect of fly ash (class-F) and zycosil on soaked and unsoaked CBR of black cotton soil, the highest unsoaked CBR was obtained at 2 % zycosyl with 3% fly ash and highest soaked CBR was obtained at 2 % zycosil with 4 % fly ash.

Charles *et al.* [4] investigated the problematic engineering properties of soils with high plasticity level, high swelling and shrinkage potentials used in pavement design in the Nigerian Niger Delta region. The application of stabilizing agents of cement and costus afer bagasse fibre (Bush Sugarcane Bagaase Fibre) were mixed in single and combines actions to improved their unique properties. Results showed that inclusion stabilizing material improved strength properties of the soils. Results of tests carried out show that the optimum moisture content increased with increasing cement ratios to both soils (clay) and (laterite). Treated soils with Cement decreased in liquid limits and increased in plastic limits. Soils with Cement and fibre products in combinations increased CBR values appreciably both at soaked and unsoaked conditions. At 8% of lime, CBR values reached optimum, beyond this range, cracks exist and 7.5% cement + 0. 75% BSBF, optimum value are reached. Charles *et al.* [5] evaluated the geotechnical properties of an expansive clay soil found along Odioku – Odiereke Rd in Ahoada-West, Rivers State, in the Niger Deltaic region. The application of two cementitious agents of cement and lime, hybridized with costus afer bagasse fiber to strengthen the failed section of the Rd. The preliminary investigation values indicated that the soils are highly plastic. The results showed the potential of using bagasse, BSBF as admixtures in cement and lime treated soils of clay and laterite with optimum values of 8 % cement and lime and 7.5% +7.5 % of cement / lime + BSBF.

Charles *et al.* [6] investigated and evaluated the engineering properties of an expansive lateritic soil with the inclusion of cement / lime and costus afer bagasse fibre ash (locally known as bush sugarcane fibre ash (BSBFA) with ratios of laterite to cement, lime and BSBFA of 2.5% 2.5%, 5.0% 5.0%, 7.5% 7.5% and 10% 10% to improve the values of CBR of less than 10%. At 8% of both cement and lime, CBR values reached optimum, beyond this range, cracks exist and 7.5% cement and lime 7.5% BSBFA, and 7.25% cement and lime 0. 7.5% BSBF, optimum value are reached. The entire results showed the potential of using bagasse, BSBFA as admixtures in cement and lime treated soils of laterite.

Kalantari *et al.*, [7] experimented the use of cement, polypropylene fibers and optimum moisture content values to strengthen peat. From their laboratory study it was observed that peat with cement and fibers can be used as the base course in the pavement construction. It appears that the fibers prevent the formation and the development of the cracks upon loading and thus increasing the strength of the samples.

Kalantari [8] investigated on civil engineering significant of peat. He points out that, this type of subsoil foundation has high compressibility and low shear strength when subjected to imposed loads from civil engineering projects. It is essential to distinguish this problematic soil from better quality soils. Visual inspections including color (dark brown to black) and odour (organic odor) tests can help to recognize peat. Field strength evaluation tests such as FVST and PLT

can give good estimates of peat shear strength. Also laboratory tests such as moisture content, organic content and UCS and CBR may be used to evaluate peat physical and mechanical properties as well.

Goyal *et al*.,[9] reported that SCBA with high specific surface area, high contents of amorphous silica and calcium oxide fulfilled the principal requirements of a pozzolanic material.

Ganesan *et al*.,[10] studied on the use of bagasse ash (BA) as partial cement replacement material in respect of cement mortars. Up to 20 % of ordinary Portland cement can be optimally replaced with well-burnt bagasse ash without any adverse effect on the desirable properties of concrete. Several studies have been carried out on the effectiveness of clay stabilization by RHA admixing.

Basha, *et al*., [11] studied the stabilization of residual soils by chemically using cement and RHA. In general, 6 %, 8 % of cement and 10 %, 15 % RHA show the optimum amount to reduce the plasticity of soil. CBR value determined maximum at 4% cement and 5 % RHA mixtures with soil. According to compressive strength and PI, 6 %, 8% of cement and 15 %, 20 % RHA showed the optimum amount to improve the properties of soils. Otoko and Blessing [12] studied the engineering behavior of stabilized marine clay with cement and lime. The authors show that the strength characteristics of the marine clay was improved as unconfined compressive strength and maximum dry density increased with increase in cement and lime content with of coarse, a corresponding decrease in the optimum moisture content

2.0 Materials and Methods

2.1 Materials

2.1.1 Soil

The soils used for the study were collected from Ebiriba Town Rdoa, in Ahoada-West Local Government, Ochigba Town Road, in Ahoada-East Local Government Area, Eneka Town Road, in Obio/Akpor Local Government Area and IsiokpoTown Rd, in Ikwerre Local Government area, all in Rivers State, Niger Delta region, Nigeria. It lies on the recent coastal plain of the North-Western of Rivers state of Niger Delta.

2.1.2 Plantain Rachis Fibre

The Plantain Rachis fibres are obtained from Ebiriba markets, in Obio/Akpor Local Area of Rivers State, they are abundantly disposed as waste products both on land and in the river.

2.1.3 Lime

The lime used for the study was purchased in the open market at Mile 3 market road, Port Harcourt

2.1.4 Cement

The cement used was Portland Cemenet, purchased in the open market at Mile 3 market road, Port Harcourt, Rivers State.

2.2 Method

2.2.1 Sampling Locality

The soil sample used in this study were collected along Ebiriba Town, (latitude 5.10° 31‘N and longitude 6.38° 8‘E), Ochigba a Town, (latitude 5.1° 30‘N and longitude 6.35° 55‘E), Eneka Town, latitude 4.90° 28‘N and longitude 7.03° 15‘E), and Isiokpo Town, latitude 5.05° 41‘N and longitude 6.92° 33‘E) all in Rivers State, Nigeria.

2.2.2 Test Conducted

Test conducted were (1) Moisture Content Determination (2) Consistency limits test (3) Particle size distribution (sieve analysis) and (4) Standard Proctor Compaction test, California Bearing Ratio test (CBR) and Unconfined compressive strength (UCS) tests;

2.2.3 Moisture Content Determination

The natural moisture content of the soil as obtained from the site was determined in accordance with BS 1377 (1990) Part 2.The sample as freshly collected was crumbled and placed loosely in the containers and the containers with the samples were weighed together to the nearest 0.01g.

2.2.4 Grain Size Analysis (Sieve Analysis)

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles.

2.2.5 Consistency Limits

The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second.

2.2.6 Moisture – Density (Compaction) Test

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort.

2.2.7 Unconfined Compression (UC) Test

The unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions

2.2.8 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was developed by the California Division of Highways as a method of relegating and evaluating soil- subgrade and base course materials for flexible pavements.

3.0 Results and Discussions

The soils classified as A-7-6 / CH on the AASHTO classification schemes / Unified Soil Classification System as shown in table 3.1 and are less matured in the soils vertical profile and probably much more sensitive to all forms of manipulation that other deltaic lateritic soils are known for.The soils are re dark grey in colour plasticity index of 28.55%, 25.97%, 33.50%, and 28.40% respectively for Ebiriba, Ochigba, Eneka and Isiokpo Town Rds. The soil has unsoaked CBR values of 6.38%, 7.75%, 8.24% and 7.85%, and soaked CBR values of 5.25%, 6.03%, 6.35% and 6.30%, unconfined compressive strength values of 68.85kPa, 77.35kPa, 79.85kPa and 65.57kPa when compacted with British Standard light.

