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Stabilization of Black Cotton Clayey Soils with Cementitious Stabilizing Agents Blended with Waste Agricultural Products

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Abstract Vulnerability of highway pavement degradation has been the problem of Niger Delta roads resulting from swelling and shrinkage potentials of expansive soils. The study evaluated the application of cementitious stabilizing agents of cement / lime and plantain rachis fibre ash in combined actions and comparatively ascertains their strength variance to the modification of clay soil. Preliminary investigation on the physical / engineering properties of the soils, classified them as A-7-6 / CH on the AASHTO classification schemes / Unified Soil Classification System. The soils are dark grey in color with plasticity index of 28.55%, 25.97%, 33.50%, and 28.40% respectively of Ebiriba, Ochigba, Eneka and Isiokpo Town roads. 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. Statically, the natural clay soils result at 100% condition on compaction test of maximum dry density (MDD) and optimum moisture content (OMC) from sampled roads 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. Results obtained of California bearing ratio (CBR) unsoaked test 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. Unconfined compressive strength test results of sampled roads are Ebiriba1.569%, Ochigba 1.638%, 1.616%, Eneka 1.703%, and Isiokpo 1.551%, respectively at 100% natural clay soils. Result of compaction tests maximum dry density (MDD) and optimum moisture content (OMC) in comparison of natural and stabilized conditions with cementitious agents of cement and lime with PRFA showed incremental percentile values increase with composite materials inclusion to soils with corresponding percentages ratio. Thus, the inclusion of composites materials to clay soils increases the compaction properties of clay soils. California bearing ratio (CBR) unsoaked and soaked from composite stabilized clay soils showed incremental percentile values to corresponding cementations agents with PRFA inclusion with optimum mix ratio of 85+7.5+7.5% with higher percentile values lead on cement as demonstrated graphically in figure 3.3. Stabilized clay soils unconfined compressive strength test results showed incremental percentile values relatively to percentages ratio inclusion of composite materials to soil with cement composition on higher to lime as illustrated graphically in figure 3.7. Consistency limits test results showed percentile decreased in plastic index properties relatively to stabilizers inclusion percentages to soils. Figures 3.4, 3.5 and 3.6 illustrated graphical representation of consistency limits with cement composition in dominance reduction over lime.

Keywords Clay soils, Plantain Rachis Fibre Ash, Cement, Lime, CBR, UCS, Consistency, Compaction

1. Introduction

Land with weak soils used for constructions result to ground improvement techniques such as soil stabilization and reinforcement, most of the soil available have better compressive strength, proper shear strength and weak in tension [1].

Kumar *et al*., [2] evaluated the strength parameters of four locally available materials for their use in the sub base course of a pavement. Fly ash had the lowest CBR of 9%, but its behavior under dynamic load is better than that of stone dust, which has shown the maximum value of CBR.

Cordeiro [3] obtained the important parameter for the production of Sugar Cane Bagasse Ash (SCBA) with pozzolanic activity. The SCBA produced with air calcination at 600°C for 3 hr. with a rate of heating of 10°C/min presents amorphous silica, low carbon content and high specific surface area. The sample produced with these characteristics presents considerable pozzolanic activity according to both mechanical and chemical methods of evaluation.

Kolias *et al*., [4] discussed on Stabilization of clayey soils with high calcium fly ash and cement in their re-search the effectiveness of using high calcium fly ash and cement in stabilizing fine-grained clayey soils (CL, CH) was investigated in the laboratory. Strength tests in uniaxial compression, in indirect (splitting) tension and flexure were carried out on samples to which various percentages of fly ash and cement had been added. Modulus of elasticity was deter-mined at 90 days with different types of load application and 90-day soaked CBR values are also reported.

Phanikumar and Sharma [5] studied the effect of fly ash (class –F) on some geotechnical properties of expansive soil and had found improvement in these properties.

Bose [6] investigated the effect of fly ash (class-F) and lime on geotechnical properties of expansive soil and had found positive effects.

Amu *et al*., [7] used (Class- F) fly ash and cement for stabilization of expansive soil. It was found that stabilizing effect of 9% cement and 3% fly ash was better than the stabilizing effect 12 % cement.

Charles *et al.* [8] 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.* [9] 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.* [10] 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.,* [11] experimented on 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.

2. Materials and Methods

2.1 Materials

2.1.1 Soil

The soils used for the study were collected from Ebiriba Town Rd, in Ahoada-West Local Government, Ochigba Town Rd, in Ahoada-East Local Government Area, Eneka Town Rd, 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 Ash

The Plantain Rachis fibres are obtained from Iwofe 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. 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 Roads. 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

Natural clay soils results at 100% condition on compaction test of maximum dry density (MDD) and optimum moisture content (OMC) from sampled roads percentile generated values from tables 3.2 and 3.3 into 3.2A and 3.3A 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%, 5.220%, 5.220%, 6.882%, clay + lime + PRFA 0.829%, 3.737%, 3.737%, 4.983%, OMC are clay + cement + PRF 6.606%, 12.101%, 12.101%, 14.604%, clay + lime + PRFA 5.421%, 12.442%, 12.442%, 15.189%.. Ochigba MDD clay + cement + PRF are 2.216%, 6.322%, 6.322%, 7.554%, clay + lime + PRFA 1.519%, 3.689%, 3.689%, 5.449%, OMC are clay + cement + PRFA, 4.869%, 10.886%, 10.886%, 13.236%, clay + lime + PRFA 4.533%, 9.232%, 9.232%, 11.009%. Eneka MDD clay + cement + PRFA are 2.034%, 4.860%, 4.860%, 7.025%, clay + lime + PRFA 1.079%, 3.846%, 3.846%, 4.868%, OMC are clay + cement + PRFA, 5.070%, 10.443%, 10.443%, 11.995%, clay + lime + PRFA, 5.652%, 10.547%, 10.547%, 12.816%. Isiokpo stabilized MDD clay + cement + PRFA are 1.242%, 5.167%, 5.167%, 6.663%, clay + lime + PRFA, 1.613%, 4.417%, 4.417%, 5.726%, OMC clay + cement + PRFA, 5.470%, 10.322%, 10.322%, 11.960%, clay + lime + PRFA, 3.869%, 8.217%, 8.217%, 11.179%.

