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EVALUATION OF CEMENT, LIME AND BAGASSE FIBRE ASH WASTE ADMIXTURE ON SWELL – SHRINK CONTROL OF ROAD EMBANKMENT MATERIALS

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ABSTRACT

The study evaluated the strength gained distinction of expansive clay soils with swelling – shrinkage attributes on the application of two cementitious stabilizing agents of cement and lime in combination with bagasse fibre ash of pozzolanic characteristics from waste agricultural products of costaceae lacerus. Preliminary investigation results factioned the soils as A - 7 - 6 on the AASHTO classification System as shown in table 3.1 and are below required laid standards and specifications for road embankment materials. The soil has unsoaked CBR values of 8.58%,8.83%, 8.05%, 7.38%, and 9.05% and soaked CBR values of 6.33%, 7.15%, 7.35%, 5.9% and 8.23%, unconfined compressive strength values of 58.85kPa, 63.35kPa, 57.75kPa, 53.75kPa and 63.85kPa and percentage paasing # 200 are 73.85%, 67.38%, 76.35%, 82.35% and 71.55% respectively of sampled roads of Ogoda, Bodo, Ogbogu, Ula-Ikata and Kaani, all in Rivers state, Nigeria. Detailed analyzed compaction test results of maximum dry density (MDD) and optimum moisture content (OMC) of all sampled roads showed incremental percentile values with inclusion of composite materials of cement / lime + CLBFA with respect to percentage ratio increase. Percentile values increased recorded more in cement to lime composition. Figures 3.2 and 3,3 showed graphical presentation with higher values in cement. Results demonstrated an incremental percentile CBR values for both unsoaked and soaked with optimum composite combined mix ratio of 0.75% + 7.5% to soil corresponding clay soil. Comparative results showed cement and lime + CLBFA good strength increased to optimum with dominance in cement to lime. Unconfined compressive strength test results obtained showed incremental percentile values with composite ratio increase for cement / lime + CLBFA combination with cement in higher values to lime composition. 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 showed graphical representation of consistency limits with cement composition in dominance reduction over lime.

Key Words: Clay soils, Costaceae Lacerus Bagasse Fibre Ash, Cement, Lime, CBR, UCS, Consistency, Compaction

1.0 Introduction

Natural soil underlying the Niger delta roads are mainly clay and silt soils of poor quality that has resulted to possible severe damaged of structures due to differential settlements of foundation, pavement embankments and retaining structures. Modification and stabilization of these soils with lime, cement, bentonite, fly-ash, bitumen, fibre or combinations of these has been one of the effective methods to improve the engineering properties of soils to meet the desired strength. Soil stabilization is aimed at the enhancement of the engineering properties of deficient soils to enable them perform and sustain their intended engineering use (Yoder and Witczak, [1]; Gillott, [2]; Osinubi, [3]; Nicholas and Lester, [4] Sherwood, [5]). Studies have shown that solid minerals and agricultural wastes could be used for the stabilization of lateritic soils (Fakiyesi and Osinubi, [6]; Osinubi, [7]). Their admixtures with lime or cement or both have also been considered in improving theengineering properties of expansive soils (Osinubi and Toro, [8]; Osinubi and Medubi, [9] [10]).

Charles *et al.* [11] 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.* [12] evaluated the geotechnical properties of an expansive clay soil found along Odioku – Odiereke road 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.* [13] 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.

2.0 Materials and Methods

2.1 Materials

2.1.1 Soil

The soils used for the study were collected from Ogoda Town Road, Ubie, Districts of Ekpeye, Ahoada-East and Ahoada-West Local Government Area, Bodo Town Road, Gokana Local Government Area, Ogbogu Town Road, Egbema/Ndoni/Egbema local Government Area, Ula-Ikata Town Road, Ahoada-East Local Government area, and Kaani Town Road, Khana Local Government Area, all of Rivers State, Niger Delta, Nigeria.

2.1.2 Costaceae Lacerus Bagasse Fibre Ash

The Costaceae Lacerus bagasse fibre are wide plants, medicinally used in the local areas, abundant in Rivers State farmlands / bushes, they covers larger areas, collected from at Oyigba Town Farmland / Bush, Ubie Clan, Ahoada-West, Rivers State, Nigeria.

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 Ogoda Town, (latitude 5.04° 59‘S and longitude 6.38° 42‘E), Bodo Town, (latitude 4.65° 05‘S and longitude 7.27° 15‘E), Ogbogu Town, latitude 5.13° 08‘S and longitude 6.33° 25‘E), U[a-Ikata Town, (latitude 5.95° 45‘S and longitude 6.66° 13‘E) and kaani Town, latitude 4.67° 13‘S and longitude 6.81° 55‘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, Califonia 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)

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

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 on the AASHTO 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 soil has unsoaked CBR values of 8.58%,8.83%, 8.05%, 7.38%, and 9.05% and soaked CBR values of 6.33%, 7.15%, 7.35%, 5.9% and 8.23%, unconfined compressive strength values of 58.85kPa, 63.35kPa, 57.75kPa, 53.75kPa and 63.85kPa when compacted with British Standard light.

3.1 Compaction Test Results

Compaction test results of maximum dry density (MDD) and Optimum moisture content (OMC) of sampled roads at 100% clay soil Ogoda derived percentile value from tables 3.2, 3.3 to tables 3.2A and 3.3A are 1.032% and 1.018%, stabilized Clay + Cement + CLBFA MDD are 6.258%, 7.025%, 8.066%, 9.272% and clay + lime + CLBFA; 2.965%,4.671%, 5.471%, 6.805% and Clay + Cement + CLBFA OMC are 3.665%, 4.813%, 7.364%, 9.405% and clay + lime + CLBFA 2.661%, 4.893%, 8.337%, 11.972%. Bodo samples at 100%, are 1.012% and 1.021%, stabilized clay + cement + CLBFA MDD are 2.378%, 3.886%, 5.030%, 10.646% and clay + lime + CLBFA 2.583%, 3.519%, 4.507%, 4.768%, OMC clay + cement + CLBFA, 4.242%, 7.189%, 8.796%, 10.270%, Clay + lime + CLBFA, 5.288%, 7.633%, 9.642%, 11.651%. Ogbogu soil at 100% are 1.013% and 1.018%, stabilized clay + cement + CLBFA MDD are 2.508%, 4.098%, 5.305%, 7.390% and clay + lime + CLBFA 2.399%, 3.716%, 5.087%, 6.404%, clay + cement + CLBFA OMC are 3.527%, 5.000%, 6.349%, 8.374% and clay + lime + CLBFA; 5.328%, 7.414%, 10.543%, 12.322%. Ula – Ikata at

100% are 1.017% and 1.021%, stabilized clay + cement + CLBFA MDD are 3.317%, 5.602%, 6.717%, 8.111% and Clay + lime + CLBFA are 2.658%, 3.661%, 6.002%, 8.622% and OMC 4.197%, 6.088%, 8.208%, 9.985%, clay + lime + CLBFA, 3.409%, 4.384%, 6.160%, 8.510%. Kaani at 100% are 1.007% and 1.023%, stabilized clay + cement + CLBFA MDD are 1.306%, 7.452%, 10.960%, 11.734% and clay + lime + CLBFA 1.204%, 6.427%, 8.724%, 11.433%, clay + cement + CLBFA OMC are 4.509%, 6.203%, 7.246%, 9.526% and clay + lime + CLBFA, 3.871%, 6.021%, 7.976%, 11.689%. Detailed analyzed compaction test results of maximum dry density (MDD) and optimum moisture content (OMC) of all sampled roads showed incremental percentile values with inclusion of composite materials of cement / lime + CLBFA with respect to percentage ratio increase. Percentile values increased recorded more in cement to lime composition. Figures 3.2 and 3,3 showed graphical presentation with higher values in cement.

