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COMPARATIVE STRENGTH EVALUATION OF CEMENTIOUS STABILIZING AGENTS BLENDED WITH PULVERIZED BAGASSE FIBRE FOR STABILIZATION OF EXPANSIVE LATERITIC SOILS

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ABSTRACT

Niger Deltaic lateritic soils are the most widely used materials for road embankment in the entire region, yet, they are less matured and do not conform to the to the widely reported parent-rock-related gradation trend common to other lateritic soils as indicated the by FMW Specifications (1997) and to achieve the required standards, soils have to be improved before use. The research work evaluated the application of agricultural waste materials of plantain rachis fibre, hybridized with cement and lime and to modify the engineering properties of expansive lateritic soils. The soils engineering properties are classified as shown in table 3.1. Descriptive Statistical comparison of the soils are maximum dry density (MDD) and optimum moisture content (OMC) test results are Ogbogoro, 1.030% and 1.020%, Egbeda 1.032% and 1.033%, Igwurut 1.025% and 1.022%, Aleto ,1.083% and 1.026% correspondingly of MDD and OMC. California bearing ratio (CBR) test results of unsoaked are 5.011%, 4.942%, 3.930%, 4.191% and soaked, 5.372%, 4.538%, 5.352%, 4.268%, for Ogbogoro, Egbeda, Igwuruta and Aleto respectively at 100% clay matural conditions. Unconfined compressive strength test of sampled roads are Ogbogoro 1.577%, Egbeda 1.612%, Igwuruta 1.339% and Aleto 1.474% respectively at 100% natural state. Results of consistency limits (Plastic index) test results from Ogbogoro 0.985%, Egbeda 0.980%, Igwuruta 0.981% and Aleto 0.979% at preliminary test 100% soils. Comparative strength of un-stabilized and stabilized soils with composite materials shown in tables 3.2 – 3.16 and figures 3.1 – 3.5, compaction test results obtained showed that maximum dry density (MDD) and optimum moisture content (OMC) of stabilized clay soils of sampled roads demonstrated incremental percentile values with inclusion of composite stabilizers agents to soils with varying percentages ratio. Computed results of California bearing ratio (CBR) of unsoaked and soaked soils stabilized with stabilizing agents of cement, lime and PRF showed percentile value rise to corresponding additivies to relatively to optimum mix ratio of 91.75+0.75+7.5%. Crack formation noticed beyond optimum with values reductions maximum ration of combinations. Unconfined compressive strength test results of stabilized soils with cementitious agents of cement / lime + PRF showed incremental percentile values as ratio of additives to soil increases. Consistency test results decreased in percentile values of (Plastic index) with increase in stabilizer agents percentages to soils ratio. Combined composite materials are good soil stabilizers for the manipulation and modification of expansive problematic soils. Comparatively as shown in the discussions, cement composite samples showed higher percentile rise to lime.

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

1.0 Introduction

Stabilization of soil with chemical additives is a common method of reducing the swelling and shrinkage tendencies of the soil and also makes the soil less plastic (Ola, [1]; Balogun, [2]; Osinubi, [3]; [4]). Cement and lime are the most effective in reducing the swelling properties of these soils (Osinubi *et al.*, [5]). The properties possessed by the soils will determine their degree of reactivity with lime and other additives, and the ultimate strength that the stabilized layers will develop. Lime has a number of effects when added into soil which can be generally categorized as soil drying, soil modification, and soil stabilization (Bhuyan, [5]).

Charles *et al.* [6] 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 road. 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.* [7] 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.

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.

Rao *et al.*, [9] studied the effects of RHA, lime and gypsum on engineering properties of expansive soil and found that UCS increased by 548 % at 28 days of curing and CBR increased by 1350 % at 14 days curing at RHA- 20%, lime -5 % and gypsum -3%.

Edeh *et al.* [10] studied the evaluation of the characteristics of lateritic soil (LS) stabilized with sawdust ash (SDA), subjected to British standard light (BSL) compactive effort to determine their index, compaction, unconfined compressive

strength (UCS), and California Bearing Ratio (CBR) results. The results of the laboratory tests show that the properties of LS improved when stabilized with SDA.

2.0 Materials and Methods

2.1 Materials

2.1.1 Soil

The soils used for the study were collected from Ogbogoro Town Rd, in Obio/Akpor Local Government, Egbeda Town Rd, in Emuoha Local Government Area, Igwuruta Town Rd, in Ikwerre Local Government Area and Aleto Town Rd, in Eleme 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 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 Rd, 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 Ogbogoro Town, (latitude 4.81° 33‘S and longitude 6.92° 18‘E), Egbeda a Town, (latitude 5.14° 15‘N and longitude 6.45° 23‘E), Igwuruta Town, latitude 4.97° 93‘N and longitude 6.99° 80‘E), and Aleto Town, latitude 4.81° 32‘S and longitude 7.09° 28‘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.

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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

his 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-2-6 SC and A-2-4 SM on the AASHTO classification schemes / Unified Soil Classification System as shown in table 3.1, are reddish in colour (from wet to dry states) plasticity index of 17.11%, 22.5%, 14.10%, and 18.51% respectively for Ogbogoro, Egbeda, Igwuruta and Aleto Town Roads. The soil has unsoaked CBR values of 9.25%, 9.48%, 7.85% and 8.65 %, and soaked CBR values of 7.40%, 8.05%, 6.65% and 6.65 %, unconfined compressive strength (UCS) values of 168kPa, 178kPa, 163kPa and 175kPa.

3.1 Compaction Test Results

Obtained percentile results from tables 3.2 and 3.3 to 3.2A and 3.3A of maximum dry density (MDD) and optimum moisture content (OMC) test are Ogbogoro, 1.030% and 1.020%, Egbeda 1.032% and 1.033%, Igwurut 1.025% and 1.022%, Aleto ,1.083% and 1.026% correspondingly of MDD and OMC. Results of stabilized clay soil results with composites materials are Ogbogoro laterite + Cement + PRF MDD, 5.951%, 12.618%, 11.934%, 12.618%, laterite + lime + PRF, 4.285%, 5.538% ,9.128%, 11.749%, OMC are laterite + Cement + PRF, 4.000%, 6.021%, 8.714%, 10.734%, laterite + lime + PRF, 5.710%, 8.336%, 10.087%, 13.589%. Egbeda MDD are laterite + cement + PRF, 5.035%,7.956%, 8.965%, 14.275%, laterite + lime + PRF 1.059%, 2.918% , 5.414%, 8.069%, OMC are laterite +

cement + PRF, 4.396%, 6.202%, 8.910%, 11.202%, laterite + cement + PRF, 3.852%, 5.588%, 7.671%, 11.282%. Igwuruta MDD are laterite + cement + PRF, 5.897%, 7.093%, 9.768%, 13.843%laterite + lime + PRF, 4.421%, 5.772%, 8.475%, 11.749% , OMC are laterite + cement + PRF, 5.107%, 8.158%, 9.815%, 11.739%, laterite + cement + PRF6.268%, 8.058%,11.042%, 14.159%. Aleto are MDD laterite + cement + PRF, 6.334%, 9.069%, 11.321%, 17.594%, laterite + lime + PRF, 3.192%, 5.873%, 8.125%, 18.634% , OMC are laterite + cement + PRF 6.499%, 8.056%, 9.614%, 11.359%, laterite + lime + PRF, 5.773%, 8.328%, 10.259%,12.191%. Figures 3.1 and 3.2 enumerated graphical representation of the behavioral characteristics of composite materials inclusions to lateritic soils with both cementitious agents with percentile increase. Summarized compaction test results obtained showed that maximum dry density (MDD) and optimum moisture content (OMC) of stabilized lateritic soils of sampled roads demonstrated incremental percentile values with inclusion of composite stabilizers agents to soils with varying percentages ratio, cement samples exhibited higher percentile minimal values over lime.