Results of compaction tests, maximum dry density (MDD) and optimum moisture content (OMC) in comparison of natural and stabilized conditions with cementitious agents of cement and lime with PRFA showed incremental percentile values increase with composite materials inclusion to soils to corresponding percentages ratio with cement at higher values at indicated in figures 3.1 and 3.2. Thus, the inclusion of composites materials to clay soils increases the compaction properties of clay soils.

3.2 California Bearing Ratio (CBR) Test

Results obtained of California bearing ratio (CBR) percentile values from table 3.4, summarized into 3.4A are unsoaked, 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 + PRFA are 55505.221%, 862.588%, 862.588%, 743.466%, clay + lime + PRFA; 374.667%, 732.817%, 732.817%, 630.937%, soaked clay + cement + PRFA), 540.177%, 988.749%, 988.749%, 830.082%, clay + lime + PRFA 404.234%, 868.043%, 868.043%, 704.805%. Ochigba stabilized unsoaked clay + cement + PRFA are 380.480%, 536.996%, 652.480%, 644.093%, clay + lime + PRFA, 338.470%, 649.824%, 649.824%, 595.244%, soaked clay + cement + PRFA, 418.459%, 894.080%, 894.080%, 767.546% clay + lime + PRFA, 423.512%, 824.176%, 824.176%, 745.403%. Eneka unsoaked clay + cement + PRFA are 419.238%, 687.684%, 687.684%, 575.427%, clay + lime + PRFA, 379.381%, 635.207%, 635.207%, 534.114%, soaked clay + cement + PRFA, 510.561%, 868.199%, 868.199%, 664.262%, clay + lime + PRFA 445.513%, 810.080%, 810.080%, 673.859%. Isiokpo unsoaked clay + cement + PRFA are 400.361%, 713.355%, 713.355%, 630.552% clay + lime + PRFA are 374.323%, 609.992%, 609.992%, 527.826%, soaked clay + cement + PRFA, 432.107%, 856.551%, 856.551%, 749.884%, clay + lime + PRFA, 440.255%, 729.938%, 729.938%, 603.430%. California bearing ratio (CBR) unsoaked and soaked from composite stabilized clay soils showed incremental percentile values to corresponding cementations agents with PRFA inclusion with optimum mix ratio of 85+7.5+7.5% with higher percentile values lead on cement as demonstrated graphically in figure 3.3.

3.3 Unconfined Compressive Strength Test

Percentile generated values of unconfined compressive strength test results of sampled roads from table 3.8, summarized into 3.8A 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 + PRFA are 93.113%, 466.388%, 466.388%, 597.107%, clay + lime + PRFA, 51.559%, 474.434%, 474.434%, 555.771%, Ochigba clay + cement + PRFA are 69.955%, 340.155%, 40.155%, 479.780%, clay + lime + PRFA 43.538%, 356.402%, 356.402%, 508.955%. Eneka clay + cement + PRFA are 74.585%, 385.168%, 385.168%, 491.617%, clay + lime + PRFA 61.318%, 360.630%, 360.630%, 530.949% and Isiokpo clay + cement + PRFA are 51.925%, 372.837%, 372.837%, 553.826%, clay + lime + PRFA 308.047%, 555.666%, 555.666%, 702.852%. Stabilized clay soils unconfined compressive strength test results showed incremental percentile values relatively to percentages ratio inclusion of composite materials to soil with cement composition on higher to lime as illustrated graphically in figure 3.7.

3.4 Consistency Limits Test

Consistency limits (Plastic index) test of sampled roads at 100% natural clay soils from tables 3.4, 3.5 and 3.6 generated into summarized percentile values of tables 3.4A, 3.5A into 3.6A are Ebiriba 0.989%, Ochigba 1.131%, Eneka 0.996% and Isiokpo 0.990%. Stabilized soils of Ebiriba clay + cement + PRFA are -2.254%, -3.655%, -3.655%,- 4.986%, clay + lime + PRFA -0.983% ,-3.015%, -3.015%, -2.910%. Eneka clay + cement + PRFA are -1.920%, -3.651%, -3.651%, -4.726%, clay + lime + PRFA -1.042%, -1.951%, -1.951%, -5.327%, Isiokpo clay + cement + PRFA are -1.343%, -3.279%, -3.279%,- 3.913%, clay + lime + PRFA -1.697%, -3.493%, -3.493%n,-4.831%. Consistency limits test results showed percentile decreased in plastic index properties relatively to stabilizers inclusion percentages to soils. Figures 3.4, 3.5 and 3.6 illustrated graphical representation of consistency limits with cement composition in dominance reduction over lime.