3.1 Compaction Test Results

Results of maximum dry density (MDD) and optimum moisture content (OMC) percentile values derived from tables 3.2 and 3.3 into 3.2A and 3.3A from compaction test at natural condition of clay soils from sampled sites are, Ebiriba, 1.005% and 1.034%, Ochigba, 1.015% and 1.030%, Eneka 1.011% and 1.020%, Isiokpo 1.014% and 1.018%, respectively of MDD and OMC. Stabilized clay soil results with composites materials of Ebiriba samples MDD clay + cement + PRF are 0.947%, 2.846%, 5.220%, 6.882% , clay + lime + PRF 1.711%, 2.135%, 4.568%, 6.111%, OMC are clay + cement + PRF 6.606%, 9.354%, 12.101%, 14.604% , clay + lime + PRF 4.826%, 8.794%, 11.663%, 14.289%. Ochigba MDD clay + cement + PRF are 3.027%, 4.376%, 6.370%, 8.540%, clay + lime + PRF 2.332%, 3.447%, 4.444%, 6.262%, OMC are clay + cement + PRF, 5.985%, 8.048%, 11.028%, 13.378%clay + lime + PRF 4.645%, 7.740%, 10.777%, 13.012%. Eneka MDD clay + cement + PRF are 2.272%, 3.836%, 5.459%, 8.466%, clay + lime + PRF 1.796%, 2.698%, 4.021%, 5.885%, OMC are clay + cement + PRF, 3.902%, 6.887%, 8.977%, 10.887%, clay + lime + PRF, 6.231%, 7.903%, 9.873%, 11.903%. Isiokpo stabilized MDD clay + cement + PRF are 2.846%, 5.587%, 6.273%, 8.266%, clay + lime + PRF, 3.704%, 5.137%, 5.947%, 7.318%, OMC clay + cement + PRF, 3.498%, 5.830%, 7.972%, 9.106%, clay + lime + PRF, 4.610%, 7.697%, 10.344%, 12.045%. Results from figures 3.2 and 3.3 demonstrated strength variance of cement and lime with PRF composition with in higher performance. Comparative results of clay soils at natural condition and composite stabilized clay soils compaction test results of maximum dry density (MDD) and optimum moisture content (OMC) possessed incremental percentile values with respect to rate of percentages ratio increase to soils.

3.2 California Bearing Ratio (CBR) Test

California bearing ratio (CBR) test of unsoaked parameters are 5.243%, 581%, 4.812%,4.306% and soaked, 5.581%, 5.199%, 5.717%, 4.540%, of Ebiriba, Ochigba, Eneka, and Isiokpo respectively at preliminary test of clay soils at natural condition. Composite materials stabilized Ebiriba unsoaked clay + cement + PRF are 505.221%, 649.892%, 862.588%, 743.466%, clay + lime + PRF; 423.499%, 601.399%, 810.647%, 701.399%, soaked clay + cement + PRF), 540.177%, 717.320%, 988.749%, 830.082%, clay + lime + PRF 441.252%, 698.014%, 919.347%, 794.586%. Ochigba stabilized unsoaked clay + cement + PRF are 445.688%, 596.011%, 757.301%, 657.688%, clay + lime + PRF, 346.778%, 519.681%, 684.843%, 585.488%, soaked clay + cement + PRF, 500.666%, 684.746%, 905.309%, 779.273%, clay + lime + PRF, 408.859%, 632.408%, 799.074%, 720.633%. Eneka unsoaked clay + cement + PRF are 460.407%, 569.024%, 760.165%, 661.621%, clay + lime + PRF, 396.088%, 479.219%, 683.102%, 551.185% , soaked clay + cement + PRF, 554.160%, 685.656%, 947.074%, 833.688%, clay + lime + PRF 475.576%, 588.490%, 864.080%, 697.151%. Isiokpo unsoaked clay + cement + PRF are 407.348%, 544.291%, 753.590%, 662.380%, clay + lime + PRF are 293.359%, 474.251%, 675.142% , 595.270%, soaked clay + cement + PRF, 431.940%, 602.258%, 896.226%, 792.734%, clay + lime + PRF, 348.418%, 564.768%, 817.148%, 677.307%. Entire results of California bearing ratio (CBR) of unsoaked and soaked stabilized soils with composite materials at combined state possessed incremental percentile values as indicated in figures 3.4 with peak mix ratio of 91.75+0.75+7.5%. Formation of cracks and reduction in percentile values were observed beyond peak mix. Comparatively, higher values recorded in cement to lime samples.

3.3 Unconfined Compressive Strength Test

Results of unconfined compressive strength test percentile derived values from table 3.8 to 3.8A of sampled roads are; Ebiriba 1.569%, Ochigba 1.638%,1.616%, Eneka 1.703%, and Isiokpo 1.551%, respectively at 100% natural clay soils. Stabilized composite materials unconfined compressive strength of Ebiriba clay + cement + PRF are 93.113%, 289.191%, 466.388%, 597.107% , clay + lime + PRF ,72.083%, 271.067%, 478.765%, 605.126%, Ochigba clay + cement + PRF are 99.723%, 243.227%, 398.366%, 549.626%, clay + lime + PRF 81.414%, 253.360%, 427.891%, 541.660%. Eneka clay + cement + PRF are 111.606%, 313.234%, 471.030%, 586.246%, clay + lime + PRF 97.918%, 271.994%, 457.342%, 575.062% and Isiokpo clay + cement + PRF are 90.672%, 308.163%, 431.357%, 597.136%, clay + lime + PRF 262.860%, 297.841%, 480.350%, 609.628%. Comparative results of unconfined compressive strength test of cementitious materials combined actions showed incremental percentile values accordingly to percentage rise of composite materials to soils ratio with cement performance in higher values to lime.

3.4 Consistency Limits Test

Generated percentile values from preliminary test of clay soils at 100% (no additives) from tables 3.5, 3.6, 3.6, 3.7 to 3.5A, 3.6A and summarized into 3.7A of consistency limits (Plastic index) are Ebiriba 0.989%, Ochigba 1.131%, Eneka 0.996% and Isiokpo 0.990%. Composite stabilized Ebiriba clay + cement + PRF are -2.254%, -2.955%, -3.655%, -4.986%, clay + lime + PRF -1.406%, -2.212%, -2.842%, -3.508%. Ochigba stabilized clay + cement + PRF are -3.977%, -4.978%, -5.645%, -6.813%, clay + lime + PRF- 4.249%, -5.250%, -5.884%, -7.219%. Eneka clay + cement + PRF are -0.898%, -1.674%, -2.360%, -3.166%, clay + lime + -0.989%, -1.587%, -2.158%, -3.015%. Isiokpo clay + cement + PRF are -1.982%, -2.651%, -3.601%, -4.411%, clay + lime + PRF -1.697%, -2.507%, -3.493%, -4.831%. Results showed the inclusion of cementitious materials to PRF decreases the plastic index properties of stabilized soils to corresponding percentages ratio.