3.2 California Bearing Ratio (CBR) Test

California bearing ratio (CBR) test results from table 3.8, derived to 3.3A showed the percentile values of unsoaked as 5.011%, 4.942%, 3.930%, 4.191% and soaked, 5.372%, 4.538%, 5.352%, 4.268%, for Ogbogoro, Egbeda, Igwuruta and Aleto respectively at 100% laterite natural conditions. Stabilized unsoaked laterite + cement + PRF of Ogbogoro are 481.124%, 589.232%, 827.070%, 669.773%, laterite + lime + PRF; 389.903%, 520.173%, 759.092%, 638.011%, soaked laterite + cement + PRFA 518.546%, 648.681%, 925.303%, 770.167%, laterite + lime + PRF, 432.172%, 617.172%, 875.280%,751.631%. Egbeda stabilized unsoaked laterite + cement + PRF are 473.964%, 600.546%, 857.402%, 799.913%, laterite + lime + PRF, 361.862%, 531.694%, 790.238%, 710.491%, soaked laterite + cement + PRF, 516.469%, 650.258%, 917.463%, 830.134%, laterite + lime + PRF, 363.101%, 578.629%, 903.474%, 750.058%, 19.902%. Igwuruta unsoaked laterite + cement + PRF are 367.548%, 528.057%, 774.554%, 685.382%laterite + lime + PRF, 161.909%, 265.114%, 449.088%, 368.319%, soaked laterite + cement + PRF, 215.624%, 315.624%, 425.346%, 359.374%, laterite + lime + PRF, 179.224%, 264.363%, 463.668%, 383.807%. Aleto unsoaked laterite + cement + PRF are 395.213%, 540.878%, 783.652%, 627.814%, laterite + lime + PRF are 364.667% , 481.083%, 626.170%, 536.574%,soaked laterite + cement + PRF431.789%, 588.355%, 885.180%, 719.668%, laterite + lime + PRF 376.226%, 527.741%,721.825%,583.297%.Igwuruta unsoaked laterite + cement + PRF are 403.335%, 572.057%, 837.470%, 763.034% ,laterite + lime + PRF, 403.335%, 572.057%, 837.470%, 763.034%, soaked laterite + cement + PRF, 289.575%, 462.808%, 770.327%, 628.372% laterite + lime + PRF, 289.575%, 462.808%, 770.327%, 628.372%. Figure 3.3 represented graphically the incremental and decreased in the behavior of unstabilized and stabilized strength variance of both cementitious stabilizing agents with maximum in cement to lime, both showed good incremental attributes. Computed percentile results of California bearing ratio (CBR) of unsoaked and soaked soils stabilized with stabilizing agents of cement, lime and PRF showed percentile value rise to corresponding additives relatively to optimum mix ratio of 91.75+0.75+7.5%. Crack formation was noticed beyond optimum with values reductions maximum ration of combinations.

3.3 Unconfined Compressive Strength Test

Derived percentile values from tables 3.8 to 3.8A of unconfined compressive strength test results from sampled roads are Ogbogoro 1.577%, Egbeda 1.612%, Igwuruta 1.339% and Aleto 1.474% respectively at 100% natural state. Stabilized composite materials cnconfined compressive strength of Ogbogoro laterite + cement + PRF are 94.342%, 136.009%,

183.628%, 237.199%, laterite + lime + PRF, 75.507%, 118.959%, 171.936%, 219.555%, Egbeda laterite + cement + PRF are 99.215%, 122.249%, 172.811%, 234.608%, laterite + lime + PRF, 79.599%, 107.599%, 146.456%, 211.028%, Igwuruta laterite + cement + PRF are 59.262%, 104.500%, 160.452%, 184.857%, laterite + lime + PRF, 33.009%,71.699%, 116.937%, 175.271%. Aleto laterite + cement + PRF are 79.599%, 107.599%, 146.456%, 211.028%, laterite + lime + PRF 45.234%, 81.806%, 123.520%, 185.806%. Unconfined compressive strength test results of stabilized soils with cementitious agents of cement / lime + PRF showed incremental percentile values as ratio of additives to soil increases. Figure 3.7 presented the graph of various percentile rise with respect to percentages of composite inclusion to soil with both cement and lime strength performance.

3.4 Consistency Limits Test

Computed results from tables 3.5, 3.6, 3.7, derived percentile to 3.5A, 3.6A and summarized to 3.7A of consistency limits (Plastic index) test results are Ogbogoro 0.985%, Egbeda 0.980%, Igwuruta 0.981% and Aleto 0.979% at preliminary test 100% soils. Stabilized Ogbogoro laterite + cement + PRF are -3.063%, -5.985%, -8.615%, -11.245%, laterite + lime + PRF -2.115%, -5.914%, -6.148%,-7.668%, Egbeda laterite + cement + PRF -3.588%, -4.832%, -6.921%, -8.921%, laterite + lime + PRF -4.041%, -5.019%, -6.663%, -8.574%, Igwuruta laterite + cement + PRF laterite + cement + PRF -4.157%, -5.859%, -8.270%, -10.752%, laterite + lime + PRF -3.867%, -7.271%, -10.108%, -12.236%, Aleto laterite + cement + PRF -4.149%, -5.662%, -8.525%, -10.578%, laterite + lime + PRF -4.039%, -6.146%, -8.847%, -11.008%. Consistency test results decreased in percentile values of (Plastic index) with increase in stabilizer agents percentages to soils ratio. Figures 3.4, 3.5 and 3.6 explained the behavior of consistency parameters at different composite materials to soil inclusions.