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
(%) 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	A-7-6/CH	A-7-6/CH	A-7-6/CH	A-7-6/CH
Unified Soil Classification System				
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 PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
MDD (Clay + Cement + PRFA)Ebiriba Town Road	1.69	1.69	1.73	1.77	1.79
MDD (kN/m^3) (Clay + Lime + PRFA) Ebiriba Town Road	1.69	1.69	1.71	1.74	1.76
MDD (Clay + Cement + PRFA) Ochigba Town Road	1.71	1.72	1.75	1.79	1.82
MDD (kN/m3) (Clay + Lime + PRFA)Ochigba Town Road	1.71	1.72	1.73	1.76	1.79
MDD (Clay + Cement + PRFA) Eneka Town Road	1.66	1.68	1.70	1.73	1.76
MDD (kN/m3) (Clay + Lime + PRFA) Eneka Town Road	1.66	1.67	1.68	1.72	1.74
MDD (Clay + Cement + PRFA)Isiokpo Town Road	1.61	1.62	1.65	1.68	1.70
MDD (kN/m3) (Clay + Lime + PRFA) Isiokpo Town Road	1.61	1.62	1.64	1.66	1.68

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

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
MDD (Clay + Cement + PRFA) Ebiriba Town Road	1.00%	0.95%	5.22%	5.22%	6.88%
MDD (kN/m3) (Clay + Lime + PRFA) Ebiriba Town Road	1.00%	0.83%	3.74%	3.74%	4.98%
MDD (Clay + Cement + PRFA) Ochigba Town Road	1.01%	2.22%	6.32%	6.32%	7.55%
MDD (kN/m^3) (Clay + Lime + PRFA) Ochigba Town Road	1.01%	1.52%	3.69%	3.69%	5.45%
MDD (Clay + Cement + PRFA) Eneka Town Road	1.01%	2.03%	4.86%	4.86%	7.03%
MDD (kN/m^3) (Clay + Lime + PRFA) Eneka Town Road	1.01%	1.08%	3.85%	3.85%	4.87%
MDD (Clay + Cement + PRFA) Isiokpo Town Road	1.01%	1.24%	5.17%	5.17%	6.66%
MDD (kN/m^3) (Clay + Lime + PRFA) Isiokpo Town Road	1.01%	1.61%	4.42%	4.42%	5.73%

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

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
OMC% (Clay + Cement + PRFA) Ebiriba Town Road	16.38	16.93	17.38	17.83	18.24
OMC% (Clay + Lime + PRFA) Ebiriba Town Road	16.38	16.83	17.53	17.98	18.43
OMC% (Clay + Cement + PRFA) Ochigba Town Road	17.45	17.88	18.38	18.93	19.34
OMC% (Clay + Lime + PRFA) Ochigba Town Road	17.45	17.85	18.23	18.67	18.98
OMC% (Clay + Cement + PRFA) Eneka Town Road	16.75	17.18	17.65	18.08	18.34
OMC% (Clay + Lime + PRFA) Eneka Town Road	16.75	17.23	17.74	18.05	18.43
OMC% (Clay + Cement + PRFA) Isiokpo Town Road	15.87	16.31	16.86	17.08	17.34
OMC% (Clay + Lime + PRFA) Isiokpo Town Road	15.87	16.18	16.48	16.87	17.34

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

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
OMC% (Clay + Cement + PRFA) Ebiriba Town Road	1.03%	6.61%	12.10%	12.10%	14.60%
OMC% (Clay + Lime + PRFA) Ebiriba Town Road	1.03%	5.42%	12.44%	12.44%	15.19%
OMC% (Clay + Cement + PRFA) Ochigba Town Road	1.02%	4.87%	10.89%	10.89%	13.24%
OMC% (Clay + Lime + PRFA) Ochigba Town Road	1.02%	4.53%	9.23%	9.23%	11.01%
OMC% (Clay + Cement + PRFA) Eneka Town Road	1.03%	5.07%	10.44%	10.44%	12.00%
OMC% (Clay + Lime + PRFA) Eneka Town Road	1.03%	5.65%	10.55%	10.55%	12.82%
OMC% (Clay + Cement + PRFA)Isiokpo Town Road	1.03%	5.47%	10.32%	10.32%	11.96%
OMC% (Clay + Lime + PRFA)Isiokpo Town Road	1.02%	3.87%	8.22%	8.22%	11.18%

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

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UNSOAKED CBR (Clay + Cement + PRFA)Ebiriba Town Road	6.38	33.45	42.68	56.25	48.65
UNSOAKED CBR (Clay + Lime + PRFA) Ebiriba Town Road	6.38	25.50	32.68	48.35	41.85
SOAKED CBR (Clay + Cement + PRFA) Ebiriba Town Road	5.25	29.30	38.60	52.85	44.52
SOAKED CBR (Clay + Lime + PRFA) Ebiriba Town Road	5.25	22.45	29.65	46.80	38.23
UNSOAKED CBR (Clay + Cement + PRFA) Ochigba Town Road	7.75	31.40	43.53	57.35	51.83
UNSOAKED CBR (Clay + Lime + PRFA) Ochigba Town Road	7.75	28.35	36.81	52.48	48.25
SOAKED CBR (Clay + Cement + PRFA) Ochigba Town Road	6.03	26.60	39.62	55.28	47.65
SOAKED CBR (Clay + Lime + PRFA) Ochigba Town Road	6.03	26.89	33.45	51.05	46.30
UNSOAKED CBR (Clay + Cement + PRFA) Eneka Town Road	8.24	36.41	43.45	58.53	49.28
UNSOAKED CBR (Clay + Lime + PRFA) Eneka Town Road	8.24	33.30	41.40	54.38	46.05
SOAKED CBR (Clay + Cement + PRFA) Eneka Town Road	6.35	33.62	39.18	56.33	43.38
SOAKED CBR (Clay + Lime + PRFA) Eneka Town Road	6.35	29.65	38.83	52.80	44.15
UNSOAKED CBR (Clay + Cement + PRFA)Isiokpo Town Road	7.85	33.28	44.96	57.85	51.35
UNSOAKED CBR (Clay + Lime + PRFA)Isiokpo Town Road	7.85	31.35	38.23	49.85	43.40
SOAKED CBR (Clay + Cement + PRFA)Isiokpo Town Road	6.30	28.61	42.85	55.35	48.63
SOAKED CBR (Clay + Lime + PRFA)Isiokpo Town Road	6.30	29.10	37.05	47.35	39.38