3.2 California Bearing Ratio (CBR) Test

Results obtained of Ogoda soil CBR at 100% natural state unsoaked and soaked percentile values derived from table 3.2 , 3.3 to 3.2A and 3.3A are 2.769% and 2.978%, stabilized clay + cement + CLBFA are 241%, 329%, 463%, 393% and clay + lime + CLBFA 207%, 346%, 519%, 451%, soaked clay + cement + CLBFA 264%, 414%, 565%, 481%, clay + lime + CLBFA 264%, 416%, 635%, 563%. Bodo CBR at 100% natural unsoaked, and soaked are 3.211% and 3.676%, stabilized clay + cement + CLBFA, 290%, 492%, 572%, 517%, clay + lime + CLBFA 246%, 471%, 574%, 517%, soaked clay + cement + CLBFA 340%, 551%, 668%, 522%, clay + lime + CLBFA 251%, 505%, 644%, 557%. Ogbogu soil CBR at 100% of unsoaked and soaked are 3.315% and 3.320%, stabilized clay + cement + CLBFA 301%, 386%, 573%, 423%, clay + lime + CLBFA 180%, 316%, 534%, 426% and soaked clay + cement + CLBFA 302%, 376%, 613%, 410%, clay + lime + CLBFA, 205%, 279%, 542%, 420%. Ula – Ikata soil CBR at 100% unsoaked and soaked are 3.171%, and unsoaked are 3.229% and clay + cement + CLBFA; 286%, 395%, 589%, 461%, clay + lime + CLBFA 262%, 390%, 520%, 438%. Soaked are clay + cement + CLBFA, 292%, 433%, 657%, 508%, clay + lime + CLBFA 279%, 440%, 583%,467%. Kaani soil CBR at 100% unsoaked and soaked are 3.122% and 3.226%, stabilized clay + cement + CLBFA are 280.119%, 502%, 601%, 559% and clay + lime + CLBFA, 287%, 381%, 592%, 451%, soaked clay + cement + CLBFA are 292%, 538%, 654%, 573%, clay + lime + CLBFA, 248%, 352%, 593%, 460%. Results demonstrated an incremental percentile CBR values for both unsoaked and soaked with optimum composite combined mix ratio of 0.75% + 7.5% to soil corresponding clay soil. Comparative results showed cement and lime + CLBFA good strength increased to optimum with dominance in cement to lime.

3.3 Unconfined Compressive Strength Test

Unconfined compressive strength (UCS) test results of sampled roads at 100% natural soil state and percentile incremental are Ogoda, 1.784%, stabilized clay + cement + CLBFA, 122%, 309%, 447%, 579%, clay + lime + CLBFA, 104%, 286%, 340%, 473%. Bodo at 100%, 1.768%, stabilized clay + cement + CLBFA 120%, 239%, 314%, 430%, clay + lime + CLBFA 108%, 204%, 306%, 360%. Ogbogu soil at 100% is 2.338%, stabilized clay + cement + CLBFA; 191%, 345%, 473%, 594%, clay + lime + CLBFA, 61%, 217%, 298%, 484%. Ula – Ikata at 100% is 2.140%, stabilized clay + cement + CLBFA are 167%, 389%, 452%, 577% and clay + lime + CLBFA; 115%, 270%, 385%, 523%. Kaani soil at 100% is 2.099%, stabilized clay + cement + CLBFA are 162%, 305%, 399%, 560% and clay + lime + CLBFA; 97%, 208%, 307%, 479%. Unconfined compressive strength test results obtained showed incremental percentile values with composite ratio increase for cement / lime + CLBFA combination with cement in higher values to lime composition.

3.4 Consistency Limits Test

Results of consistency limits (plastic index) properties of clay at 100% of Ogoda is 0.993%, stabilized clay + cement + CLBFA are -1.481%, -2.711%, -3.449%, -6.105%, clay + lime + CLBFA -4.981%, -6.899%, -10.785%, -12.703%. Bodo soil at 100% is 1.012%, stabilized clay + cement + CLBFA -4.674%, -6.899%, -8.015%, -9.735%, clay + lime + CLBFA -4.976%, 7.285%, -7.679%, -9.742%. Ogbogu soil at 100% is 0.977%, stabilized clay + cement + CLBFA; -4.630%, -6.461%, -8.612%, -10.580%, clay + lime + CLBFA -10.336%, -12.120%, -13.631%,- 14.592%. Ula – Ikata soil at 100% is 0.948%, stabilized clay + cement + CLBFA; -10.67%, -9.14%, -11.21%,-12.96% , clay + lime + CLBFA; -2.751%, -4.008%, -6.139% -8.216%. Kaani soil at 100% is 0.975%, stabilized clay + cement + CLBFA; --4.976%, -7.187%, -8.760%, -9.988% and clay + lime + CLBFA; -2.970%, -2.528%, -3.806%, -5.740%. 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 showed graphical representation of consistency limits with cement composition in dominance reduction over lime.

Table 3.1: Engineering Properties of Soil Samples of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

Location Description	Ogoda Town Road, Ahoada-West L.G.A Rivers State	Bodo Town Road ,Gokana L.G.A Rivers State	Ogbogu Town Road,Ogba/Egbema Ndoni L.G.A Rivers State	Ula-Ikata Town Road, Ahoada-Bema East L.G.A Rivers State	Kaani Town Road, Khanna L.G.A Rivers State
Depth of sampling (m)	1.5	1.5	1.5	1.5	1.5
Percentage(%) passing BS sieve #200	73.85	67.38	76.35	82.35	71.55
Colour	Grey	Grey	Grey	Grey	Grey
Specific gravity	2.71	2.68	2.63	2.63	2.71
Natural moisture content (%)	46.25	45.38	45.86	49.30	46.85
Consistency Limits					
Liquid limit (%)	58.85	59.45	58.35	56.67	48.25
Plastic limit (%)	38.52	39.10	37.50	30.37	24.90
Plasticity Index	20.33	20.35	21.85	26.30	21.35
AASHTO soil classification	A – 7 – 6	A – 7 – 6	A – 7 – 6	A – 7 – 6	A – 7 – 6
Optimum moisture content (%)	15.68	14.93	16.30	17.45	15.35
Maximum dry density ($kN/m^{3)}$	1.875	1.923	1.823	1.795	1.9.85
Gravel (%)	1.85	0.85	2.45	0.53	1.95
Sand (%)	12.35	11.08	9.75	7.34	13.25
Silt (%)	52.35	47.35	47.85	53.68	48.25
Clay (%)	33.45	40.72	39.95	38.45	36.55
Unconfined compressive strength (kPa)	58.85	63.35	57.75	53.75	63.85
California Bearing Capacity (CBR)					
Unsoaked (%) CBR	8.58	8.83	8.05	7.38	9.05
Soaked (%) CBR	6.33	7.15	7.35	5.9	8.23