Table 3.1: Engineering Properties of Soil Samples

Location Description	Ogobogoro Road Obio/Akpor L.G.A	Egbeda Road Emuoha L.G.A	Igwuruta Road Ikwere L.G.A	Aleto Road Eleme L.G.A
Depth of sampling (m)	1.5	1.5	1.5	1.5
(%) passing BS sieve #200	38.35	42.15	36.35	39.40
Colour	Reddish	Reddish	Reddish	Reddish
Specific gravity	2.59	2.78	2.77	15.35
Natural moisture content (%)	22.6	19.48	10.95	15.35
Consistency				
Liquid limit (%)	38.46	42.35	35.15	38.65
Plastic limit (%)	21.35	19.85	21.05	20.14
Plasticity Index	17.11	22.50	14.1 0	18.51
AASHTO soil classification Unified Soil Classification System	A-2-4/SM	A-2-4/SM	A-2-4/SC	A-2-4/SC
Optimum moisture content (%)	14.85	14.40	15.08	16.05
Maximum dry density (kN/m$^{3)}$	1.755	1.883	1.924	1.865
Gravel (%)	3.25	2.85	3.83	2.35
Sand (%)	38.65	36.50	32.58	39.45

Silt (%)	23.85	38.75	33.45	37.85
Clay (%)	34.25	22.90	30.14	20.35
Unconfined compressive strength (kPa)	168	178	163	175
California Bearing Capacity (CBR)				
Unsoaked (%) CBR	9.25	9.48	7.85	8.65
Soaked (%) CBR	7.40	8.05	6.65	6.93

Table 3.2: Results of Maximum Dry Density (MDD) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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 (Laterite + Cement + PRF) Ogbogoro Town Road	1.76	1.81	1.93	1.97	2.02
MDD (kN/m3) (Laterite + Lime + PRF)OgbogoroTown Road	1.76	1.79	1.82	1.88	1.92
MDD (Laterite + Cement + PRF) Aleto Town Road	1.87	1.93	1.98	2.12	2.34
MDD (kN/m3) (Laterite + Lime + PRF)AletoTown Road	1.87	1.90	1.95	1.99	2.18
MDD (Laterite + Cement + PRF) Egbeda Town Road	1.88	1.93	1.99	2.21	2.31
MDD (kN/m3) (Laterite + Lime + PRF)EgbedaTown Road	1.88	1.89	1.93	1.98	2.03
MDD (Laterite + Cement + PRF) Igwuruta Town Road	1.92	2.08	2.23	2.45	2.49
MDD (kN/m3) (Laterite + Lime + PRF)IgwurutaTown Road	1.92	1.97	2.04	2.25	2.37

Table 3.2A: Results of Maximum Dry Density (MDD) Percentile Increase of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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 (Laterite + Cement + PRF) Ogbogoro Town Road	1.03%	5.95%	12.62%	15.35%	17.75%
MDD (kN/m3) (Laterite + Lime + PRF)OgbogoroTown Road	1.02%	4.28%	5.54%	9.13%	11.75%
MDD (Laterite + Cement + PRF) Aleto Town Road	1.03%	6.33%	9.07%	16.68%	28.32%
MDD (kN/m3) (Laterite + Lime + PRF)AletoTown Road	1.02%	3.19%	5.87%	8.12%	18.63%
MDD (Laterite + Cement + PRF) Egbeda Town Road	1.03%	5.03%	7.96%	19.59%	24.90%
MDD (kN/m3) (Laterite + Lime + PRF)EgbedaTown Road	1.01%	1.06%	2.92%	5.41%	8.07%
MDD (Laterite + Cement + PRF) Igwuruta Town Road	1.08%	15.90%	23.33%	34.97%	36.84%
MDD (kN/m3) (Laterite + Lime + PRF)IgwurutaTown Road	1.02%	4.42%	7.96%	18.87%	25.26%

Table 3.3: Results of Optimum Moisture Content (OMC) of Niger Deltaic Lateritic Soils Subgrade with PRFA + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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%
OMC%(Laterite + Cement + PRF) OgbogoroTown Road	14.85	15.15	15.45	15.85	16.15
OMC%(Laterite + Lime + PRF) OgbogoroTown Road	14.85	15.28	15.67	15.93	16.45
OMC%(Laterite + Cement + PRF) AletoTown Road	16.05	16.58	16.83	17.08	17.36
OMC%(Laterite + Lime + PRF) AletoTown Road	16.05	16.52	16.93	17.24	17.55
OMC%(Laterite + Cement + PRF) EgbedaTown Road	14.40	14.72	14.98	15.37	15.70
OMC%(Laterite + Lime + PRF) EgbedaTown Road	14.40	14.68	14.93	15.23	15.75
OMC%(Laterite + Cement + PRF) IgwurutaTown Road	15.08	15.47	15.93	16.18	16.47
OMC%(Laterite + Lime + PRF) IgwurutaTown Road	15.08	15.56	15.83	16.28	16.75

Table 3.3A: Results of Optimum Moisture Content (OMC) Percentile Increase of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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%
OMC%(Laterite + Cement + PRF) OgbogoroTown Road	1.02%	4.00%	6.02%	8.71%	10.73%
OMC%(Laterite + Lime + PRF) OgbogoroTown Road	1.03%	5.71%	8.34%	10.09%	13.59%
OMC%(Laterite + Cement + PRF) AletoTown Road	1.03%	6.50%	8.06%	9.61%	11.36%
OMC%(Laterite + Lime + PRF) AletoTown Road	1.03%	5.77%	8.33%	10.26%	12.19%
OMC%(Laterite + Cement + PRF) EgbedaTown Road	1.02%	4.40%	6.20%	8.91%	11.20%
OMC%(Laterite + Lime + PRF) EgbedaTown Road	1.02%	3.85%	5.59%	7.67%	11.28%
OMC%(Laterite + Cement + PRF) IgwurutaTown Road	1.03%	5.11%	8.16%	9.82%	11.74%
OMC%(Laterite + Lime + PRF) IgwurutaTown Road	1.03%	6.27%	8.06%	11.04%	14.16%

Table 3.4: Results of California Bearing Ratio (CBR) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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 (Laterite + Cement + PRF) OgbogoroTown Road	9.25	46.35	56.35	78.35	63.80
UNSOAKED CBR (Laterite + Lime + PRF) OgbogoroTown Road	9.25	38.30	50.35	72.45	61.25
SOAKED CBR (Laterite + Cement + PRF) OgbogoroTown Road	7.40	39.75	49.38	69.85	58.37
SOAKED CBR (Laterite + Lime + PRF) OgbogoroTown Road	7.40	33.61	47.30	66.40	57.25
UNSOAKED CBR (Laterite + Cement + PRF) AletoTown Road	8.65	36.25	48.85	69.85	56.37
UNSOAKED CBR (Laterite + Lime + PRF) AletoTown Road	8.65	33.76	43.83	56.38	48.63
SOAKED CBR (Laterite + Cement + PRF) AletoTown Road	6.93	31.45	42.30	62.87	51.40
SOAKED CBR (Laterite + Lime + PRF) AletoTown Road	6.93	27.80	38.30	51.75	42.15
UNSOAKED CBR (Laterite + Cement + PRF) EgbedaTown Road	9.48	46.85	58.85	83.20	77.75
UNSOAKED CBR (Laterite + Lime + PRF) EgbedaTown Road	9.48	36.75	52.85	77.36	69.80