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

RATIO %	100.00%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UNSOAKED CBR (Clay + Cement + PRFA)Ebiriba Town Road	5.24%	505.22%	862.59%	862.59%	743.47%
UNSOAKED CBR (Clay + Lime + PRFA) Ebiriba Town Road	4.00%	374.67%	732.82%	732.82%	630.94%
SOAKED CBR (Clay + Cement + PRFA) Ebiriba Town Road	5.58%	540.18%	988.75%	988.75%	830.08%
SOAKED CBR (Clay + Lime + PRFA) Ebiriba Town Road	4.28%	404.23%	868.04%	868.04%	704.81%
UNSOAKED CBR (Clay + Cement + PRFA) Ochigba Town Road	4.05%	380.48%	537.00%	652.48%	644.09%
UNSOAKED CBR (Clay + Lime + PRFA) Ochigba Town Road	3.66%	338.47%	649.82%	649.82%	595.24%
SOAKED CBR (Clay + Cement + PRFA) Ochigba Town Road	4.41%	418.46%	894.08%	894.08%	767.55%
SOAKED CBR (Clay + Lime + PRFA) Ochigba Town Road	4.46%	423.51%	824.18%	824.18%	745.40%
UNSOAKED CBR (Clay + Cement + PRFA) Eneka Town Road	4.42%	419.24%	687.68%	687.68%	575.43%
UNSOAKED CBR (Clay + Lime + PRFA) Eneka Town Road	4.04%	379.38%	635.21%	635.21%	534.11%
SOAKED CBR (Clay + Cement + PRFA) Eneka Town Road	5.29%	510.56%	868.20%	868.20%	664.26%
SOAKED CBR (Clay + Lime + PRFA) Eneka Town Road	4.67%	445.51%	810.08%	810.08%	673.86%
UNSOAKED CBR (Clay + Cement + PRFA)Isiokpo Town Road	4.24%	400.36%	713.35%	713.35%	630.55%
UNSOAKED CBR (Clay + Lime + PRFA)Isiokpo Town Road	3.99%	374.32%	609.99%	609.99%	527.83%
SOAKED CBR (Clay + Cement + PRFA)Isiokpo Town Road	4.54%	432.11%	856.55%	856.55%	749.88%
SOAKED CBR (Clay + Lime + PRFA)Isiokpo Town Road	4.62%	440.26%	729.94%	729.94%	603.43%

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

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
LL(Clay + Cement + PRFA) Ebiriba Town Road	57.30	57.58	57.74	58.05	58.38
LL (Clay + Lime + PRFA) Ebiriba Town Road	57.30	57.83	58.30	58.62	58.93
LL(Clay + Cement + PRFA) Ochigba Town Road	56.35	56.83	57.18	57.45	57.98
LL (Clay + Lime + PRFA) Ochigba Town Road	56.35	57.71	57.18	57.45	57.93
LL(Clay + Cement + PRFA) Eneka Town Road	63.30	63.68	64.15	64.48	64.73
LL (Clay + Lime + PRFA) Eneka Town Road	63.30	63.57	63.93	64.13	64.58
LL(Clay + Cement + PRFA) Isiokpo Town Road	57.75	58.15	58.35	58.70	58.93
LL (Clay + Lime + PRFA) Isiokpo Town Road	57.75	57.53	57.81	58.08	58.53

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

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
LL(Clay + Cement + PRFA) Ebiriba Town Road	1.00%	0.97%	1.80%	1.80%	2.37%
LL (Clay + Lime + PRFA) Ebiriba Town Road	1.01%	1.84%	3.22%	3.22%	3.76%
LL(Clay + Cement + PRFA) Ochigba Town Road	1.01%	1.70%	2.80%	2.80%	3.74%
LL (Clay + Lime + PRFA) Ochigba Town Road	1.02%	4.77%	4.31%	4.31%	5.16%
LL(Clay + Cement + PRFA) Eneka Town Road	1.01%	1.20%	2.46%	2.46%	2.86%
LL (Clay + Lime + PRFA) Eneka Town Road	1.00%	0.85%	1.74%	1.74%	2.45%
LL(Clay + Cement + PRFA) Isiokpo Town Road	1.01%	1.38%	2.33%	2.33%	2.73%
LL (Clay + Lime + PRFA) Isiokpo Town Road	1.00%	-0.76%	0.19%	0.19%	0.97%