Table 3.1: Engineering Properties of Soil Samples of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

Location Description	Ebiriba Rd Ahoada West L.G.A	Ochigba Rd Ahoada East L.G.A	Eneka Rd Obio/Akpor L.G.A	Isiokpo Rd Ikwerre L.G.A
Depth of sampling (m)	1.0	1.0	1.0	1.0
Percentage(%) passing BS sieve #200	75.55	75.05	82.85	69.55
Colour	Greyish/black	Grey	Greyish	Greyish
Specific gravity	2.45	2.68	2.62	2.48
Natural moisture content (%)	47.36	43.85	47.80	48.15
Consistency limits				
Liquid limit (%)	57.30	56.35	63.30	57.75
Plastic limit (%)	28.75	30.38	29.80	29.35
Plasticity Index	28.55	25.97	33.50	28.40
AASHTO soil classification Unified Soil Classification System	A-7-6/CH	A-7-6/CH	A-7-6/CH	A-7-6/CH
Compaction characteristics				
Optimum moisture content (%)	16.38	17.45	16.75	15.87
Maximum dry density ($kN/m^{3)}$	1.685	1.705	1.663	1.665
Grain size distribution				
Gravel (%)	0	0	0	0

Sand (%)	16.25	12.35	12.80	14.35
Silt (%)	43.83	39.85	41.85	42.35
Clay (%)	39.92	46.80	45.35	56.70
Unconfined compressive strength (kPa)	68.85	77.35	79.85	65.57
California Bearing Capacity (CBR)				
Unsoaked (%) CBR	6.38	7.75	8.24	7.85
Soaked (%) CBR	5.25	6.03	6.35	6.30

Table 3.2: Results of Maximum Dry Density (MDD of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
MDD (Clay + Cement + PRF) Ebiriba Town Road Town Road	1.685	1.693	1.725	1.765	1.793
MDD (kN/m3) (Clay + Lime + PRF)EBIRIBA TOWN ROAD	1.685	1.691	1.715	1.756	1.782
MDD (Clay + Cement + PRF) OCHIGBA TOWN ROAD	1.705	1.731	1.754	1.788	1.825
MDD (kN/m3) (Clay + Lime + PRF)OCHIGBA TOWN ROAD	1.705	1.725	1.744	1.761	1.792
MDD (Clay + Cement + PRF) ENEKA TOWN ROAD	1.663	1.682	1.708	1.735	1.785
MDD (kN/m3) (Clay + Lime + PRF)ENEKA TOWN ROAD	1.663	1.678	1.693	1.715	1.746
MDD (Clay + Cement + PRF) ISIOKPO TOWN ROAD	1.605	1.628	1.672	1.683	1.715
MDD (kN/m3) (Clay + Lime + PRF)ISIOKPO TOWN ROAD	1.605	1.635	1.658	1.671	1.693

Table 3.2A: Results of Maximum Dry Density (MDD) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100.00%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD	1.00%	0.95%	2.85%	5.22%	6.88%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD	1.00%	0.71%	2.14%	4.57%	6.11%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD	1.02%	3.03%	4.38%	6.37%	8.54%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD	1.01%	2.33%	3.45%	4.44%	6.26%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD	1.01%	2.27%	3.84%	5.46%	8.47%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD	1.01%	1.80%	2.70%	4.02%	5.88%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD TOWN ROAD	1.01%	2.85%	5.59%	6.27%	8.27%
MDD (CLAY + CEMENT + PRF) EBIRIBA TOWN ROAD	1.02%	3.70%	5.14%	5.95%	7.32%

Table 3.3: Results of Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	1.000%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5	89+1.0 +10%
OMC% (Clay + Cement + PRF) EBIRIBA TOWN ROAD	16.380	16.930	17.380	17.830	18.240
OMC% (Clay + Lime + PRF) EBIRIBA TOWN ROAD	16.380	16.780	17.430	17.900	18.330
OMC% (Clay + Cement + PRF) OCHIGBA TOWN ROAD	17.450	17.980	18.340	18.860	19.270

OMC%(Clay + Lime + PRF) OCHIGBA TOWN ROAD	17.450	17.860	18.400	18.930	19.320
OMC%(Clay + Cement + PRF) ENEKA TOWN ROAD	16.750	17.080	17.580	17.930	18.250
OMC%(Clay + Lime + PRF) ENEKA TOWN ROAD	16.750	17.280	17.560	17.890	18.230
OMC%(Clay + Cement + PRF) ISIOKPO TOWN ROAD	15.870	16.150	16.520	16.860	17.040
OMC%(Clay + Lime + PRF) ISIOKPO TOWN ROAD	15.870	16.240	16.730	17.150	17.420

Table 3.3A: Results of Optimum Moisture Content (OMC) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100.00%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
OMC%(Clay + Cement + PRF) EBIRIBA TOWN ROAD	1.03%	6.61%	9.35%	12.10%	14.60%
OMC%(Clay + Lime + PRF) EBIRIBA TOWN ROAD	1.02%	4.83%	8.79%	11.66%	14.29%
OMC%(Clay + Cement + PRF) OCHIGBA TOWN ROAD	1.03%	5.98%	8.05%	11.03%	13.38%
OMC%(Clay + Lime + PRF) OCHIGBA TOWN ROAD	1.02%	4.65%	7.74%	10.78%	13.01%
OMC%(Clay + Cement + PRF) ENEKA TOWN ROAD	1.02%	3.90%	6.89%	8.98%	10.89%
OMC%(Clay + Lime + PRF) ENEKA TOWN ROAD	1.03%	6.23%	7.90%	9.87%	11.90%
OMC%(Clay + Cement + PRF) ISIOKPO TOWN ROAD	1.02%	3.50%	5.83%	7.97%	9.11%
OMC%(Clay + Lime + PRF) ISIOKPO TOWN ROAD	1.02%	4.61%	7.70%	10.34%	12.05%

Table 3.4: Results of California Bearing ratio (CBR) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
UNSOAKED CBR (Clay + Cement + PRF) EBIRIBA TOWN ROAD	6.38	33.45	42.68	56.25	48.65
UNSOAKED CBR (Clay + Lime + PRF) EBIRIBA TOWN ROAD	6.38	28.45	39.80	53.15	46.18
SOAKED CBR (Clay + Cement + PRF) EBIRIBA TOWN ROAD	5.25	29.30	38.60	52.85	44.52
SOAKED CBR (Clay + Lime + PRF) EBIRIBA TOWN ROAD	5.25	24.30	37.78	49.40	42.85
UNSOAKED CBR (Clay + Cement + PRF) OCHIGBA TOWN ROAD	7.75	36.20	47.85	60.35	52.63
UNSOAKED CBR (Clay + Lime + PRF) OCHIGBA TOWN ROAD	7.75	28.95	42.35	55.15	47.45
SOAKED CBR (Clay + Cement + PRF) OCHIGBA TOWN ROAD	6.03	31.35	42.45	55.75	48.15
SOAKED CBR (Clay + Lime + PRF) OCHIGBA TOWN ROAD	6.03	26.05	39.53	49.58	44.85
UNSOAKED CBR (Clay + Cement + PRF) ENEKA TOWN ROAD	8.24	39.65	48.60	64.35	56.23
UNSOAKED CBR (Clay + Lime + PRF) ENEKA TOWN ROAD	8.24	34.60	41.45	58.25	47.38
SOAKED CBR (Clay + Cement + PRF) ENEKA TOWN ROAD	6.35	36.30	44.65	61.25	54.05
SOAKED CBR (Clay + Lime + PRF) ENEKA TOWN ROAD	6.35	31.48	38.65	56.15	45.55