SOAKED CBR (Laterite + Cement + PRF) EgbedaTown Road	8.05	43.08	53.85	75.36	68.33
SOAKED CBR (Laterite + Lime + PRF) Egbeda Town Road	8.05	31.30	48.65	74.80	62.45
UNSOAKED CBR (Laterite + Cement + PRF) IgwurutaTown Road	7.85	30.85	43.45	62.80	55.80
UNSOAKED CBR (Laterite + Lime + PRF) IgwurutaTown Road	7.85	22.85	39.34	58.35	49.67
SOAKED CBR (Laterite + Cement + PRF) IgwurutaTown Road	6.65	28.38	39.60	57.25	52.30
SOAKED CBR (Laterite + Lime + PRF) IgwurutaTown Road	6.65	21.33	32.85	53.30	43.86

Table 3.4A: Results of California Bearing Ratio (CBR) Percentile Increase of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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 (Laterite + Cement + PRF) Ogbogoro Town Road	5.01%	481.12%	589.23%	827.07%	669.77%
UNSOAKED CBR (Laterite + Lime + PRF) Ogbogoro Town Road	4.14%	389.90%	520.17%	759.09%	638.01%
SOAKED CBR (Laterite + Cement + PRF) Ogbogoro Town Road	5.37%	518.55%	648.68%	925.30%	770.17%
SOAKED CBR (Laterite + Lime + PRF) Ogbogoro Town Road	4.54%	432.17%	617.17%	875.28%	751.63%
UNSOAKED CBR (Laterite + Cement + PRF) AletoTown Road	4.19%	395.21%	540.88%	783.65%	627.81%
UNSOAKED CBR (Laterite + Lime + PRF) Aleto Town Road	3.90%	364.67%	481.08%	626.17%	536.57%
SOAKED CBR (Laterite + Cement + PRF) Aleto Town Road	4.54%	431.79%	588.35%	885.18%	719.67%
SOAKED CBR (Laterite + Lime + PRF) Aleto Town Road	4.01%	376.23%	527.74%	721.83%	583.30%
UNSOAKED CBR (Laterite + Cement + PRF) Egbeda Town Road	4.94%	473.96%	600.55%	857.40%	799.91%
UNSOAKED CBR (Laterite + Lime + PRF) Egbeda Town Road	3.88%	361.86%	531.69%	790.24%	710.49%
SOAKED CBR (Laterite + Cement + PRF) EgbedaTown Road	5.35%	516.47%	650.26%	917.46%	830.13%
SOAKED CBR (Laterite + Lime + PRF) Egbeda Town Road	3.89%	363.10%	578.63%	903.47%	750.06%
UNSOAKED CBR (Laterite + Cement + PRF) IgwurutaTown Road	3.93%	367.55%	528.06%	774.55%	685.38%
UNSOAKED CBR (Laterite + Lime + PRF) Igwuruta Town Road	2.91%	256.73%	466.79%	708.96%	598.38%
SOAKED CBR (Laterite + Cement + PRF) Igwuruta Town Road	4.27%	403.33%	572.06%	837.47%	763.03%
SOAKED CBR (Laterite + Lime + PRF) Igwuruta Town Road	3.21%	289.58%	462.81%	770.33%	628.37%

Table 3.5: Results of Liquid Limits (LL) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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(Laterite + Cement + PRF) OgbogoroTown Road	38.46	38.96	39.75	40.65	41.82
LL (Laterite + Lime + PRF) OgbogoroTown Road	38.46	39.06	39.76	40.86	41.65
LL(Laterite + Cement + PRF) AletoTown Road	38.65	39.85	40.40	40.85	41.62
LL (Laterite + Lime + PRF) AletoTown Road	38.65	38.98	39.58	39.93	40.28
LL(Laterite + Cement + PRF) EgbedaTown Road	42.35	43.75	44.37	44.93	45.35
LL (Laterite + Lime + PRF) EgbedaTown Road	42.35	42.68	43.16	43.65	44.08
LL(Laterite + Cement + PRF) IgwurutaTown Road	35.15	35.62	36.08	36.75	37.18
LL (Laterite + Lime + PRF) IgwurutaTown Road	35.15	35.53	35.89	36.23	36.72

Table 3.5A: Results of Liquid Limits (LL) Percentile Increase of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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(Laterite + Cement + PRF) Ogbogoro Town Road	1.01%	2.58%	4.64%	6.98%	10.02%
LL (Laterite + Lime + PRF) Ogbogoro Town Road	1.02%	3.10%	4.92%	7.78%	9.83%
LL(Laterite + Cement + PRF) Aleto Town Road	1.03%	6.12%	7.54%	8.70%	10.70%
LL (Laterite + Lime + PRF) Aleto Town Road	1.01%	1.70%	3.25%	4.16%	5.06%
LL(Laterite + Cement + PRF) Egbeda Town Road	1.03%	6.51%	7.97%	9.29%	10.28%
LL (Laterite + Lime + PRF) Egbeda Town Road	1.01%	1.55%	2.69%	3.84%	4.86%
LL(Laterite + Cement + PRF) Igwuruta Town Road	1.01%	2.66%	3.97%	5.87%	7.09%
LL (Laterite + Lime + PRF) Igwuruta Town Road	1.01%	2.15%	3.17%	4.14%	5.54%

Table 3.6: Results of Plastic Limits (LL) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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(Laterite + Cement + PRF) Ogbogoro Town Road	21.35	22.11	23.40	24.75	26.37
PL (Laterite + Lime + PRF) Ogbogoro Town Road	21.35	22.13	23.08	24.62	25.67
PL(Laterite + Cement + PRF) Aleto Town Road	20.14	21.72	22.55	23.50	24.68
PL (Laterite + Lime + PRF) Aleto Town Road	20.14	20.84	21.83	22.68	23.43
PL(Laterite + Cement + PRF) Egbeda Town Road	19.85	21.65	22.55	23.58	24.45
PL (Laterite + Lime + PRF) Egbeda Town Road	19.85	20.63	21.33	22.19	23.05
PL(Laterite + Cement + PRF) Igwuruta Town Road	21.05	21.81	22.51	23.52	24.30
PL (Laterite + Lime + PRF) Igwuruta Town Road	21.05	21.70	22.04	23.28	24.07