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

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PL(Clay + Cement + PRFA) Ebiriba Town Road	28.75	29.35	29.71	30.22	31.35
PL (Clay + Lime + PRFA) Ebiriba Town Road	28.75	29.41	30.12	30.19	31.07
PL(Clay + Cement + PRFA) Ochigba Town Road	30.38	27.55	28.22	28.82	29.68
PL (Clay + Lime + PRFA) Ochigba Town Road	30.38	30.42	28.18	28.57	29.37
PL(Clay + Cement + PRFA) Eneka Town Road	29.80	30.50	31.22	31.81	32.49
PL (Clay + Lime + PRFA) Eneka Town Road	29.80	25.27	25.87	26.18	26.93
PL(Clay + Cement + PRFA) Isiokpo Town Road	29.35	30.07	30.41	31.04	31.45
PL (Clay + Lime + PRFA)Isiokpo Town Road	29.35	29.32	29.78	30.22	31.10

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

RATIO %	100.00%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PL(Clay + Cement + PRFA) Ebiriba Town Road	1.02%	4.13%	7.16%	7.16%	11.09%
PL (Clay + Lime + PRFA) Ebiriba Town Road	1.02%	4.54%	7.25%	7.25%	10.31%
PL(Clay + Cement + PRFA) Ochigba Town Road	0.91%	5.59%	8.41%	11.41%	12.58%
PL (Clay + Lime + PRFA) Ochigba Town Road	1.00%	5.06%	5.83%	7.83%	9.19%
PL(Clay + Cement + PRFA) Eneka Town Road	1.02%	4.64%	9.04%	9.04%	11.32%
PL (Clay + Lime + PRFA) Eneka Town Road	0.85%	3.13%	5.07%	7.07%	7.56%
PL(Clay + Cement + PRFA) Isiokpo Town Road	1.02%	4.85%	8.15%	8.15%	9.55%
PL (Clay + Lime + PRFA) Isiokpo Town Road	1.00%	4.20%	7.86%	8.06%	5.86%

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

RATIO %	100%	95+2.5+2.5%	90+5.0+5.0%	85+7.5+7.5%	80+10.0+10%
PI (Clay + Cement + PRFA) Ebiriba Town Road	28.55	28.23	28.03	27.83	27.45
PI (Clay + Lime + PRFA) Ebiriba Town Road	28.55	28.41	28.18	27.83	27.86
PI (Clay + Cement + PRFA) Ochigba Town Road	25.97	29.28	28.96	28.63	28.30
PI (Clay + Lime + PRFA) Ochigba Town Road	25.97	29.45	29.00	28.88	28.56
PI (Clay + Cement + PRFA) Eneka Town Road	33.50	33.18	32.93	32.60	32.24
PI (Clay + Lime + PRFA) Eneka Town Road	38.50	38.30	38.06	37.95	36.65
PI (Clay + Cement + PRFA) Isiokpo Town Road	28.40	28.21	27.94	27.66	27.48
PI (Clay + Lime + PRFA) 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 PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

RATIO %	100.00%	95+2.5+2.5%	90+5.0+5.0%	85+7.5+7.5%	80+10.0+10%
PI (Clay + Cement + PRFA) Ebiriba Town Road	0.99%	-2.25%	-3.66%	-3.66%	-4.99%
PI (Clay + Lime + PRFA) Ebiriba Town Road	1.00%	-0.98%	-3.01%	-3.01%	-2.91%
PI (Clay + Cement + PRFA) Ochigba Town Road	1.13%	-2.05%	-2.55%	-3.55%	-3.88%
PI (Clay + Lime + PRFA) Ochigba Town Road	1.13%	-1.22%	-2.02%	-3.02%	-4.79%
PI (Clay + Cement + PRFA) Eneka Town Road	0.99%	-1.92%	-3.65%	-3.65%	-4.73%
PI (Clay + Lime + PRFA) Eneka Town Road	0.99%	-1.04%	-1.95%	-1.95%	-5.33%
PI (Clay + Cement + PRFA)Isiokpo Town Road	0.99%	-1.34%	-3.28%	-3.28%	-3.91%
PI (Clay + Lime + PRFA)Isiokpo Town Road	0.99%	-1.70%	-3.49%	-3.49%	-4.83%

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

RATIO %	100 %	95+2.5+2.5 %	90+5.0+5.0 %	85+7.5+7.5 %	80+10.0+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	88.85	197.00	380.00	436.00
UCS (Clay + Cement + CLBF) Ochigba Town Road	77.35	109.00	225.00	318.00	426.00
UCS(Clay + Lime + CLBF) Ochigba Town Road	77.35	96.00	216.00	338.00	456.00
UCS(Clay + Cement + CLBF) Eneka Town Road	79.85	115.00	268.00	363.00	448.00
UCS (Clay + Lime + CLBF) Eneka Town Road	79.85	108.00	263.00	347.00	483.00
UCS (Clay + Cement + CLBF) Isiokpo Town Road	65.75	85.00	163.00	296.00	415.00
UCS(Clay + Lime + CLBF) Isiokpo Town Road	57.75	195.00	218.00	338.00	423.00

Table 3.8A: Results of Unconfined Compressive Strength (UCS) 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%	95+2.5+2.5%	90+5.0+5.0%	85+7.5+7.5%	80+10.0+10%
UCS (Clay + Cement + CLBF) Ebiriba Town Road	1.569%	93.113%	466.388%	466.388%	597.107%
UCS(Clay + Lime + CLBF) Ebiriba Town Road	1.290%	51.559%	474.434%	474.434%	555.771%
UCS (Clay + Cement + CLBF) Ochigba Town Road	1.409%	69.955%	340.155%	340.155%	479.780%
UCS(Clay + Lime + CLBF)Ochigba Town Road	1.241%	43.538%	356.402%	356.402%	508.955%
UCS(Clay + Cement + CLBF) Eneka Town Road	1.440%	74.585%	385.168%	385.168%	491.617%
UCS (Clay + Lime + CLBF) Eneka Town Road	1.353%	61.318%	360.630%	360.630%	530.949%
UCS (Clay + Cement + CLBF) Isiokpo Town Road	1.293%	51.925%	372.837%	372.837%	553.826%
UCS(Clay + Lime + CLBF)Isiokpo Town Road	3.377%	308.05%	555.666%	555.666%	702.852%