UNSOAKED CBR (Clay + Cement + PRF) ISIOKPO TOWN ROAD	7.85	33.80	44.55	60.98	53.82
UNSOAKED CBR (Clay + Lime + PRF) ISIOKPO TOWN ROAD	7.85	25.45	39.65	55.42	49.15
SOAKED CBR (Clay + Cement + PRF) ISIOKPO TOWN ROAD	6.30	28.60	39.33	57.85	51.33
SOAKED CBR (Clay + Lime + PRF) ISIOKPO TOWN ROAD	6.30	23.63	37.26	53.16	44.35

Table 3.4A: Results of California Bearing ratio (CBR) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
UNSOAKED CBR (Clay + Cement + PRF) EBIRIBA TOWN ROAD	5.24%	505.22%	649.89%	862.59%	743.47%
UNSOAKED CBR (Clay + Lime + PRF) EBIRIBA TOWN ROAD	4.46%	423.50%	601.40%	810.65%	701.40%
SOAKED CBR (Clay + Cement + PRF) EBIRIBA TOWN ROAD	5.58%	540.18%	717.32%	988.75%	830.08%
SOAKED CBR (Clay + Lime + PRF) EBIRIBA TOWN ROAD	4.63%	441.25%	698.01%	919.35%	794.59%
UNSOAKED CBR (Clay + Cement + PRF) OCHIGBA TOWN ROAD	4.67%	445.69%	596.01%	757.30%	657.69%
UNSOAKED CBR (Clay + Lime + PRF) OCHIGBA TOWN ROAD	3.74%	346.78%	519.68%	684.84%	585.49%
SOAKED CBR (Clay + Cement + PRF) OCHIGBA TOWN ROAD	5.20%	500.67%	684.75%	905.31%	779.27%
SOAKED CBR (Clay + Lime + PRF) OCHIGBA TOWN ROAD	4.32%	408.86%	632.41%	799.07%	720.63%
UNSOAKED CBR (Clay + Cement + PRF) ENEKA TOWN ROAD	4.81%	460.41%	569.02%	760.16%	661.62%
UNSOAKED CBR (Clay + Lime + PRF) ENEKA TOWN ROAD	4.20%	396.09%	479.22%	683.10%	551.18%
SOAKED CBR (Clay + Cement + PRF) ENEKA TOWN ROAD	5.72%	554.16%	685.66%	947.07%	833.69%
SOAKED CBR (Clay + Lime + PRF) ENEKA TOWN ROAD	4.96%	475.58%	588.49%	864.08%	697.15%
UNSOAKED CBR (Clay + Cement + PRF) ISIOKPO TOWN ROAD	4.31%	407.35%	544.29%	753.59%	662.38%
UNSOAKED CBR (Clay + Lime + PRF) ISIOKPO TOWN ROAD	3.24%	293.36%	474.25%	675.14%	595.27%
SOAKED CBR (Clay + Cement + PRF) ISIOKPO TOWN ROAD	4.54%	431.94%	602.26%	896.23%	792.73%
SOAKED CBR (Clay + Lime + PRF) ISIOKPO TOWN ROAD	3.75%	348.42%	564.77%	817.15%	677.31%

Table 3.5: Results of Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
LL(Clay + Cement + PRF) EBIRIBA TOWN ROAD	57.30	57.58	57.74	58.05	58.38

LL (Clay + Lime + PRF)EBIRIBA TOWN ROAD	57.30	57.30	58.28	58.56	58.74
LL(Clay + Cement + PRF) OCHIGBA TOWN ROAD	56.35	56.73	57.92	58.15	58.46
LL (Clay + Lime + PRF)OCHIGBA TOWN ROAD	56.35	56.78	56.99	57.28	57.57
LL(Clay + Cement + PRF) ENEKA TOWN ROAD	63.30	63.58	63.85	64.08	64.39
LL (Clay + Lime + PRF)ENEKA TOWN ROAD	63.30	63.65	63.92	64.25	64.65
LL(Clay + Cement + PRF) ISIOKPO TOWN ROAD	57.75	57.92	58.23	58.57	58.83
LL (Clay + Lime + PRF)ISIOKPO TOWN ROAD	57.75	57.85	58.18	58.45	58.81

Table 3.5A: Results of Liquid Limit (LL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
LL(Clay + Cement + PRF) EBIRIBA TOWN ROAD	1.00%	0.97%	1.25%	1.80%	2.37%
LL (Clay + Lime + PRF)EBIRIBA TOWN ROAD	1.01%	1.74%	2.58%	3.06%	3.38%
LL(Clay + Cement + PRF) OCHIGBA TOWN ROAD	1.01%	1.34%	3.46%	3.86%	4.41%
LL (Clay + Lime + PRF)OCHIGBA TOWN ROAD	1.01%	1.52%	1.89%	2.41%	2.92%
LL(Clay + Cement + PRF) ENEKA TOWN ROAD	1.00%	0.88%	1.31%	1.67%	2.16%
LL (Clay + Lime + PRF)ENEKA TOWN ROAD	1.01%	1.10%	1.53%	2.05%	2.68%
LL(Clay + Cement + PRF) ISIOKPO TOWN ROAD	1.00%	0.59%	1.12%	1.71%	2.16%
LL (Clay + Lime + PRF)ISIOKPO TOWN ROAD	1.00%	0.35%	0.92%	1.38%	2.01%

Table 3.6: Results of Plastic Limit (PL)of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25+2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
PL(Clay + Cement + PRF) EBIRIBA TOWN ROAD	28.75	29.35	29.71	30.22	31.35
PL (Clay + Lime + PRF) EBIRIBA TOWN ROAD	28.75	28.75	30.16	30.62	30.99
PL(Clay + Cement + PRF) OCHIGBA TOWN ROAD	30.38	27.35	22.84	23.27	23.96
PL (Clay + Lime + PRF) OCHIGBA TOWN ROAD	30.38	27.44	27.95	28.43	29.12
PL(Clay + Cement + PRF) ENEKA TOWN ROAD	29.80	30.23	30.76	31.22	31.80
PL (Clay + Lime + PRF) ENEKA TOWN ROAD	29.80	25.34	25.84	26.39	27.12
PL(Clay + Cement + PRF) ISIOKPO TOWN ROAD	29.35	29.80	30.30	30.91	31.40
PL (Clay + Lime + PRF) ISIOKPO TOWN ROAD	29.35	29.69	30.25	30.80	31.54

Table 3.6A: Results of Plastic Limit (PL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
PL(Clay + Cement + PRF) EBIRIBA TOWN ROAD	1.02%	4.13%	5.38%	7.16%	11.09%
PL (Clay + Lime + PRF) EBIRIBA TOWN ROAD	1.03%	6.84%	8.27%	9.87%	11.15%