Table 3.6A: Results of Plastic Limits (LL) Percentile Increase of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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(Laterite + Cement + PRF) OgbogoroTown Road	1.04%	7.00%	13.04%	19.36%	26.95%
PL (Laterite + Lime + PRF) OgbogoroTown Road	1.04%	7.18%	11.63%	18.84%	23.76%
PL(Laterite + Cement + PRF) AletoTown Road	1.08%	15.12%	19.24%	23.96%	29.82%
PL (Laterite + Lime + PRF) AletoTown Road	1.03%	6.83%	11.75%	15.97%	19.69%
PL(Laterite + Cement + PRF) EgbedaTown Road	1.09%	17.38%	21.92%	27.11%	31.49%
PL (Laterite + Lime + PRF) EgbedaTown Road	1.04%	7.71%	11.24%	15.57%	19.90%
PL(Laterite + Cement + PRF) IgwurutaTown Road	1.04%	7.10%	10.42%	15.22%	18.92%
PL (Laterite + Lime + PRF) IgwurutaTown Road	1.03%	6.08%	7.70%	13.59%	17.34%

Table 3.7: Results of Plastic Index (PI) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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 (Laterite + Cement + PRF) Ogbogoro Town Road	17.11	16.85	16.35	15.90	15.45
PI (Laterite + Lime + PRF) Ogbogoro Town Road	17.11	16.93	16.28	16.24	15.98
PI (Laterite + Cement + PRF) Aleto Town Road	18.51	18.13	17.85	17.32	16.94
PI (Laterite + Lime + PRF) Aleto Town Road	18.51	18.14	17.75	17.25	16.85
PI (Laterite + Cement + PRF) Egbeda Town Road	22.50	22.10	21.82	21.35	20.90
PI (Laterite + Lime + PRF) Egbeda Town Road	22.50	22.05	21.83	21.46	21.03
PI (Laterite + Cement + PRF) Igwuruta Town Road	14.10	13.81	13.57	13.23	12.88
PI (Laterite + Lime + PRF) Igwuruta Town Road	14.10	13.83	13.35	12.95	12.65

Table 3.7A: Results of Plastic Limits (LL) Percentile Increase of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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 (Laterite + Cement + PRF) Ogbogoro Town Road	0.98%	-3.06%	-5.98%	-8.61%	-11.24%
PI (Laterite + Lime + PRF) Ogbogoro Town Road	0.99%	-2.12%	-5.91%	-6.15%	-7.67%
PI (Laterite + Cement + PRF) Aleto Town Road	0.98%	-4.15%	-5.66%	-8.52%	-10.58%
PI (Laterite + Lime + PRF) Aleto Town Road	0.98%	-4.04%	-6.15%	-8.85%	-11.01%
PI (Laterite + Cement + PRF) Egbeda Town Road	0.98%	-3.59%	-4.83%	-6.92%	-8.92%
PI (Laterite + Lime + PRF) Egbeda Town Road	0.98%	-4.04%	-5.02%	-6.66%	-8.57%
PI (Laterite + Cement + PRF) Igwuruta Town Road	0.98%	-4.16%	-5.86%	-8.27%	-10.75%
PI (Laterite + Lime + PRF) IgwurutaT own Road	0.98%	-3.87%	-7.27%	-10.11%	-12.24%

Table 3.8: Results of Unconfined Compressive Strength (USC) Test of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers Sta

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 (Laterite + Cement + PRF) Ogbogoro Town Road	168.00	265.00	335.00	415.00	505.00
UCS(Laterite + Lime + PRF) Ogbogoro Town Road	168.00	243.00	316.00	405.00	485.00
UCS (Laterite + Cement + PRF) Aleto Town Road	175.00	258.00	307.00	375.00	488.00
UCS(Laterite + Lime + PRF) Aleto Town Road	175.00	219.00	283.00	356.00	465.00
UCS(Laterite + Cement + PRF) Egbeda Town Road	178.00	287.00	328.00	418.00	528.00
UCS (Laterite + Lime + PRF) Egbeda Town Road	178.00	231.00	305.00	388.00	508.00
UCS (Laterite + Cement + PRF) Igwuruta Town Road	168.00	225.00	301.00	395.00	436.00
UCS(Laterite + Lime + PRF) Igwuruta Town Road	168.00	198.00	263.00	339.00	437.00

Table 3.7: Results of Unconfined Compressive Strength (USC) Test) Percentile Increase of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime at Different Percentages and Combination of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), 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 (Laterite + Cement + PRF) Ogbogoro Town Road	1.58%	94.34%	136.01%	183.63%	237.20%
UCS(Laterite + Lime + PRF) Ogbogoro Town Road	1.45%	75.51%	118.96%	171.94%	219.55%
UCS (Laterite + Cement + PRF) Aleto Town Road	1.47%	79.60%	107.60%	146.46%	211.03%
UCS(Laterite + Lime + PRF) Aleto Town Road	1.25%	45.23%	81.81%	123.52%	185.81%
UCS(Laterite + Cement + PRF) Egbeda Town Road	1.61%	99.22%	122.25%	172.81%	234.61%
UCS (Laterite + Lime + PRF) Egbeda Town Road	1.30%	52.72%	94.29%	140.92%	208.34%
UCS (Laterite + Cement + PRF) Igwuruta Town Road	1.34%	59.26%	104.50%	160.45%	184.86%
UCS(Laterite + Lime + PRF) Igwuruta Town Road	1.18%	33.01%	71.70%	116.94%	175.27%

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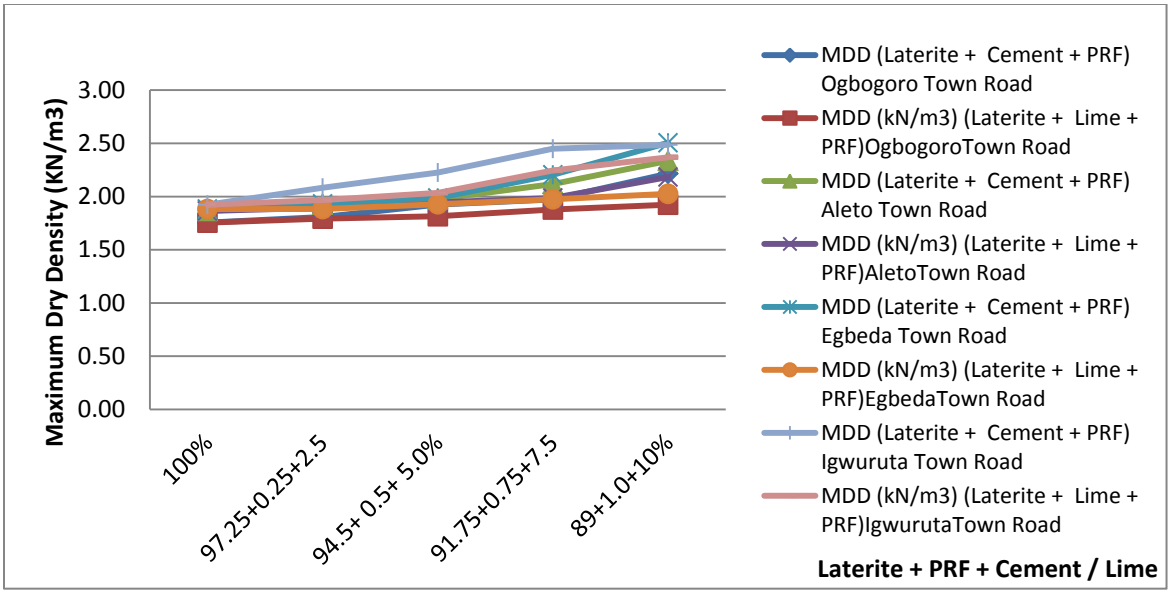