Table 3.2: Results of Maximum Dry Density (MDD) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	1.83	1.88	1.90	1.92	1.94
MDD (kN/m3) (Clay + Lime + CLBFA)OGODA TOWN ROAD	1.88	1.90	1.94	1.95	1.98
MDD (Clay + Cement + CLBFA) BODO TOWN ROAD	1.92	1.95	1.98	2.00	2.11
MDD (kN/m3) (Clay + Lime + CLBFA)BODO TOWN ROAD	1.92	1.95	1.97	1.99	1.99
MDD (Clay + Cement + CLBF) OGBOGU TOWN ROAD	1.82	1.85	1.88	1.90	1.94
MDD (kN/m3) (Clay + Lime + CLBF) OGBOGU TOWN ROAD	1.82	1.85	1.87	1.89	1.92
MDD (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	1.79	1.82	1.87	1.89	1.91
MDD (kN/m3) (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	1.79	1.82	1.84	1.88	1.93
MDD (Clay + Cement + CLBFA) KAANI TOWN ROAD,	1.99	2.00	2.12	2.19	2.21
MDD (kN/m3) (Clay + Lime + CLBFA) KAANI TOWN ROAD,	1.99	2.00	2.11	2.15	2.20

Table 3.2A: Results of Maximum Dry Density (MDD) Percentile Increase of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	1.032%	6.258%	7.025%	8.066%	9.272%
MDD (kN/m3) (Clay + Lime + CLBFA)OGODA TOWN ROAD	1.015%	2.965%	4.671%	5.471%	6.805%
MDD (Clay + Cement + CLBFA) BODO TOWN ROAD	1.012%	2.378%	3.886%	5.030%	10.646%
MDD (kN/m3) (Clay + Lime + CLBFA)BODO TOWN ROAD	1.013%	2.583%	3.519%	4.507%	4.768%
MDD (Clay + Cement + CLBF) OGBOGU TOWN ROAD	1.013%	2.508%	4.098%	5.305%	7.390%
MDD (kN/m3) (Clay + Lime + CLBF) OGBOGU TOWN ROAD	1.012%	2.399%	3.716%	5.087%	6.404%
MDD (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	1.017%	3.317%	5.602%	6.717%	8.111%
MDD (kN/m3) (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	1.013%	2.658%	3.661%	6.002%	8.622%
MDD (Clay + Cement + CLBFA) KAANI TOWN ROAD,	1.007%	1.306%	7.452%	10.877%	11.734%
MDD (kN/m3) (Clay + Lime + CLBFA) KAANI TOWN ROAD,	1.005%	1.005%	6.547%	8.864%	11.433%

Table 3.3: Results of Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	15.68	15.97	16.15	16.55	16.87
OMC%(Clay + Lime + CLBFA) OGODA TOWN ROAD	15.68	15.89	16.24	16.78	17.35
OMC%(Clay + Cement + CLBFA) BODO TOWN ROAD	14.93	15.25	15.69	15.93	16.15
OMC%(Clay + Lime + CLBFA) BODO TOWN ROAD	14.93	15.33	15.68	15.98	16.28
OMC%(Clay + Cement + CLBF) OGBOGU TOWN ROAD	16.30	16.59	16.83	17.05	17.38
OMC%(Clay + Lime + CLBF) OGBOGU TOWN ROAD	16.30	16.74	17.08	17.59	17.88
OMC%(Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	17.45	17.82	18.15	18.52	18.83
OMC%(Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	17.45	17.75	17.92	18.23	18.64
OMC%(Clay + Cement + CLBFA) KAANI TOWN ROAD,	15.35	15.70	15.96	16.12	16.47
OMC%(Clay + Lime + CLBFA) KAANI TOWN ROAD,	15.35	15.65	15.98	16.28	16.85

Table 3.3A: Results of Optimum Moisture Content (OMC) Percentile Increase of Niger Deltaic Clay Soils Subgrade with CLBFAA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	1.018%	3.665%	4.813%	7.364%	9.405%
OMC%(Clay + Lime + CLBFA) OGODA TOWN ROAD	1.013%	2.661%	4.893%	8.337%	11.972%
OMC%(Clay + Cement + CLBFA) BODO TOWN ROAD	1.021%	4.242%	7.189%	8.796%	10.270%
OMC%(Clay + Lime + CLBFA) BODO TOWN ROAD	1.027%	5.288%	7.633%	9.642%	11.651%
OMC%(Clay + Cement + CLBF) OGBOGU TOWN ROAD	1.018%	3.527%	5.000%	6.349%	8.374%
OMC%(Clay + Lime + CLBF) OGBOGU TOWN ROAD	1.027%	5.328%	7.414%	10.543%	12.322%
OMC%(Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	1.021%	4.197%	6.088%	8.208%	9.985%
OMC%(Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	1.017%	3.409%	4.384%	6.160%	8.510%
OMC%(Clay + Cement + CLBFA) KAANI TOWN ROAD,	1.023%	4.509%	6.203%	7.246%	9.526%
OMC%(Clay + Lime + CLBFA) KAANI TOWN ROAD,	1.020%	3.871%	6.021%	7.976%	11.689%

Table 3.4: Results of California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

RATIO %	100%	95+2.5+2.5 %	90+5.0+5.0 %	85+7.5+7.5 %	80+10.0+10 %
UNSOAKED (Clay + Cement + CLBFA) OGODA TOWN ROAD	8.58	23.76	31.35	42.80	36.85
UNSOAKED (Clay + Lime + CLBFA) OGODA TOWN ROAD	8.65	21.38	33.45	48.35	42.50
SOAKED(Clay + Cement + CLBFA) OGODA TOWN ROAD	6.33	18.85	28.31	37.87	32.55
SOAKED (Clay + Lime + CLBFA) OGODA TOWN ROAD	6.33	18.85	28.45	42.30	37.75
UNSOAKED (Clay + Cement + CLBFA) BODO TOWN ROAD	8.83	28.35	46.23	53.30	48.36
UNSOAKED (Clay + Lime + CLBFA) BODO TOWN ROAD	8.83	24.85	44.75	53.80	48.75
SOAKED(Clay + Cement + CLBFA) BODO TOWN ROAD	7.15	26.28	41.35	49.71	39.30
SOAKED (Clay + Lime + CLBFA) BODO TOWN ROAD	7.15	20.43	38.60	48.53	42.35
UNSOAKED (Clay + Cement + CLBF) OGBOGU TOWN ROAD	8.25	27.35	34.30	49.75	37.37
UNSOAKED (Clay + Lime + CLBF) OGBOGU TOWN ROAD	8.25	18.50	29.75	47.75	38.80
SOAKED(Clay + Cement + CLBF) OGBOGU TOWN ROAD	7.35	24.40	29.88	47.25	32.35
SOAKED (Clay + Lime + CLBF) OGBOGU TOWN ROAD	7.35	18.05	23.50	42.85	33.85
UNSOAKED (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	7.38	23.40	31.45	45.80	36.35
UNSOAKED (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	7.38	21.83	31.25	40.85	34.80
SOAKED(Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	5.90	19.05	27.35	40.60	31.78
SOAKED (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	5.90	18.35	27.83	36.30	29.45
UNSOAKED (Clay + Cement + CLBFA) KAANI TOWN ROAD,	9.05	28.25	48.35	57.30	53.45
UNSOAKED (Clay + Lime + CLBFA) KAANI TOWN ROAD,	9.05	28.81	37.35	56.40	43.65
SOAKED(Clay + Cement + CLBFA) KAANI TOWN ROAD,	8.23	26.55	46.85	56.35	49.75
SOAKED (Clay + Lime + CLBFA) KAANI TOWN ROAD,	8.23	23.33	31.85	51.67	40.75