PL(Clay + Cement + PRF) OCHIGBA TOWN ROAD	0.90%	6.05%	7.90%	9.48%	12.21%
PL (Clay + Lime + PRF) OCHIGBA TOWN ROAD	0.90%	5.39%	6.71%	7.13%	10.86%
IP (Clay + Cement + PRF) OCHIGBA TOWN ROAD	1.13%	4.74%	6.58%	6.81%	8.46%
PL(Clay + Cement + PRF) ENEKA TOWN ROAD	1.01%	2.87%	4.64%	6.19%	8.13%
PL (Clay + Lime + PRF) ENEKA TOWN ROAD	0.85%	4.57%	7.89%	9.04%	9.59%
IP (Clay + Cement + PRF) ENEKA TOWN ROAD	1.00%	4.90%	5.67%	5.36%	7.17%
PL(Clay + Cement + PRF) ISIOKPO TOWN ROAD	1.02%	3.04%	4.75%	6.83%	8.49%
PL (Clay + Lime + PRF) ISIOKPO TOWN ROAD	1.01%	2.30%	4.21%	6.09%	8.61%

Table 3.7: Results of Plastic Index (PI)of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
PI (Clay + Cement + PRF) EBIRIBA TOWN ROAD	28.55	28.23	28.03	27.83	27.45
PI (Clay + Lime + PRF) EBIRIBA TOWN ROAD	28.55	28.55	28.12	27.94	27.75
PI (Clay + Cement + PRF) OCHIGBA TOWN ROAD	25.97	29.38	29.08	28.88	28.53
PI (Clay + Lime + PRF) OCHIGBA TOWN ROAD	25.97	29.34	29.04	28.85	28.45
PI (Clay + Cement + PRF) ENEKA TOWN ROAD	33.50	33.35	33.09	32.86	32.59
PI (Clay + Lime + PRF) ENEKA TOWN ROAD	38.50	38.31	38.08	37.86	37.53
PI (Clay + Cement + PRF) ISIOKPO TOWN ROAD	28.40	28.12	27.93	27.66	27.43
PI (Clay + Lime + PRF) ISIOKPO TOWN ROAD	28.40	28.16	27.93	27.65	27.27

Table 3.7A: Results of Plastic Limit (PL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100.00%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
PI (Clay + Cement + PRF) EBIRIBA TOWN ROAD	0.99%	-2.25%	-2.95%	-3.66%	-4.99%
PI (Clay + Lime + PRF) EBIRIBA TOWN ROAD	1.04%	1.89%	1.88%	1.25%	0.58%
PI (Clay + Cement + PRF) OCHIGBA TOWN ROAD	1.13%	-1.74%	-2.58%	-3.81%	-4.46%
PI (Clay + Lime + PRF) OCHIGBA TOWN ROAD	1.13%	-1.46%	-1.81%	-2.58%	-3.04%
PI (Clay + Cement + PRF) ENEKA TOWN ROAD	1.00%	-0.90%	-1.67%	-2.36%	-3.17%
PI (Clay + Lime + PRF) ENEKA TOWN ROAD	1.00%	-0.99%	-1.59%	-2.16%	-3.02%
PI (Clay + Cement + PRF) ISIOKPO TOWN ROAD	0.99%	-1.98%	-2.65%	-3.60%	-4.41%
PI (Clay + Lime + PRF) ISIOKPO TOWN ROAD	0.99%	-1.70%	-2.51%	-3.49%	-4.83%

Table 3.8: Results of Unconfined Compressive Strength (UCS) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
UCS (Clay + Cement + CLBF) EBIRIBA TOWN ROAD	68.85	108.00	243.00	365.00	455.00
UCS(Clay + Lime + CLBF) EBIRIBA TOWN ROAD	68.85	98.00	235.00	378.00	465.00
UCS (Clay + Cement + CLBF) OCHIGBA TOWN ROAD	77.35	125.00	236.00	356.00	473.00

UCS(Clay + Lime + CLBF)OCHIGBA TOWN ROAD	77.35	115.00	248.00	383.00	471.00
UCS(Clay + Cement + CLBF) ENEKA TOWN ROAD	79.85	136.00	297.00	423.00	515.00
UCS (Clay + Lime + CLBF) ENEKA TOWN ROAD	79.85	128.00	267.00	415.00	509.00
UCS (Clay + Cement + CLBF) ISIOKPO TOWN ROAD	65.75	102.00	245.00	326.00	435.00
UCS(Clay + Lime + CLB\) ISIOKPO TOWN ROAD	65.75	195.00	218.00	338.00	423.00

Table 3.8A: Results of Unconfined Compressive Strength (UCS) Percentile Difference of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
UCS (Clay + Cement + CLBF) EBIRIBA TOWN ROAD	1.569%	93.113%	289.191%	466.388%	597.107%
UCS(Clay + Lime + CLBF) EBIRIBA TOWN ROAD	1.423%	72.083%	271.067%	478.765%	605.126%
UCS (Clay + Cement + CLBF) OCHIGBA TOWN ROAD	1.616%	99.723%	243.227%	398.366%	549.626%
UCS(Clay + Lime + CLBF)OCHIGBA TOWN ROAD	1.487%	81.414%	253.360%	427.891%	541.660%
UCS(Clay + Cement + CLBF) ENEKA TOWN ROAD	1.703%	111.606%	313.234%	471.030%	586.246%
UCS (Clay + Lime + CLBF) ENEKA TOWN ROAD	1.603%	97.918%	271.994%	457.342%	575.062%
UCS (Clay + Cement + CLBF) ISIOKPO TOWN ROAD	1.551%	90.672%	308.163%	431.357%	597.136%
UCS(Clay + Lime + CLBF) ISIOKPO TOWN ROAD	2.966%	262.860%	297.841%	480.350%	609.628%