Figure 3.1: Maximum Dry Density (MDD) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers State

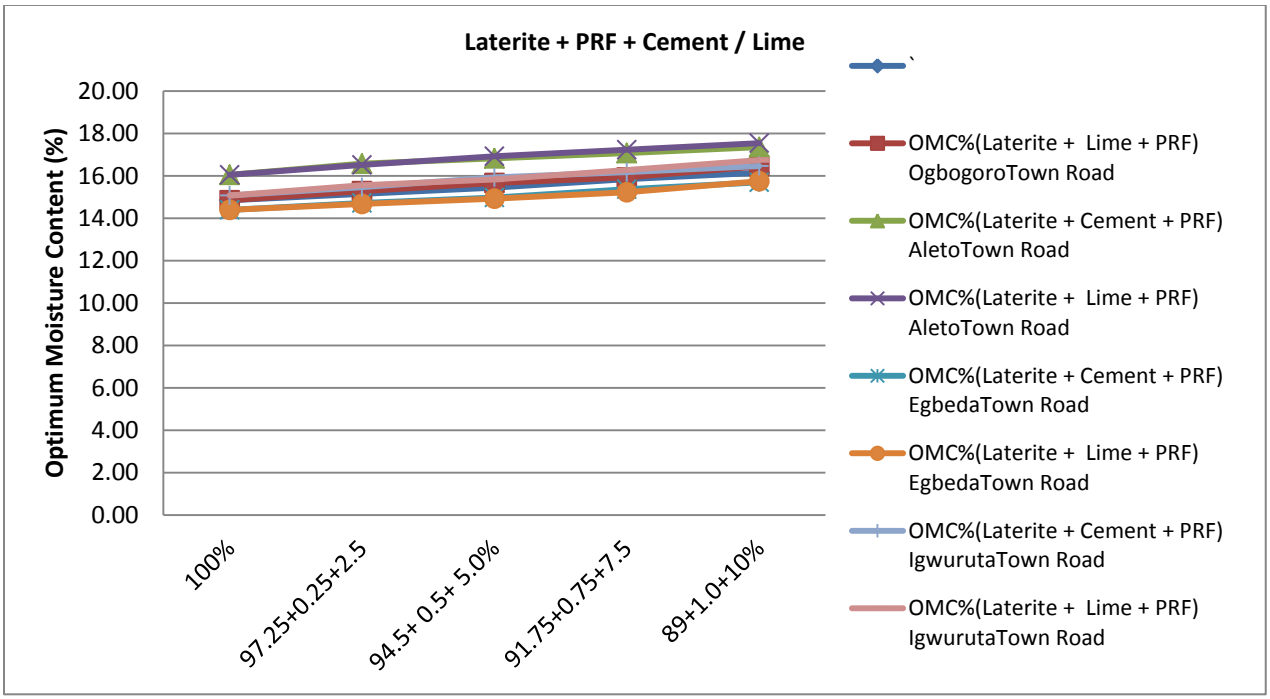

Figure 3.2: Optimum Moisture Content (OM) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers State

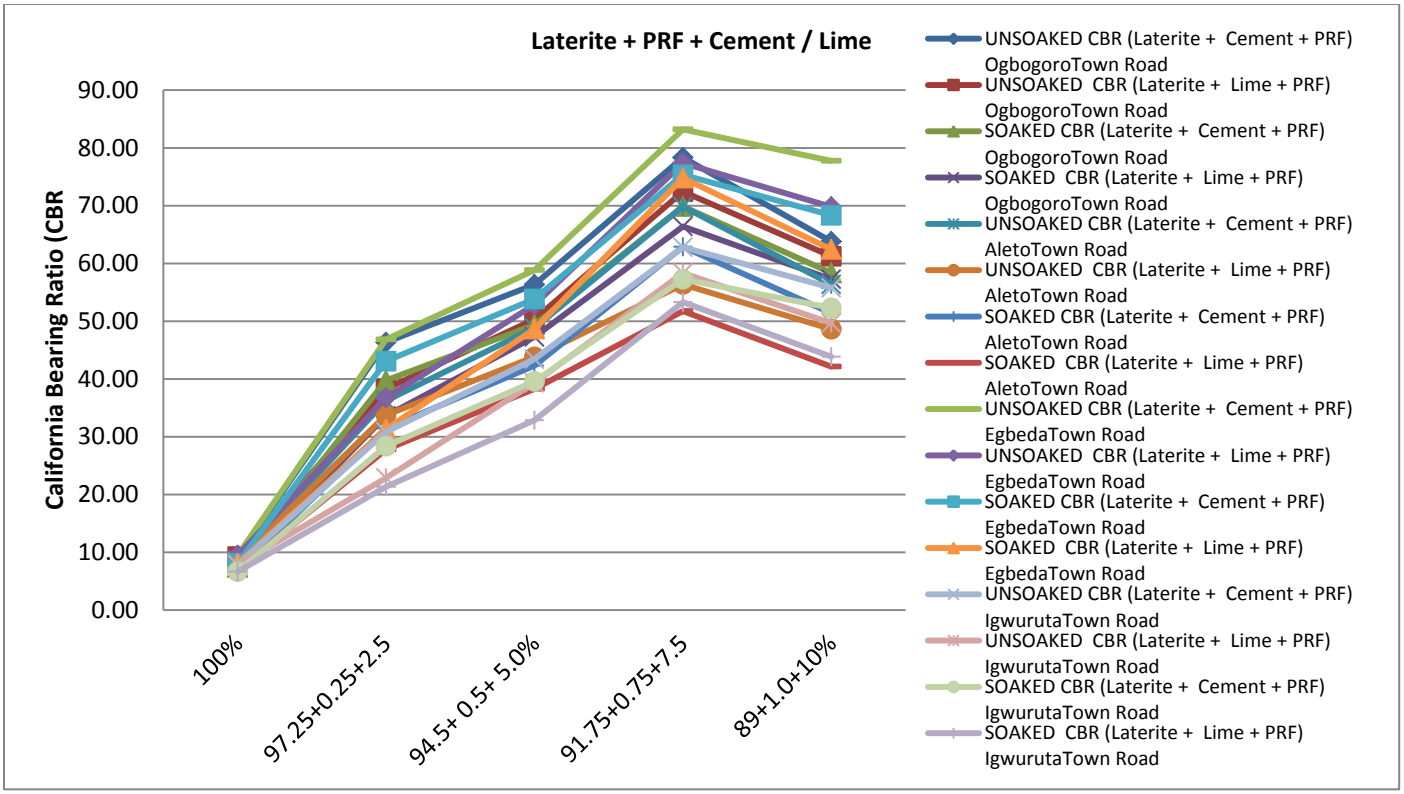

Figure 3.3: California Bearing Ratio (CBR) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers State