Table 3.4A: Results of California Bearing Ratio (CBR) Percentile Increase of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

RATIO %	100%	95+2.5+2.5 %	90+5.0+5.0 %	85+7.5+7.5 %	80+10.0+10 %
UNSOAKED (Clay + Cement + CLBFA) OGODA TOWN ROAD	2.769%	241%	329%	463%	393%

UNSOAKED (Clay + Lime + CLBFA) OGODA TOWN ROAD	2.472%	207%	346%	519%	451%
SOAKED(Clay + Cement + CLBFA) OGODA TOWN ROAD	2.978%	264%	414%	565%	481%
SOAKED (Clay + Lime + CLBFA) OGODA TOWN ROAD	2.978%	264%	416%	635%	563%
UNSOAKED (Clay + Cement + CLBFA) BODO TOWN ROAD	3.211%	290%	492%	572%	517%
UNSOAKED (Clay + Lime + CLBFA) BODO TOWN ROAD	2.814%	246%	471%	574%	517%
SOAKED(Clay + Cement + CLBFA) BODO TOWN ROAD	3.676%	340%	551%	668%	522%
SOAKED (Clay + Lime + CLBFA) BODO TOWN ROAD	2.857%	251%	505%	644%	557%
UNSOAKED (Clay + Cement + CLBF) OGBOGU TOWN ROAD	3.315%	301%	386%	573%	423%
UNSOAKED (Clay + Lime + CLBF) OGBOGU TOWN ROAD	2.242%	180%	316%	534%	426%
SOAKED(Clay + Cement + CLBF) OGBOGU TOWN ROAD	3.320%	302%	376%	613%	410%
SOAKED (Clay + Lime + CLBF) OGBOGU TOWN ROAD	2.456%	205%	279%	542%	420%
UNSOAKED (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	3.171%	286%	395%	589%	461%
UNSOAKED (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	2.958%	262%	390%	520%	438%
SOAKED(Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	3.229%	292%	433%	657%	508%
SOAKED (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	3.110%	279%	440%	583%	467%
UNSOAKED (Clay + Cement + CLBFA) KAANI TOWN ROAD,	3.122%	280.12%	502%	601%	559%
UNSOAKED (Clay + Lime + CLBFA) KAANI TOWN ROAD,	3.183%	287%	381%	592%	451%
SOAKED(Clay + Cement + CLBFA) KAANI TOWN ROAD,	3.226%	292%	538%	654%	573%
SOAKED (Clay + Lime + CLBFA) KAANI TOWN ROAD,	2.835%	248%	352%	593%	460%

Table 3.5: Results of Liquid Limits (LL) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	58.85	60.45	60.86	61.25	62.87
LL (Clay + Lime + CLBFA)OGODA TOWN ROAD	58.85	59.18	59.45	59.93	60.35
LL(Clay + Cement + CLBFA) BODO TOWN ROAD	59.45	61.35	61.86	62.20	62.65
LL (Clay + Lime + CLBFA) BODO TOWN ROAD	59.45	59.73	61.23	61.65	61.87
LL(Clay + Cement + CLBF) OGBOGU TOWN ROAD	58.35	59.85	60.18	60.66	60.97
LL (Clay + Lime + CLBF) OGBOGU TOWN ROAD	58.35	59.05	59.33	59.77	60.18
LL(Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	56.67	57.15	57.65	58.15	58.65
LL (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	56.67	57.21	57.68	58.15	58.75
LL(Clay + Cement + CLBFA) KAANI TOWN ROAD,	48.25	48.53	48.96	49.23	49.75
LL (Clay + Lime + CLBFA) KAANI TOWN ROAD,	48.25	48.58	49.35	50.18	50.35

Table 3.5A: Results of Liquid Limits (LL) Percentile Increase of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	1.027%	5.366%	6.062%	6.725%	9.478%
LL (Clay + Lime + CLBFA)OGODA TOWN ROAD	1.006%	1.118%	1.577%	2.393%	3.106%
LL(Clay + Cement + CLBFA) BODO TOWN ROAD	1.032%	6.293%	7.151%	7.723%	8.480%
LL (Clay + Lime + CLBFA) BODO TOWN ROAD	1.005%	0.940%	3.463%	4.169%	4.539%
LL(Clay + Cement + CLBF) OGBOGU TOWN ROAD	1.026%	5.077%	5.643%	6.465%	6.996%
LL (Clay + Lime + CLBF) OGBOGU TOWN ROAD	1.012%	2.385%	2.865%	3.619%	4.322%
LL(Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	1.008%	1.687%	2.569%	3.452%	4.334%
LL (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	1.010%	1.897%	2.726%	3.556%	4.614%
LL(Clay + Cement + CLBFA) KAANI TOWN ROAD,	1.006%	1.157%	2.048%	2.608%	3.686%
LL (Clay + Lime + CLBFA) KAANI TOWN ROAD,	1.007%	1.363%	2.959%	4.679%	5.032%

Table 3.6: Results of Plastic Limits (LL) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	38.52	40.62	41.42	42.60	44.61
PL (Clay + Lime + CLBFA) OGODA TOWN ROAD	38.52	39.00	39.52	40.15	41.11
PL(Clay + Cement + CLBFA) BODO TOWN ROAD	39.10	41.50	42.03	43.87	43.77
PL (Clay + Lime + CLBFA) BODO TOWN ROAD	39.10	39.85	41.70	42.45	43.02
PL(Clay + Cement + CLBF) OGBOGU TOWN ROAD	37.50	39.10	39.82	40.63	41.15
PL (Clay + Lime + CLBF) OGBOGU TOWN ROAD	37.50	37.70	38.88	39.21	40.13
PL(Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	38.37	34.10	39.83	40.72	41.60
PL (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	38.37	39.26	40.05	40.90	41.83
PL(Clay + Cement + CLBFA) KAANI TOWN ROAD,	27.90	28.48	29.82	29.35	28.97
PL (Clay + Lime + CLBFA) KAANI TOWN ROAD,	27.90	28.73	29.95	31.10	31.52

Table 3.6A: Results of Plastic Limits (LL) Percentile Increase of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	1.055%	10.622%	12.698%	15.762%	20.98%
PL (Clay + Lime + CLBFA) OGODA TOWN ROAD	1.012%	2.477%	3.827%	5.462%	7.955%
PL(Clay + Cement + CLBFA) BODO TOWN ROAD	1.061%	11.921%	13.277%	17.983%	17.727%
PL (Clay + Lime + CLBFA) BODO TOWN ROAD	1.019%	3.800%	8.532%	10.450%	11.908%
PL(Clay + Cement + CLBF) OGBOGU TOWN ROAD	1.043%	8.359%	10.279%	12.439%	13.825%
PL (Clay + Lime + CLBF) OGBOGU TOWN ROAD	1.005%	1.064%	4.211%	5.091%	7.544%
PL (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	1.023%	5.76%	6.645%	8.861%	11.284%
PL(Clay + Cement + CLBFA) KAANI TOWN ROAD,	1.021%	4.115%	6.92%	8.61%	9.97%
PL (Clay + Lime + CLBFA) KAANI TOWN ROAD,	1.030%	5.864%	10.237%	14.359%	15.864%