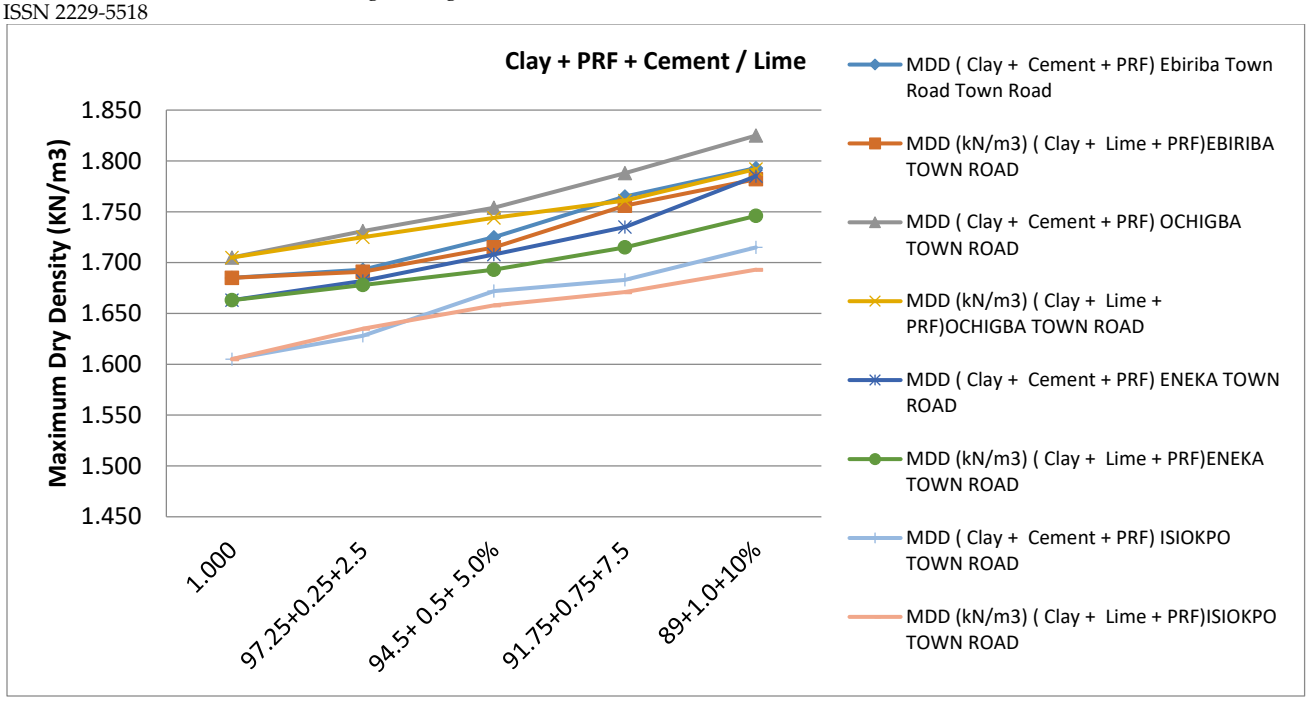

Figure 3.1: Maximum Dry Density (MDD of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