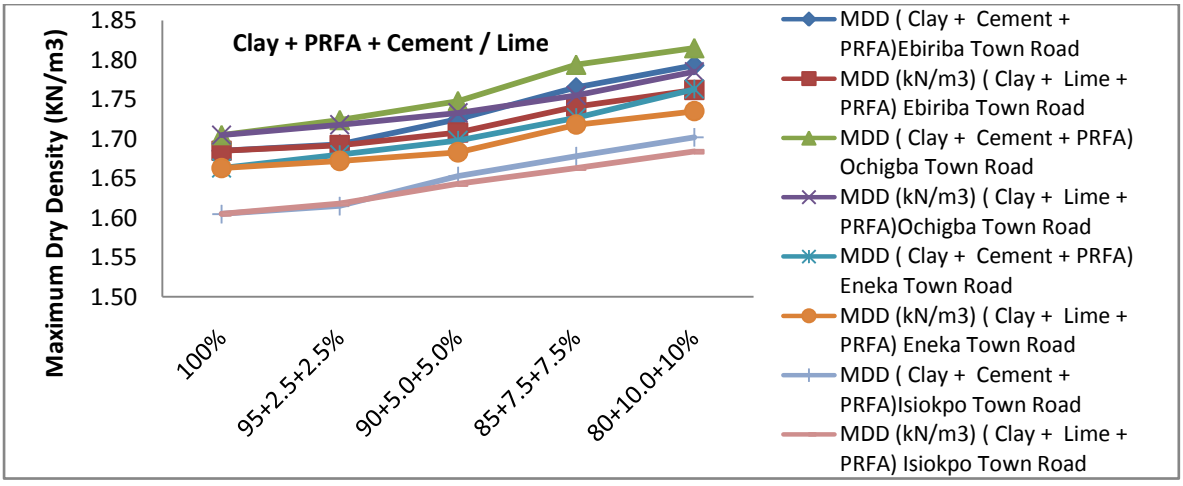

Figure 3.1: Maximum Dry Density (MDD) of Niger Deltaic Clay Soils Subgrade with PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