Table 3.7: Results of Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	20.33	20.18	19.93	19.78	19.24
PI (Clay + Limet + CLBFA) OGODA TOWN ROAD	20.33	19.83	19.44	18.65	18.26
PI (Clay + Cement + CLBFA) BODO TOWN ROAD	20.35	19.88	19.53	19.20	18.85
PI (Clay + Lime + CLBFA) BODO TOWN ROAD	20.35	19.85	19.38	19.30	18.88
PI (Clay + Cement + CLBF)OGBOGU TOWN ROAD	21.85	21.35	20.95	20.48	20.05
PI (Clay + Limet + CLBF)OGBOGU TOWN ROAD	21.85	20.75	20.36	20.03	19.82
PI (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	18.30	17.35	17.63	17.25	16.93
PI (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	18.30	18.05	17.82	17.43	17.05
PI (Clay + Cement + CLBFA) KAANI TOWN ROAD,	20.35	19.85	19.40	19.08	18.83
PI (Clay + Lime + CLBFA) KAANI TOWN ROAD,	20.35	20.05	20.14	19.88	30.98

Table 3.7A: Results of Plastic Limits (LL) Percentile Increase of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	0.993%	-1.481%	-2.711%	-3.449%	-6.105%
PI (Clay + Limet + CLBFA) OGODA TOWN ROAD	0.975%	-4.981%	-6.899%	-10.79%	-12.70%
PI (Clay + Cement + CLBFA) BODO TOWN ROAD	0.977%	-4.674%	-6.394%	-8.015%	-9.735%
PI (Clay + Lime + CLBFA) BODO TOWN ROAD	0.975%	-4.976%	-7.285%	-7.679%	-9.742%
PI (Clay + Cement + CLBF)OGBOGU TOWN ROAD	0.977%	-4.63%	-6.46%	-8.61%	-10.58%
PI (Clay + Limet + CLBF)OGBOGU TOWN ROAD	0.950%	-10.34%	-12.12%	-13.63%	-14.59%
PI (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	0.948%	-10.67%	-9.14%	-11.21%	-12.96%
PI (Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	0.986%	-2.751%	-4.008%	-6.139%	-8.216%
PI (Clay + Cement + CLBFA) KAANI TOWN ROAD,	0.975%	-4.976%	-7.187%	-8.760%	-9.988%
PI (Clay + Lime + CLBFA) KAANI TOWN ROAD,	0.985%	-2.970%	-2.528%	-3.806%	-5.740%

Table 3.8: Results of Unconfined Compressive Strength (USC) Test of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	58.85	105.00	215.00	296.00	374.00
UCS(Clay + Lime + CLBFA) OGODA TOWN ROAD	58.85	97.00	204.00	236.00	314.00
UCS (Clay + Cement + CLBFA) BODO TOWN ROAD	63.35	112.00	187.00	235.00	308.00
UCS(Clay + Lime + CLBFA)BODO TOWN ROAD	63.35	106.00	167.00	232.00	266.00
UCS(Clay + Cement + CLBFA) OGBOGU TOWN ROAD	57.75	135.00	224.00	298.00	368.00
UCS (Clay + Lime + CLBFA) OGBOGU TOWN ROAD	57.75	78.00	168.00	215.00	322.00
UCS (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	53.75	115.00	234.00	268.00	335.00
UCS(Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	53.75	93.00	176.00	238.00	312.00
UCS (Clay + Cement + CLBFA) KAANI TOWN ROAD,	63.85	134.00	225.00	285.00	388.00
UCS(Clay + Lime + CLBFA) KAANI TOWN ROAD,	63.85	102.00	173.00	236.00	346.00

Table 3.7: Results of Unconfined Compressive Strength (USC) Test Percentile Increase of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), 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 + CLBFA) OGODA TOWN ROAD	1.784%	122%	309%	447%	579%
UCS(Clay + Lime + CLBFA) OGODA TOWN ROAD	1.648%	104%	286%	340%	473%
UCS (Clay + Cement + CLBFA) BODO TOWN ROAD	1.768%	120%	239%	314%	430%
UCS(Clay + Lime + CLBFA)BODO TOWN ROAD	1.673%	108%	204%	306%	360%
UCS(Clay + Cement + CLBFA) OGBOGU TOWN ROAD	2.338%	191%	345%	473%	594%
UCS (Clay + Lime + CLBFA) OGBOGU TOWN ROAD	1.351%	61%	217%	298%	484%
UCS (Clay + Cement + CLBFA) ULA-IKATA TOWN ROAD	2.140%	167%	389%	452%	577%
UCS(Clay + Lime + CLBFA) ULA-IKATA TOWN ROAD	1.730%	115%	270%	385%	523%
UCS (Clay + Cement + CLBFAA) KAANI TOWN ROAD,	2.099%	162%	305%	399%	560%
UCS(Clay + Lime + CLBFA) KAANI TOWN ROAD,	1.597%	97%	208%	307%	479%

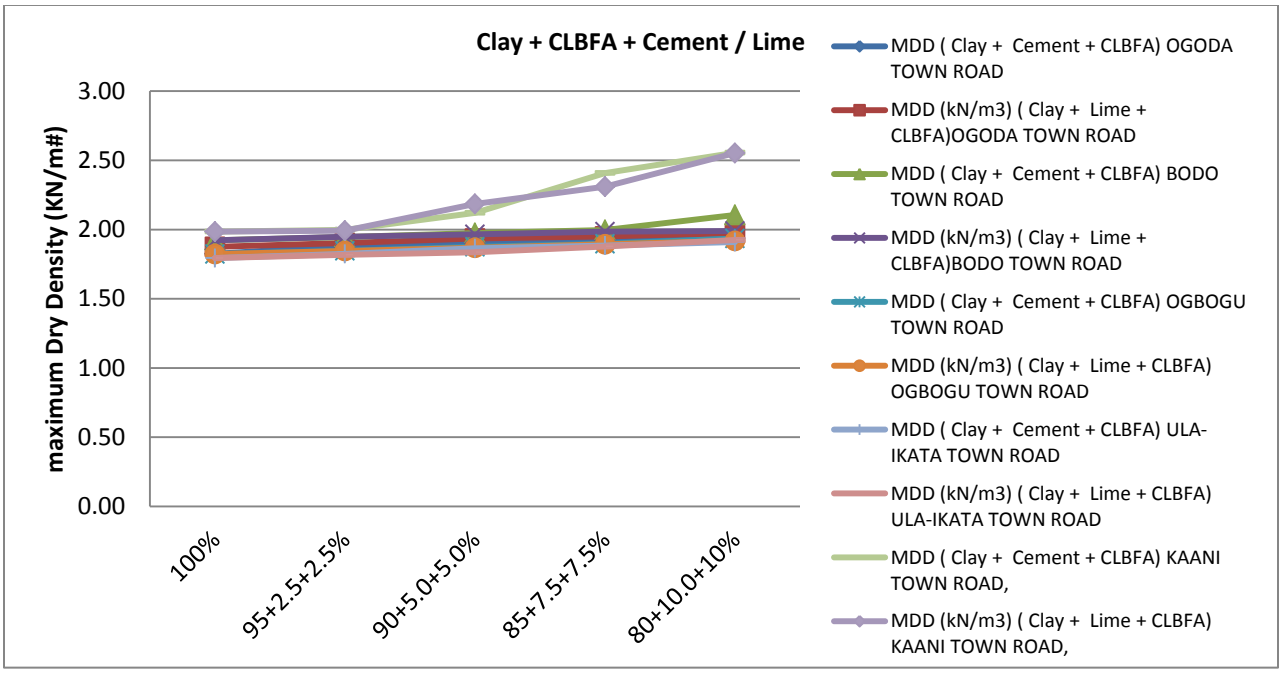

Figure 3.1: Maximum Dry Density (MDD) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