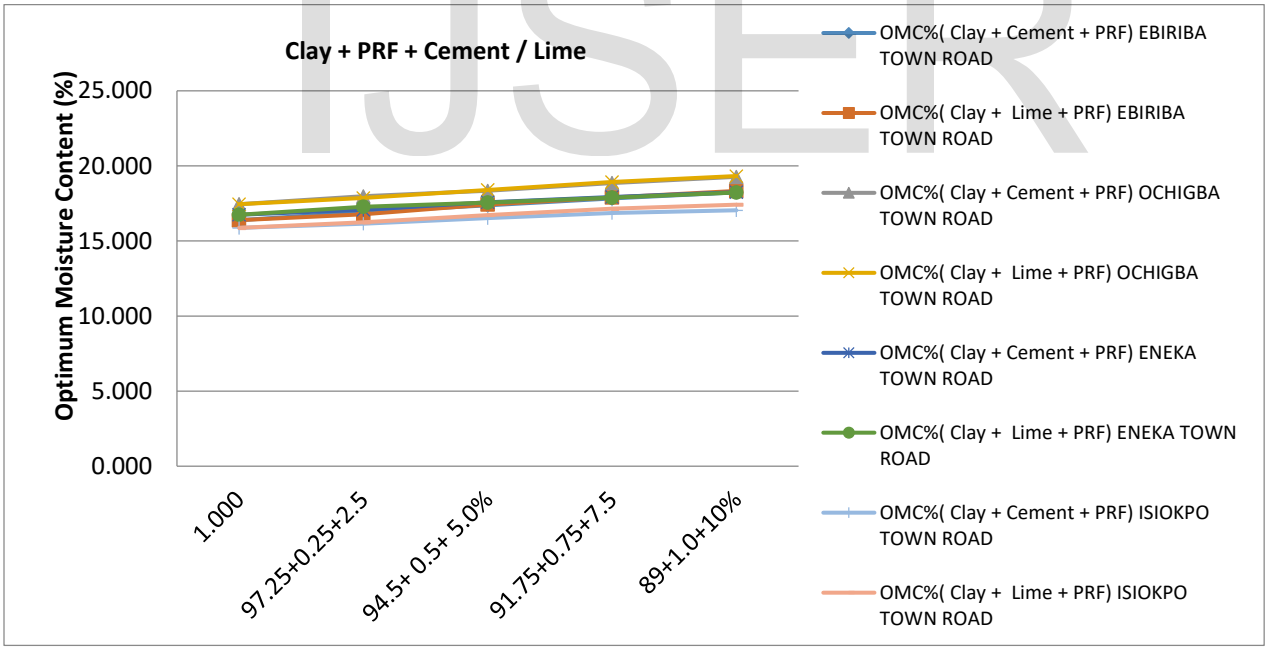

Figure 3.2: Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

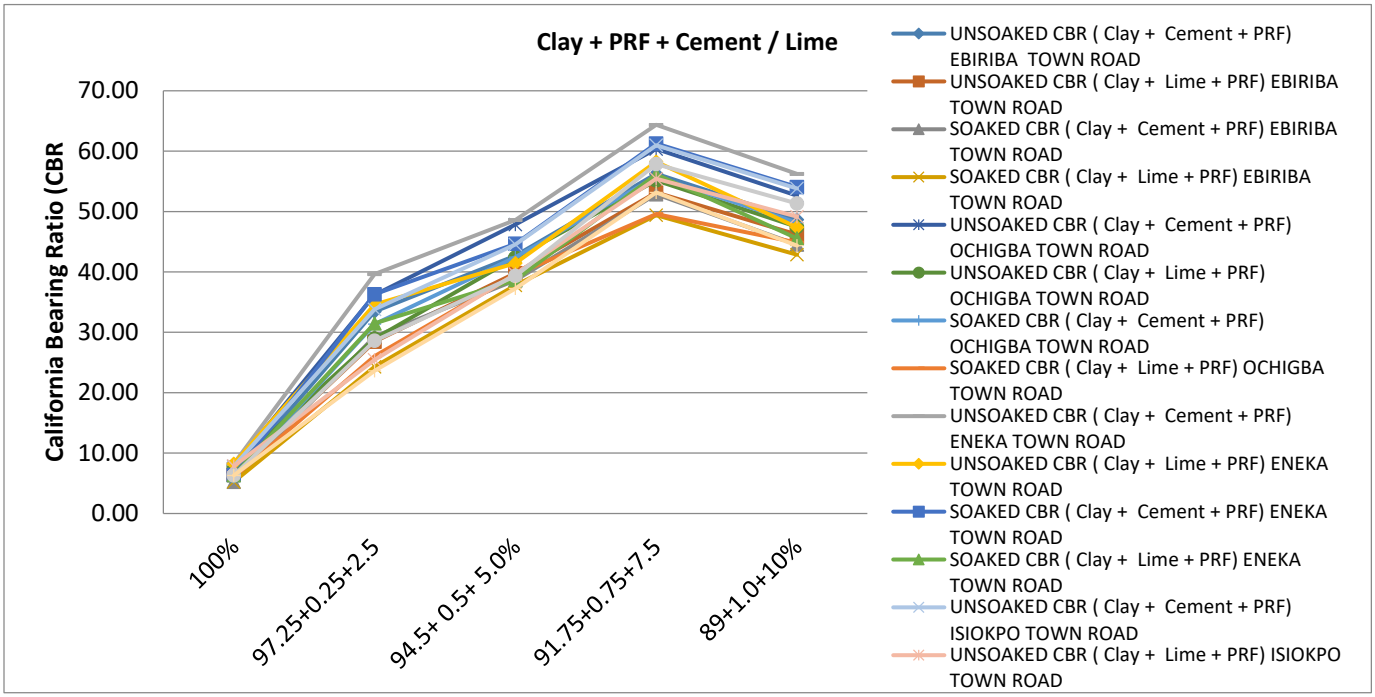

Figure 3.3: California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

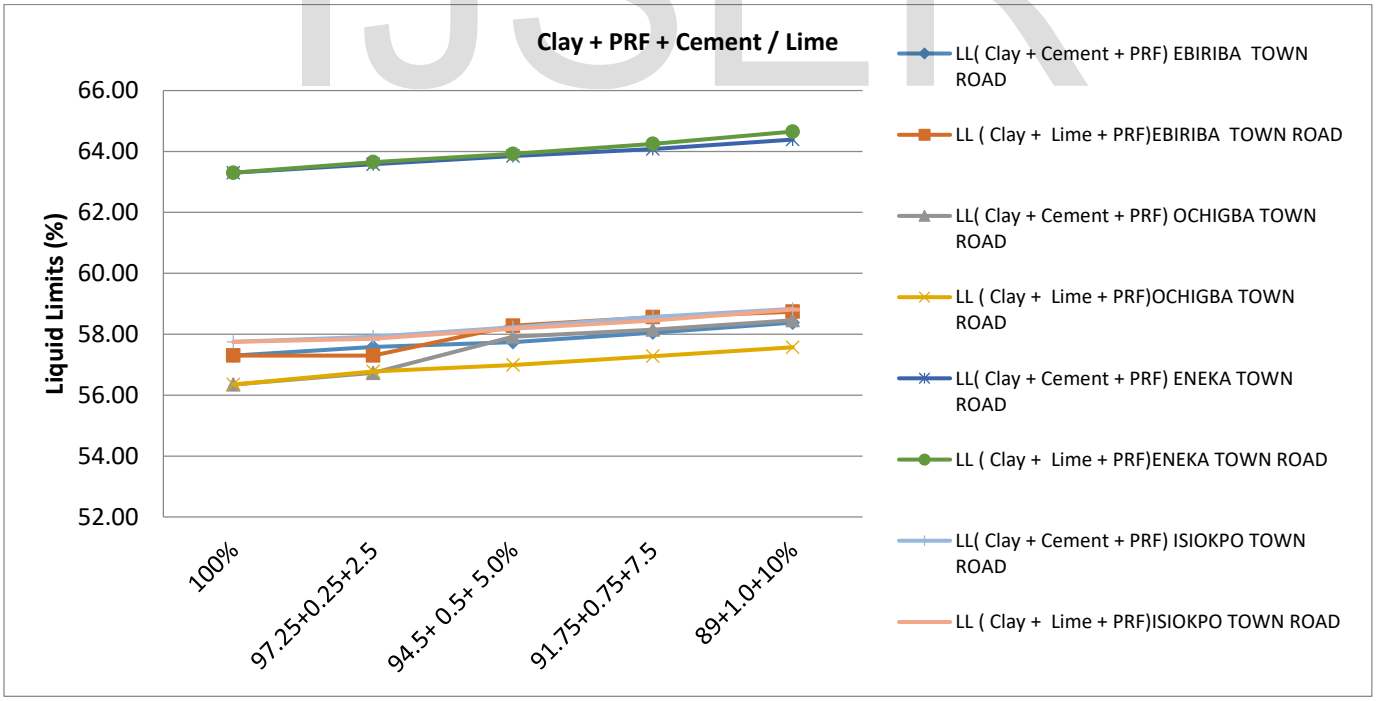

Figure 3.4: Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

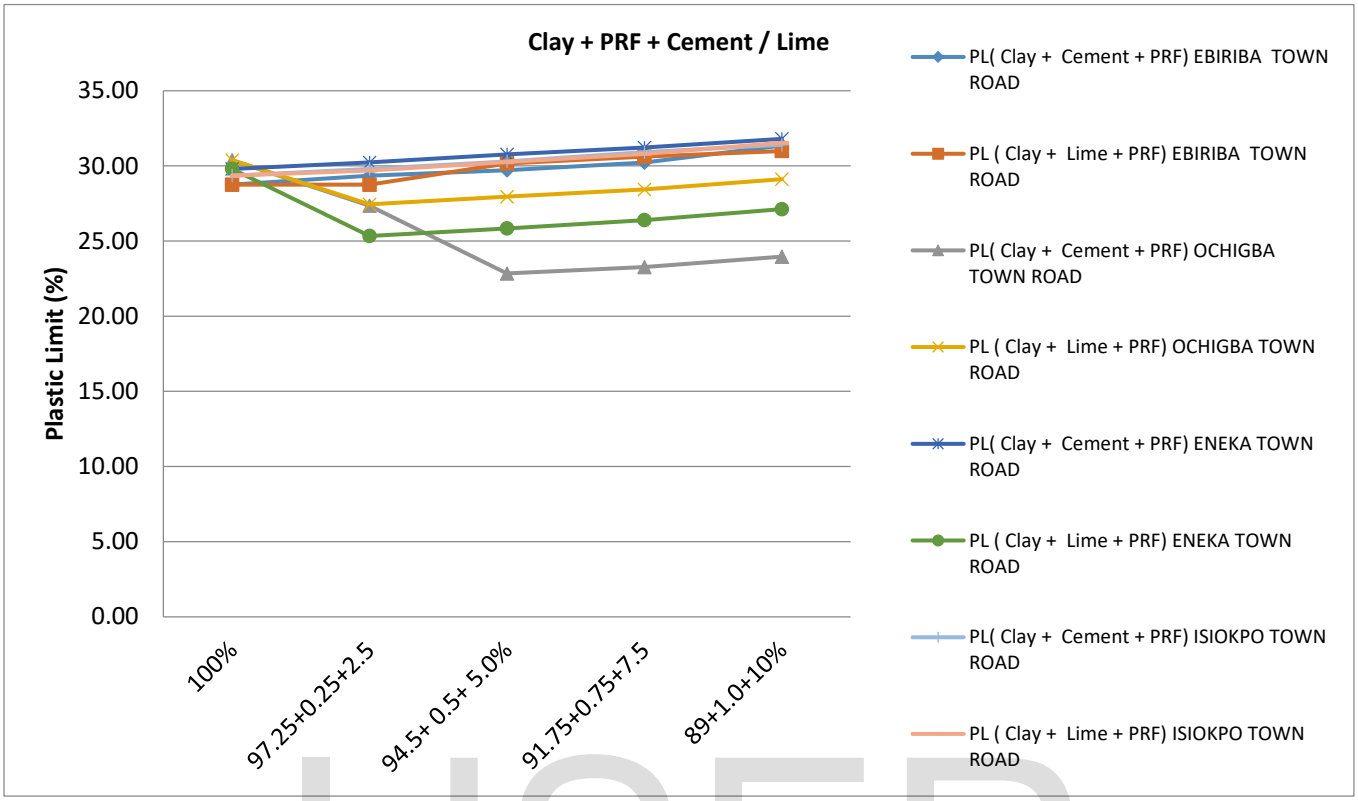

Figure 3.5: Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

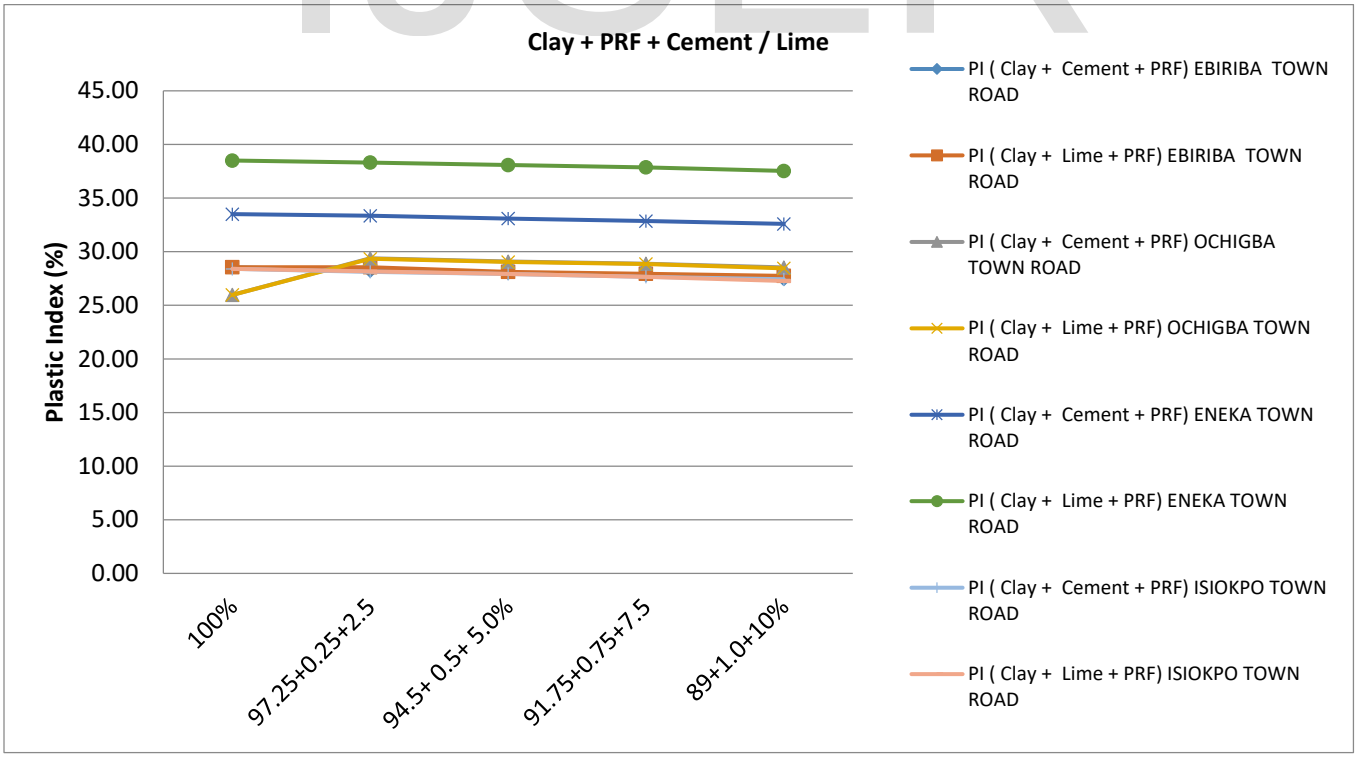

Figure 3.6: Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with PRF + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

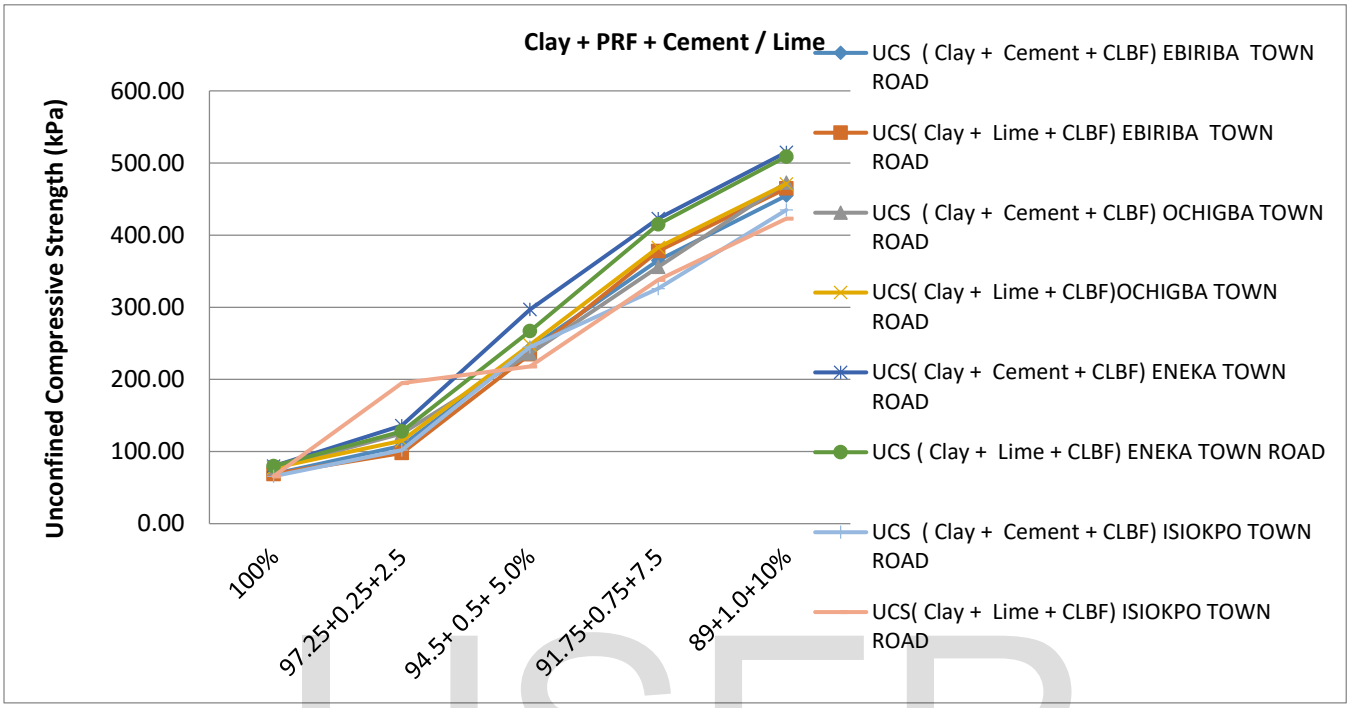

Figure 3.5: Unconfined Compressive Strength (UCS) of Niger Deltaic Clay Soils Subgrade with PRF+ Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

4.0 Conclusions

The following conclusions were made from the experimental research results.

i. The soils classified as A-7-6/CH on the AASHTO classification schemes / Unified Soil Classification System

ii. The soil has unsoaked CBR values of 6.38%, 7.75%, 8.24% and 7.85%, and soaked CBR values of 5.25%, 6.03%, 6.35% and 6.30%.

iii. Unconfined compressive strength values of 68.85kPa, 77.35kPa, 79.85kPa and 65.57kPa when compacted with British Standard light

iv. Comparative results of clay soils at natural condition and composite stabilized clay soils compaction test results of maximum dry density (MDD) and optimum moisture content (OMC) possessed incremental percentile values with respect to rate of percentages ratio increase to soils.

v. Entire results of California bearing ratio (CBR) of unsoaked and soaked stabilized soils with composite materials at combined state possessed incrementalpercentile values as indicated in figures 3.1 – 3.4 with peak mix ratio of 91.75+0.75+7.5%. Formation of cracks and reduction in percentile values were observed beyond peak mix
.

vi. Comparative results of unconfined compressive strength test of cementitious materials combined actions showed incremental percentile values accordingly to percentage rise of composite materials to soils ratio.

vii. Results showed the inclusion of cementitious materials to PRF decreases the plastic index properties of stabilized soils to corresponding percentages ratio.

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