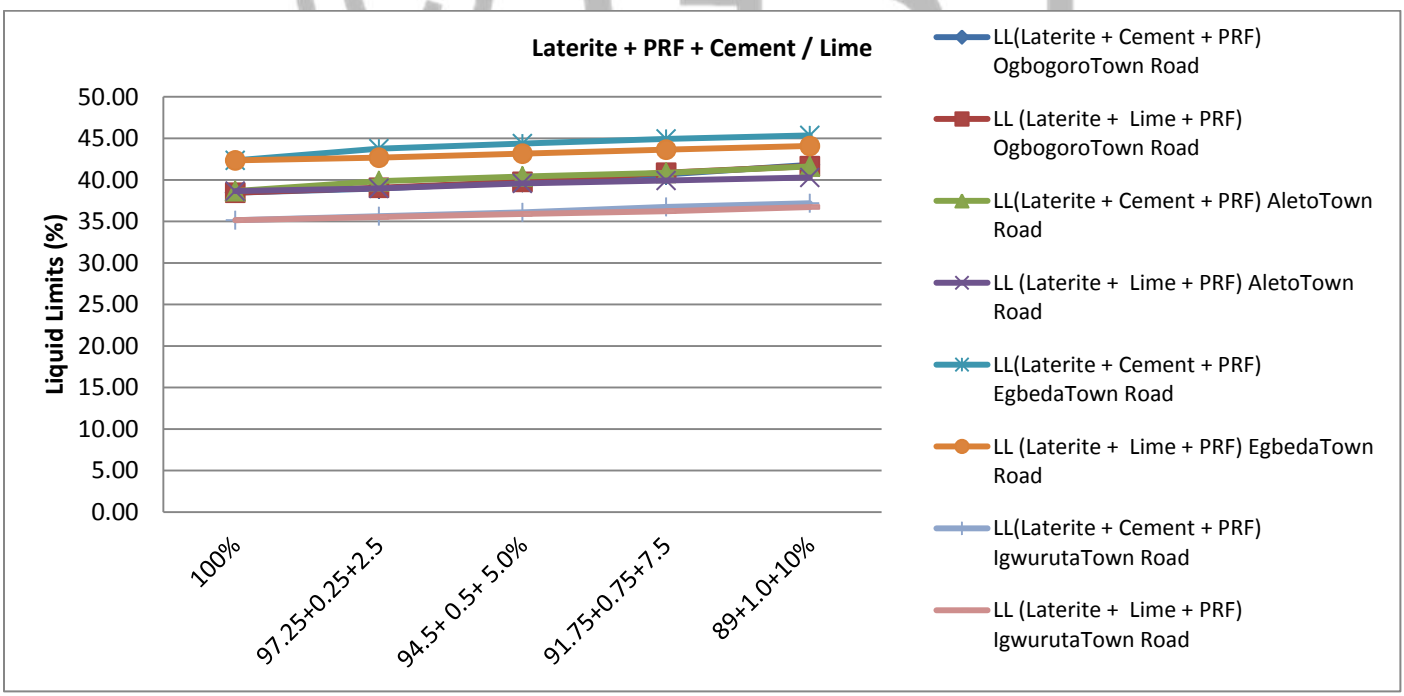

Figure 3.4: Liquid Limit (LL) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers State

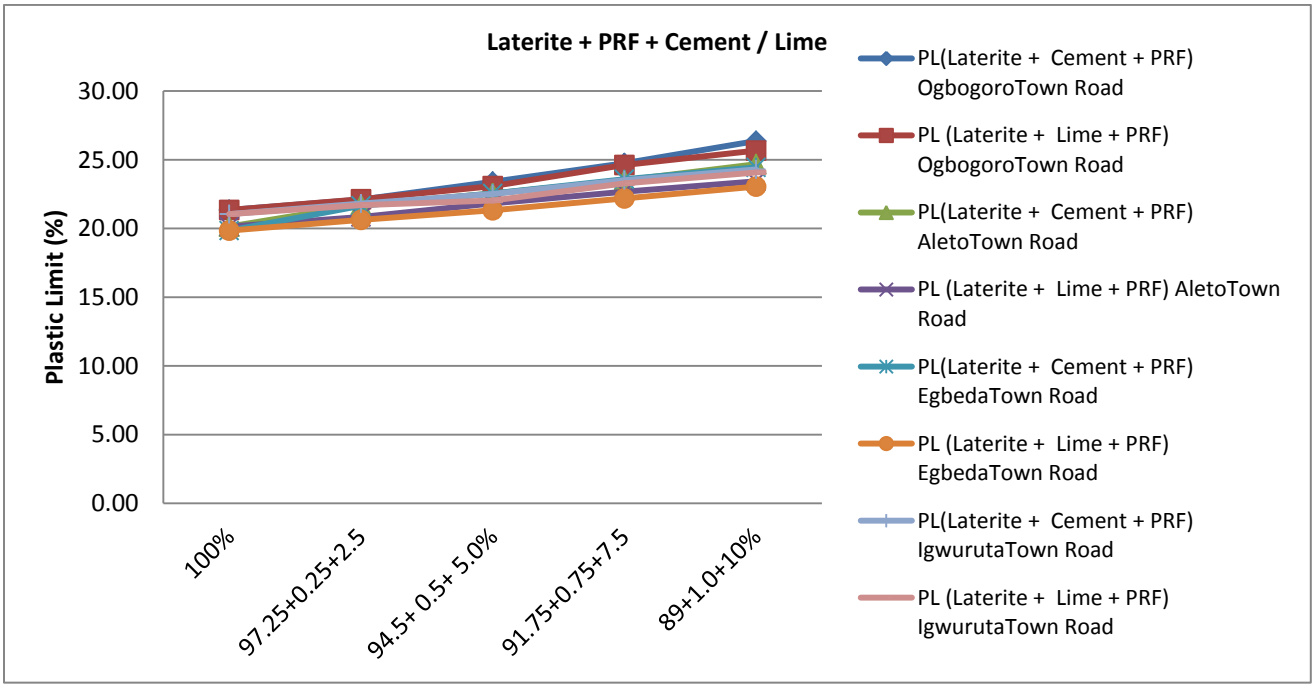

Figure 3.5: Plastic Limit (PL) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers State