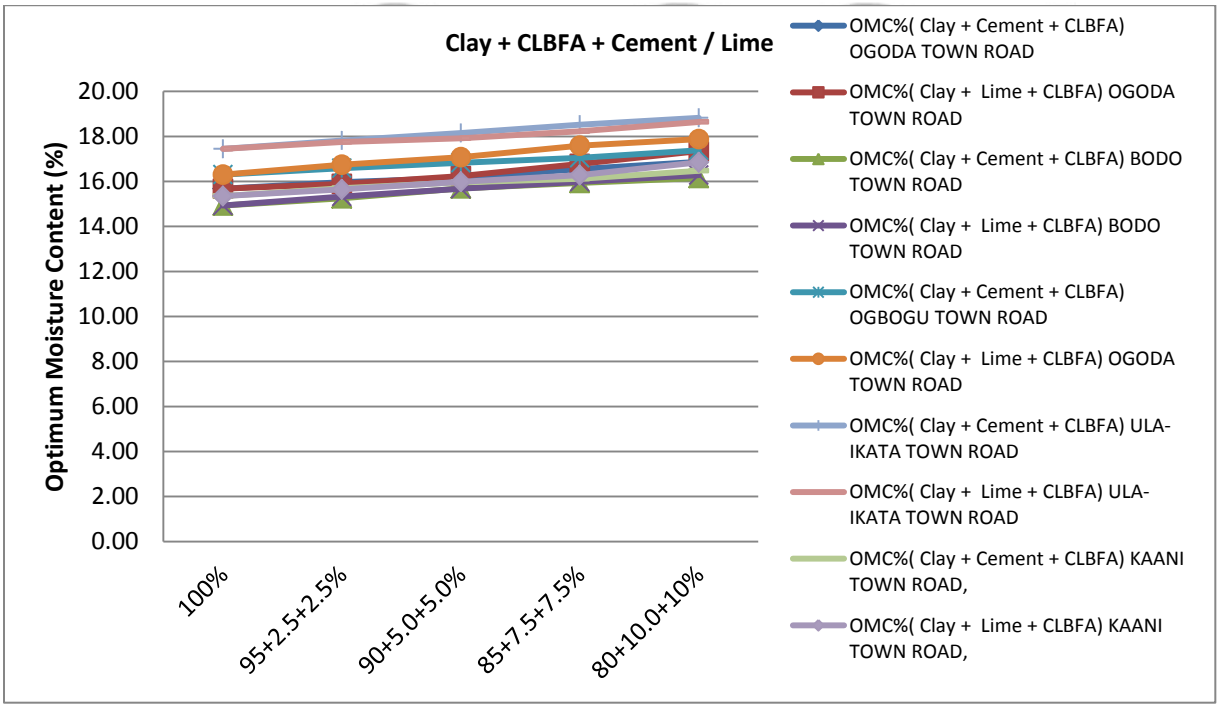

Figure 3.2: Optimum Moisture Content (OM) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