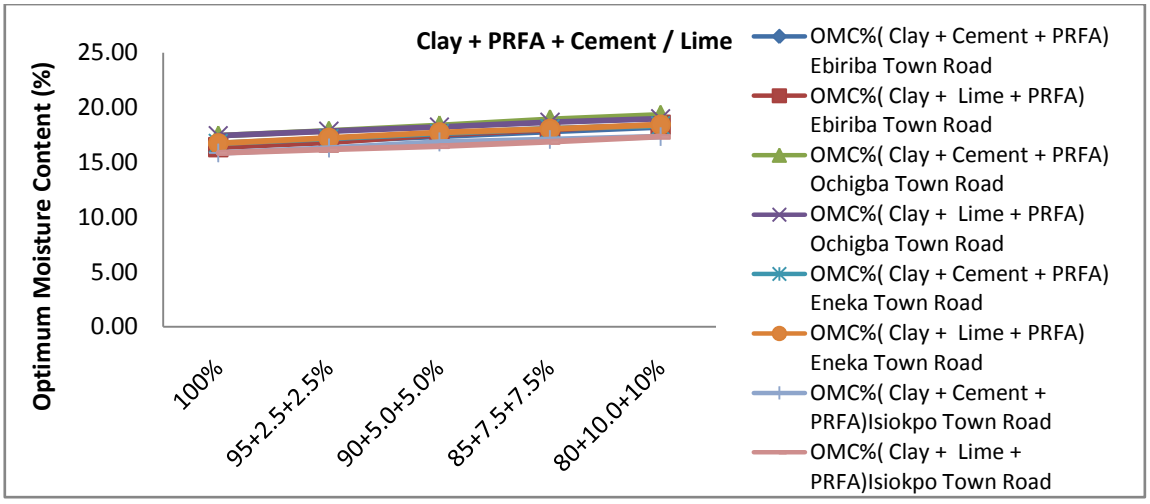

Figure 3.2: Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

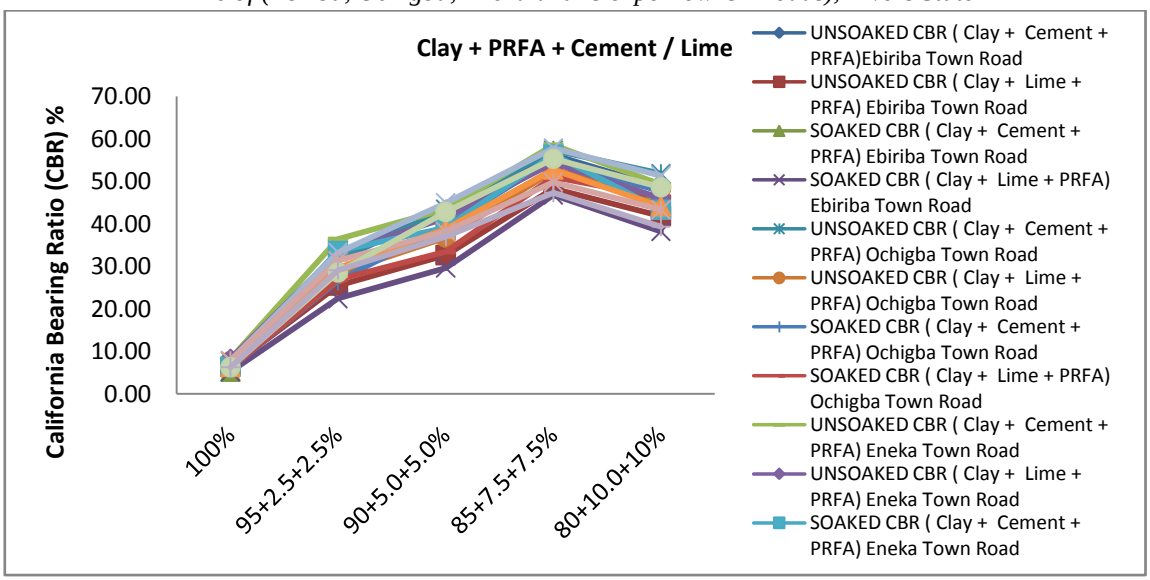

Figure 3.3: California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

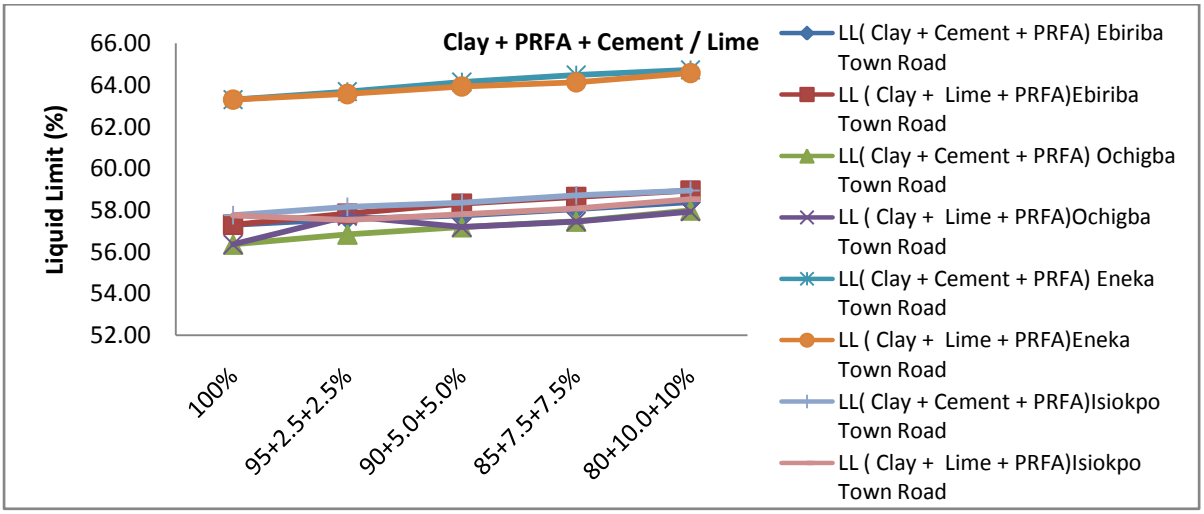

Figure 3.4: Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

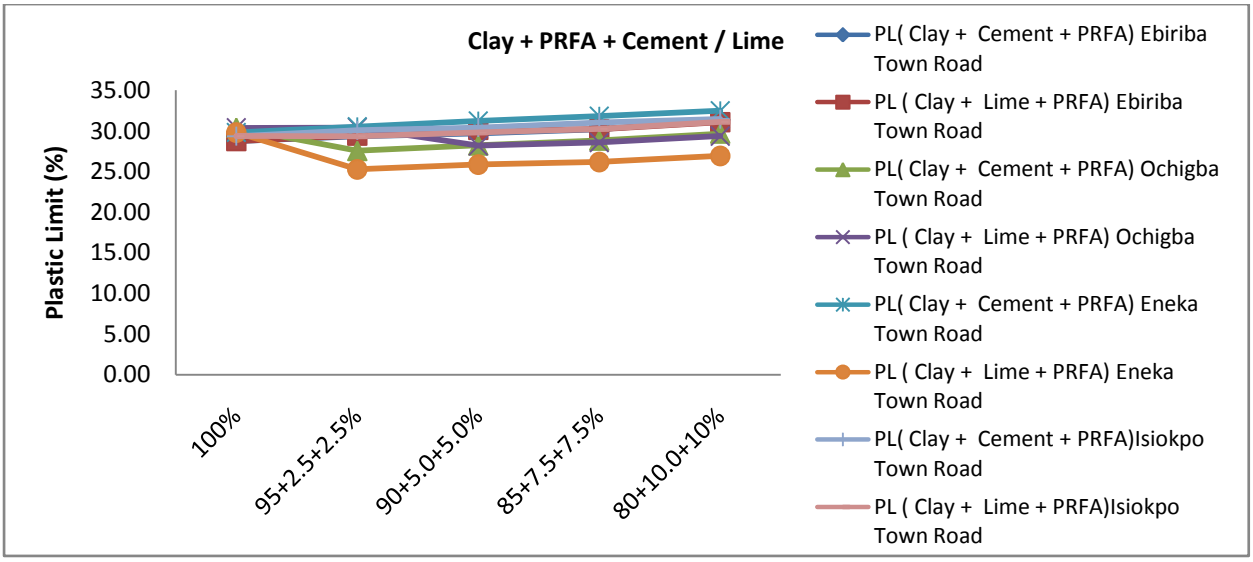

Figure 3.5: Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

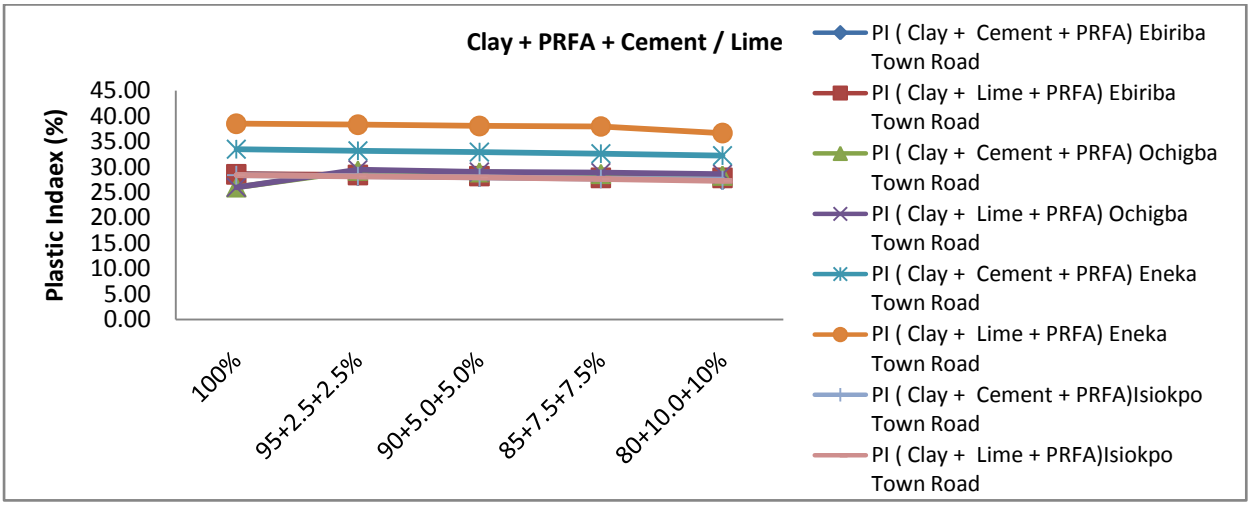

Figure 3.6: Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

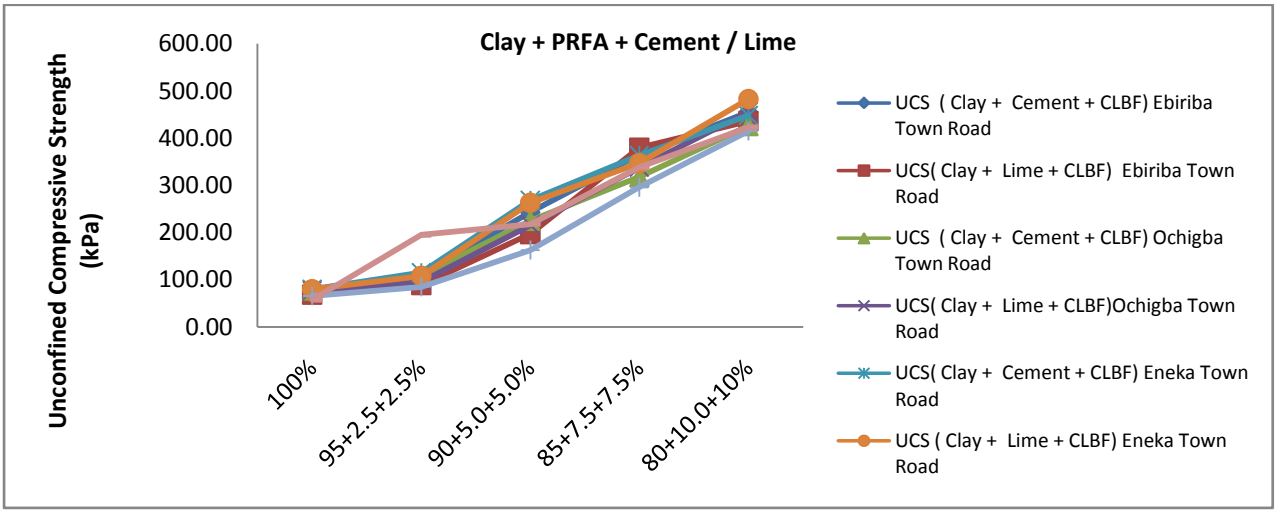

Figure 3.7: Unconfined Compressive Strength (UCS) of Niger Deltaic Clay Soils Subgrade with PRFA + Cement / Lime of (Ebriba, Ochigba, Eneka and Isiokpo Towns Roads), Rivers State

4. 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 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 Roads.

iii. 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.

iv. Results of compaction tests, maximum dry density (MDD) and optimum moisture content (OMC) in comparison of natural and stabilized conditions with cementitious agents of cement and lime with PRFA showed incremental percentile values increase with composite materials inclusion to soils to corresponding percentages ratio that natural condition. Thus, the inclusion of composites materials to clay soils increases the compaction properties of clay soils

v. California bearing ratio (CBR) unsoaked and soaked from composite stabilized clay soils showed incremental percentile values to corresponding cementations agents with PRFA inclusion with optimum mix ratio of 85+7.5+7.5%.

vi. Stabilized clay soils unconfined compressive strength test results showed incremental percentile values relatively to percentages ratio inclusion of composite materials to soil.

vii. Consistency limits test results showed percentile decreased in plastic index properties relatively to stabilizers inclusion percentages to soils

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