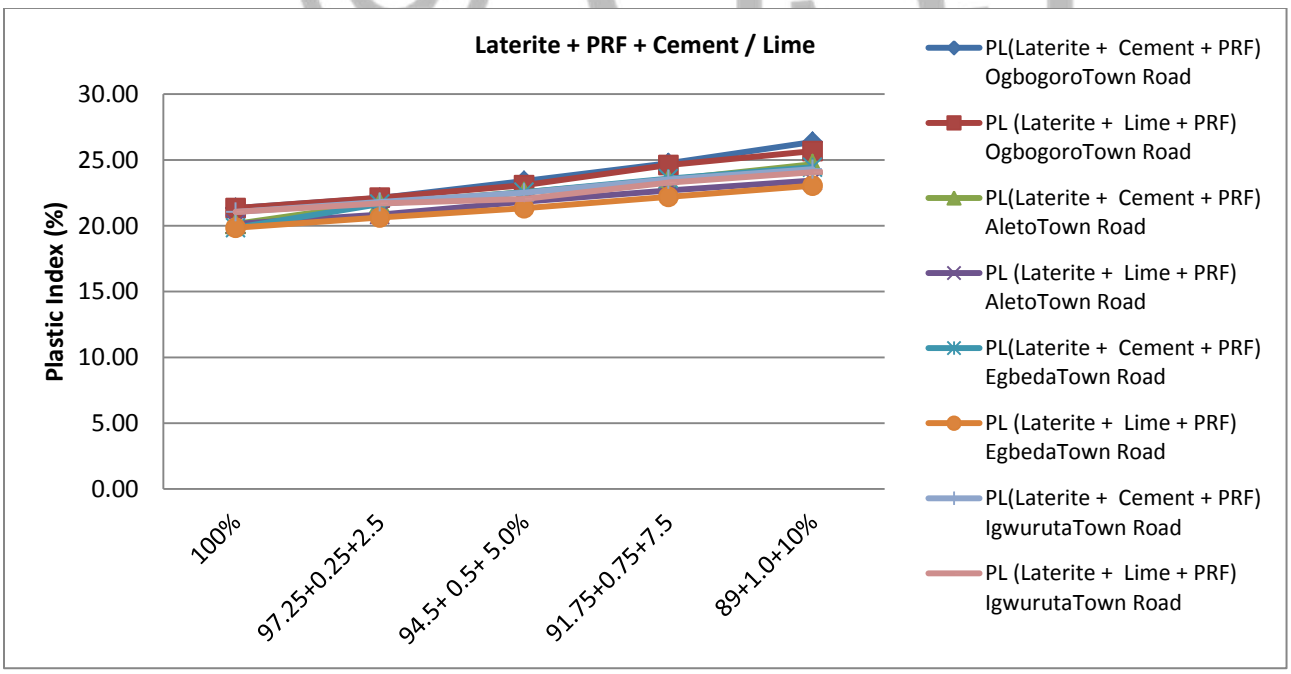

Figure 3.6: Plastic Index (PI) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers State

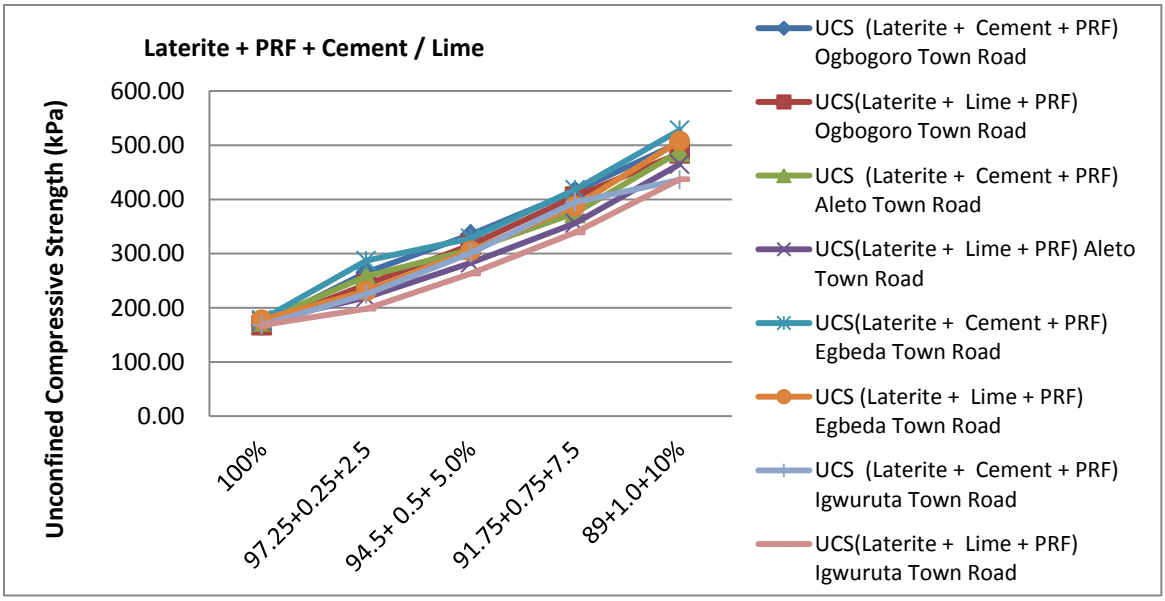

Figure 3.7: Unconfined Compressive Strength (UCS) of Niger Deltaic Lateritic Soils Subgrade with PRF + Cement / Lime of (Ogbogoro, Aleto, Egbeda and Igwuruta Towns), Rivers State

4.0 Conclusions

The following conclusions were made from the experimental research results.

i. The soils engineering properties are classified as shown in table 3.1. DescrPItive Statistical comparison of the soils are maximum dry density (MDD) and optimum moisture content (OMC) test results are Ogbogoro, 1.030% and 1.020%, Egbeda 1.032% and 1.033%, Igwurut 1.025% and 1.022%, Aleto ,1.083% and 1.026% correspondingly of MDD and OMC

ii. California bearing ratio (CBR) test results of unsoaked are 5.011%, 4.942%, 3.930%, 4.191% and soaked, 5.372%, 4.538%, 5.352%, 4.268%, for Ogbogoro, Egbeda, Igwuruta and Aleto respectively at 100% clay matural conditions.

iii. Unconfined compressive strength test of sampled roads are Ogbogoro 1.577%, Egbeda 1.612%, Igwuruta 1.339% and Aleto 1.474% respectively at 100% natural state. Results of consistency limits (Plastic index) test results from Ogbogoro 0.985%, Egbeda 0.980%, Igwuruta 0.981% and Aleto 0.979% at preliminary test 100% soils

iv. Comparative strength of un-stabilized and stabilized soils with composite materials shown in tables 3.2 – 3.16 and figures 3.1 – 3.5, compaction test results obtained showed that maximum dry density (MDD) and optimum moisture content (OMC) of stabilized clay soils of sampled roads demonstrated incremental percentile values with inclusion of composite stabilizers agents to soils with varying percentages ratio.

v. Computed results of California bearing ratio (CBR) of unsoaked and soaked soils stabilized with stabilizing agents of cement, lime and PRF showed percentile value rise to corresponding additives to relatively to optimum mix ratio of 91.75+0.75+7.5%.

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