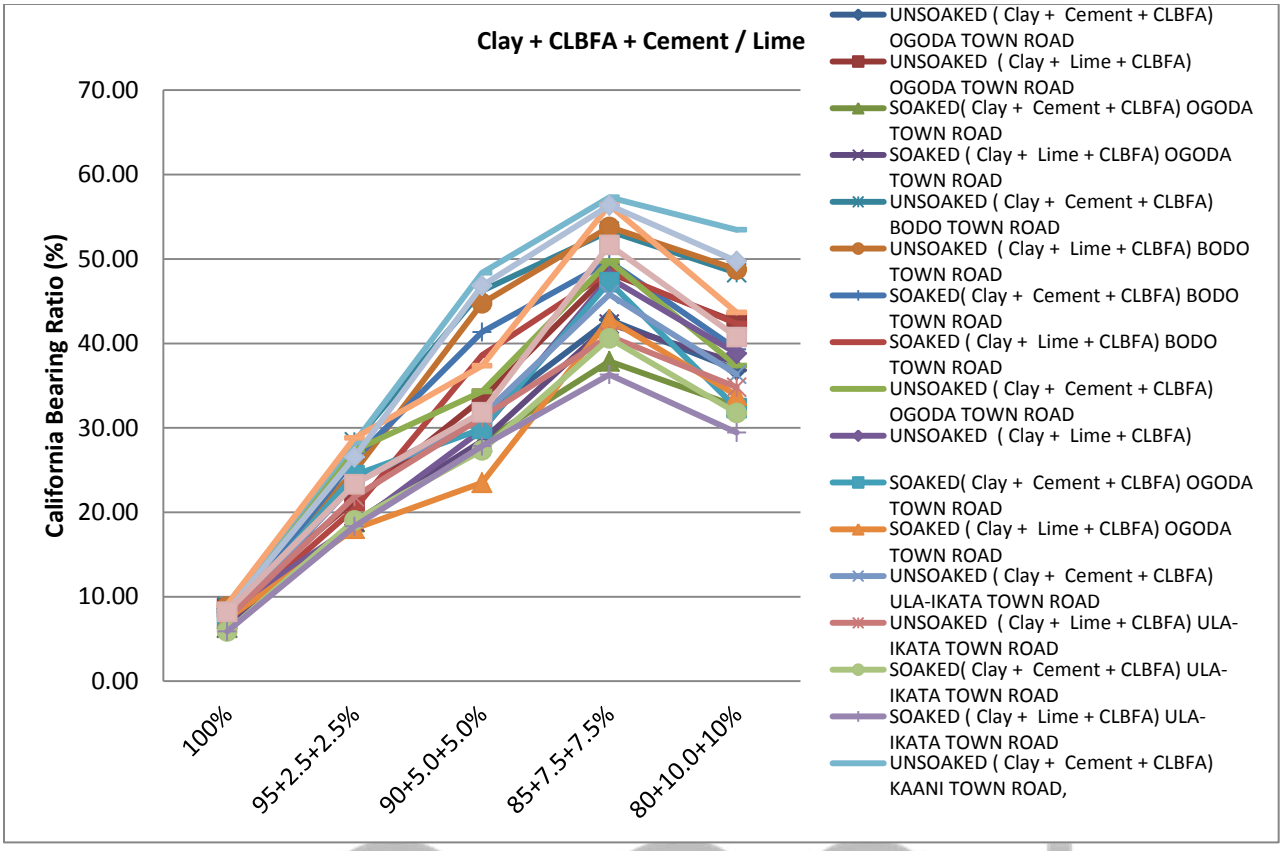

Figure 3.3: California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

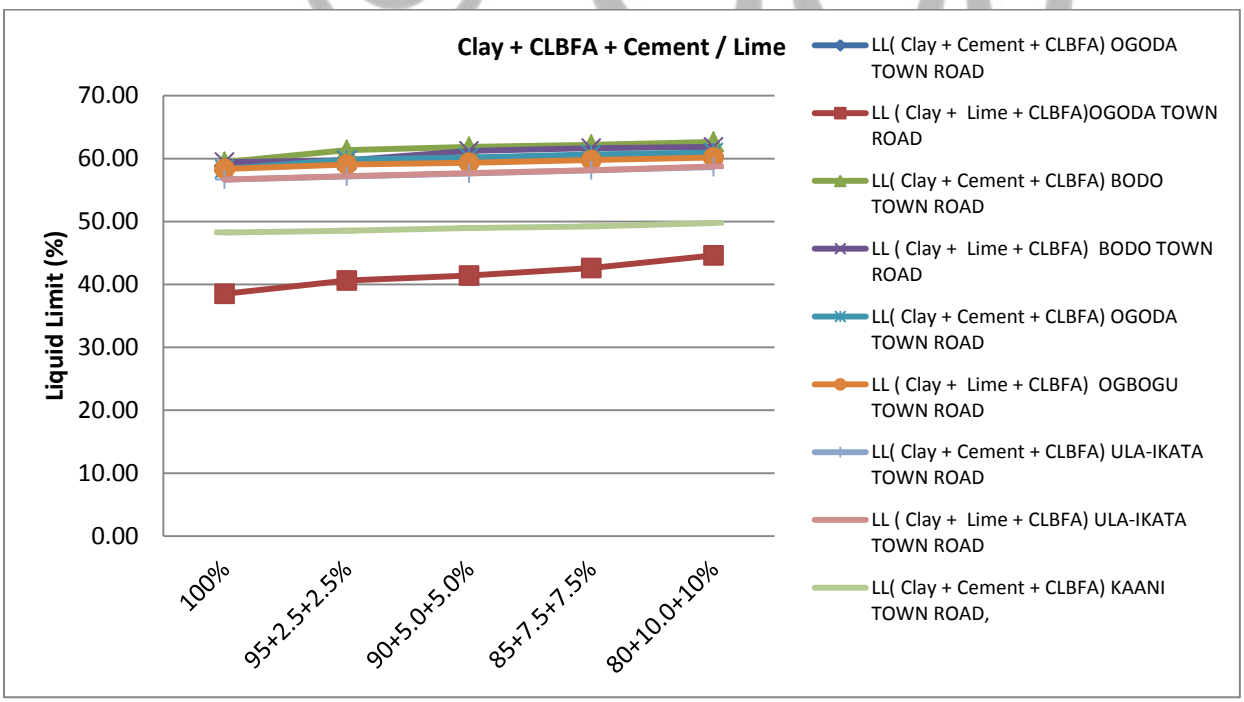

Figure 3.4: Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

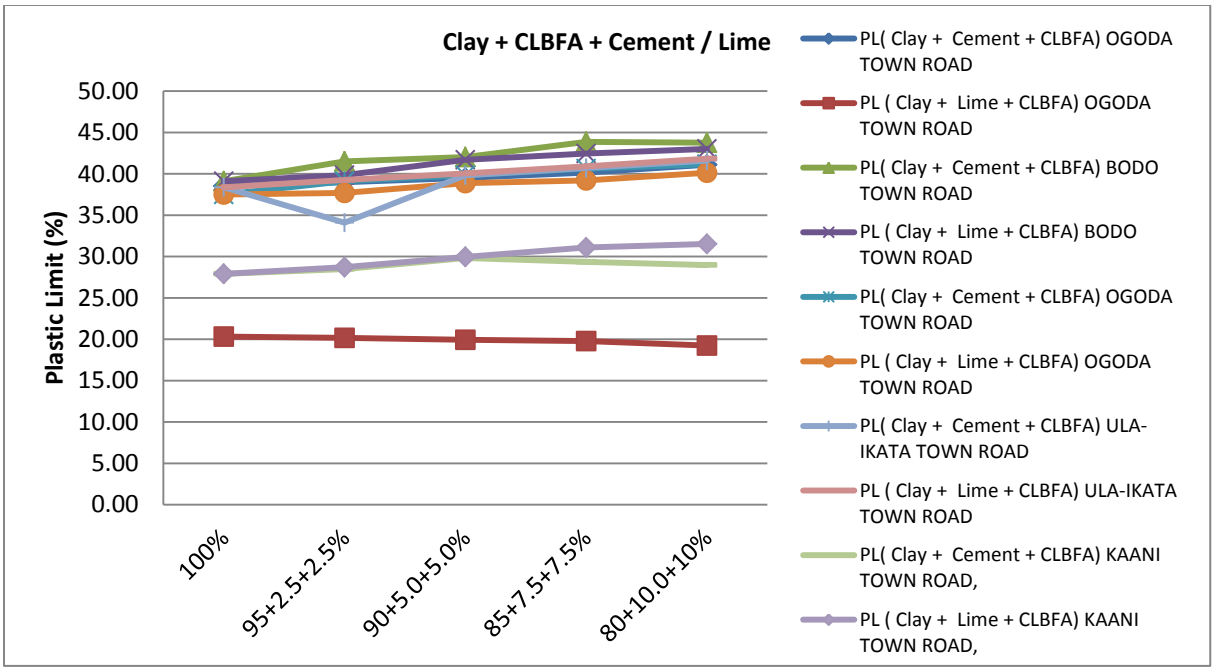

Figure 3.5: Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

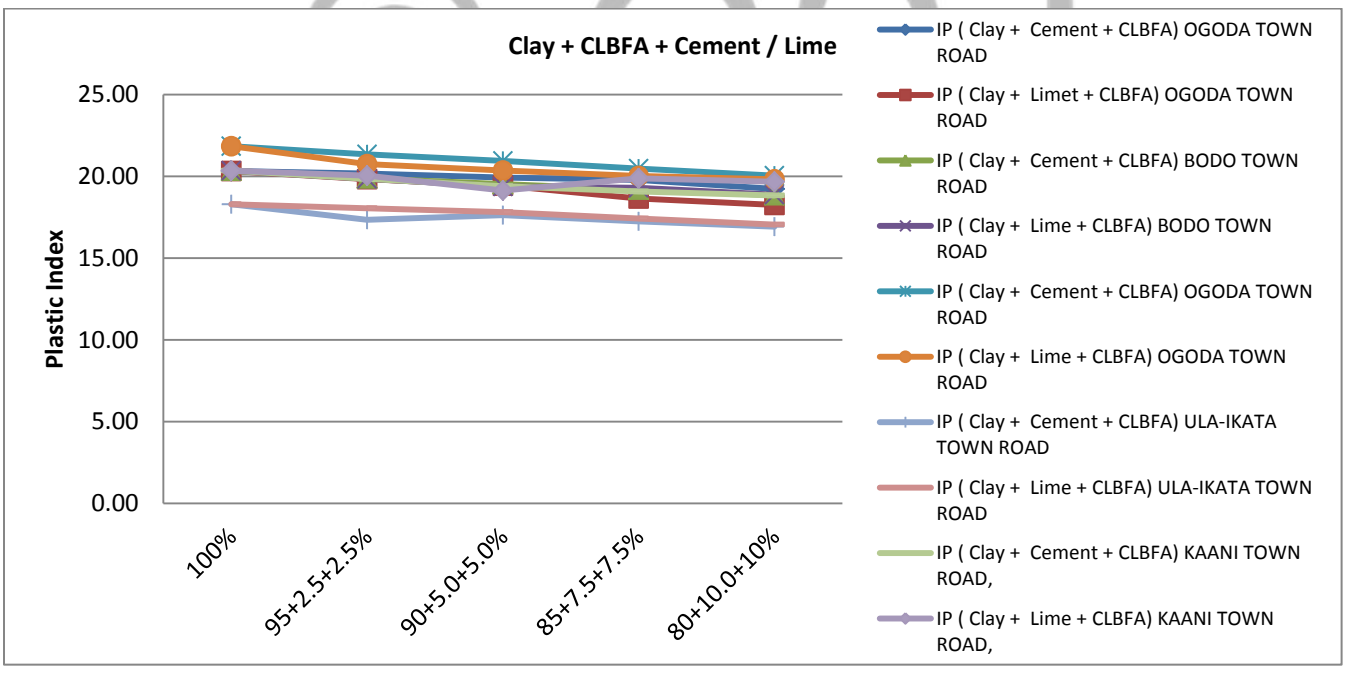

Figure 3.6: Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

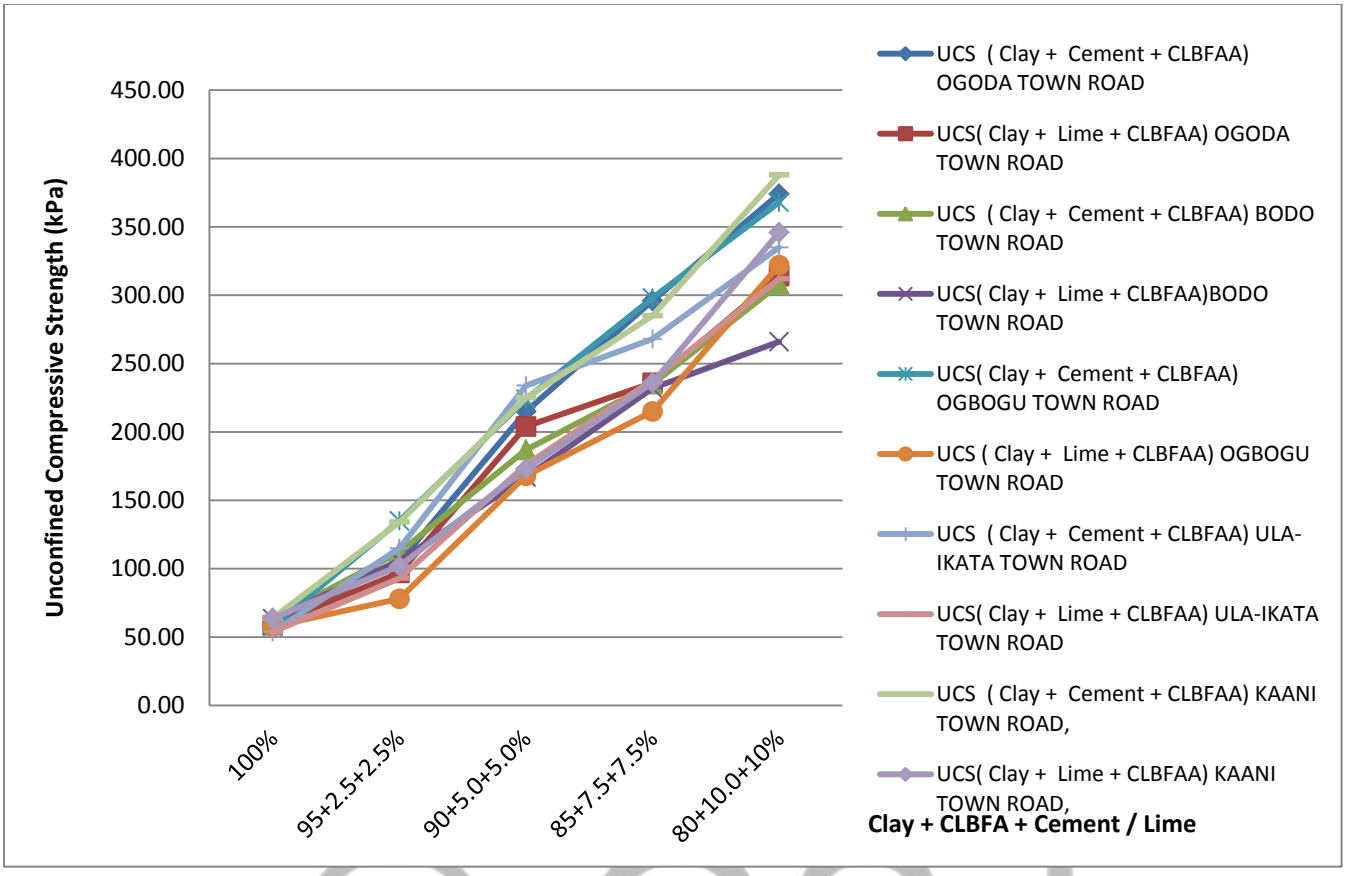

Figure 3.7: Unconfined Compressive Strength (UCS) of Niger Deltaic Clay Soils Subgrade with CLBFA + Cement / Lime of (Ogoda, Bodo, Ogbogu, Ula-Ikata, Kaani Towns), Rivers State

4.0 Conclusions

The following conclusions were made from the experimental research results.

i. The soils classified as A - 7 - 6 on the AASHTO classification System
ii. The soil has unsoaked CBR values of 8.58%,8.83%, 8.05%, 7.38%, and 9.05% and soaked CBR values of 6.33%, 7.15%, 7.35%, 5.9% and 8.23%, unconfined compressive strength values of 58.85kPa, 63.35kPa, 57.75kPa, 53.75kPa and 63.85kPa
iii. Clay Soils are dark grey in color (from wet to dry states) PLasticity index of 20.33%, 20.35%, 21.85%, 26.30%, and 21.35% respectively for Ogoda, Bodo, Ogbogu, Ula-Ikata and Kaani.
iv. Detailed analyzed compaction test results of maximum dry density (MDD) and optimum moisture content (OMC) of all sampled roads showed incremental percentile values with inclusion of composite materials of cement / lime + CLBFA with respect to percentage ratio increase
v. Results demonstrated an incremental percentile CBR values for both unsoaked and soaked with optimum composite combined mix ratio of 0.75% + 7.5% to soil corresponding clay soil.
vi. Unconfined compressive strength test results obtained showed incremental percentile values with composite ratio increase for cement / lime + CLBFA combination.
vii. Results obtained demonstrated decreased in percentile values of plastic index properties with increase in composites ratio to soil.

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