Strength Variance Evaluation of Cement / Lime with irvinga gabonesis fibre Stabilized Black Cotton Soil

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ABSTRACT

The research work investigated the incremental and reductive percentile values of treated expansive problematic clay soils with cement, lime and irvinga gabonesis fibre with varying percentages combination and strength variance comparatives of cementitious agents in combined actions. Preliminary results on clay soils as seen in detailed test results given in Tables: 3.1 showed that the physical and engineering properties does not meet standards for subgrade pavement. The soils classified as A - 7 - 6 / CH on the AASHTO classification schemes / Unified Soil Classification System. Results compaction test obtained of clay soils from sampled roads maximum dry density (MDD) and optimum moisture content (OMC) are, Iwofe, 1.0475% and 1.0242%, Chokocho, 1.0012% and 1.0123%, Ndoni, 1.0187%, and 1.0193% and 1.025%, Ogbele, 1.0106% and 1.0076% correspondingly of MDD and OMC at 100% natural soils. Results obtained of California bearing ratio (CBR) test conducted at preliminary state of 100% are unsoaked, 4.2789%, 3.8490%, 4.2147%, 3.6713%, and soaked, 3.9843%, 4.0369%, 4.0213%, 3.6713%, of Iwofe, Chokocho, Ndoni, and Ogbele respectively. Unconfined compressive strength test conducted at preliminary stages of 100% natural soil from sampled roads yielded percentile results as, Iwofe, 1.5709%, Chokocho, 1.6635%, Ndoni, 1.9474% and Ogbele, 2.3515%, respectively. Consistency limits (Plastic index) at preliminary tests of 100% natural and at composite stabilized states are iwofe 0.995%, Chokocho 0.989%, Ndoni 0.988% and Ogbele 0.987%. Entire compaction test results showed incremental percentile value of maximum dry density (MDD) and optimum moisture content (OMC) of composite stabilized clay soils hybridized with cement / lime + IGF with increase in mix ratio to soils. Comparative results demonstrated in figures 3.1 and 3.2 showed that cement composition are of higher incremental values to lime. Stabilized California bearing ratio (CBR) composite materials of cement, lime and IGF showed incremental percentile values with ratio variation. Both cementitious materials showed percentile increased to optimum mix ratio of 91.75+ 0.75+ 7.5%. Declined percentile values were observed beyond optimum with cracks formation. Unconfined compressive strength results of composite stabilized clay soils with cement / lime + IGF showed incremental percentile values with respect to percentage of composite mix ratio with peak values recorded in cement over lime. Consistency limit test of plastic index indicated decreased in values with respect to increase in percentile values of composite materials to soil ratio with peak reduction values in cement. Entire results showed the potentials of both stabilizing agents with peak percentile values in cement.

Key Words: Clay soils, Irvinga Gabonesis Fibre, Cement, Lime, CBR, UCS, Consistency, Compaction

1.0 Introduction

The presence of expansive soils is one of Nigeria's prevalent causes of damage to buildings and other construction works which occur extensively in tropical climate. A notable and observable damage caused by expansive soils includes foundation crack, soil heaving and cracking of sidewalks and depression in roads Akaha and Adunola [1]. The remedy to these provocative trends of expansive soils is stabilization. It has proved to be very economical as it provides cheap materials for the construction of low cost roads. Local materials can be used effectively. Numerous kinds of stabilizers were used as soil additives to improve its engineering properties. A number of stabilizers, such as lime, cement and fly ash, depend on their chemical reactions with the soil elements in the presence of water (Azadegan *et al.*[2]; Mallela *et al.*[3]; Ramadas *et al.* [4]). Other additives, such as geofiber and geogrid, depend on their physical effects to improve soil properties (Alawaji, [5]; Viswanadham *et al.* [6]. In addition, it can be combined both of chemical and physical stabilization, for example, by using lime and geofiber or geotextile together (Yang *et al.* [7]; Chong and Kassim, [8]).
Charles *et al.* [9] 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 were mixed in single and combines actions to improved their unique properties. Results of tests carried out show that the optimum moisture content increased with increasing cement ratios to both soils and. 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.

Charles *et al.* [10] 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 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 clay with optimum values of 8 % cement and lime and 7.5% +7.5 % of cement / lime + BSBF.

Charles *et al.* [11] 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 clay 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 clay.

2.0 Materials and Methods

2.1 Materials

2.1.1 Soil

The soils used for the study were collected within failed sections of the at 1.5 m depth from Iwofe Town Rodd, in Obio/Akpor Local Government Area, Chokocho Town Rd, in Etche Local Government Area, Ndoni Town Road, in Ogba/Egbema/Ndoni Local Government Area and Ogbele Town Road in ahoada – East Local Government Area, all in Rivers State, Nigeria.

2.1.2 Irvinga Gabonesis Fibre (Bush Mango)

The irvinga gabonesis, popularly called Bush mango, with Nigerian native name (Egbono) are widely spread plants across Nigerian bushes and farm land with edible fruits that bears the fibre , they are collected from at Olokuma village, a river side area in Ubie Clan, Ahoada-West, Rivers State, Nigeria.

2.2 Method

2.2.1 Sampling Locality

The soil sample used in this study were collected along Iwofe Town, (latitude 4.49° 41‘S and longitude 6.57° 24‘E), Chokocho Town, (latitude 4.9882° N ° 34‘S and longitude 7.0525° ° 13‘E), Ndoni Town, latitude 5.5487 ° 21‘S and longitude 6.5917° ° 39‘E), Ogbele Town, (latitude 4.9198 ° 23‘S and longitude 6.6751 ° 34‘E) all in Rivers State, Nigeria.

2.2.2 Test Conducted

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

2.2.3 Moisture Content Determination

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

2.2.4 Grain Size Analysis (Sieve Analysis)

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

2.2.5 Consistency Limits

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

2.2.6 Moisture – Density (Compaction) Test

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

2.2.7 Unconfined Compression (UC) Test

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

2.2.8 California Bearing Ratio (CBR) Test

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

3.0 Results and Discussions

Preliminary results on clay soils as seen in detailed test results given in Tables: 3.1 showed that the physical and engineering properties fall below the minimum requirement for such application and needs stabilization to improve its properties. 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 soil has unsoaked CBR values of 7.35%, 7.75%, 8.15%, and 7.85% and soaked CBR values of 6.35%, 6.23%, 7.05% and 5.55%, unconfined compressive strength values of 87.85kPa , 78.75kPa, 105.75kPa and 85.35kPa.

3.1 Compaction Test Results

Compaction test parameters obtained at 100% natural state of clay and composite stabilized materials shown in tables 3.2 and 3.3 then summarized into 3.2A and 3.3Afrom sampled roads maximum dry density (MDD) and optimum moisture content (OMC) are, Iwofe, 1.0475% and 1.0242%, Chokocho, 1.0012% and 1.0123%, Ndoni 1.0187%, and 1.0193% and 1.025%, Ogbele 1.0106% and 1.0076% correspondingly of MDD and OMC at 100% natural soils. Stabilized clay soil results with composites materials of Iwofe samples MDD are clay + cement + IGF 9.2804%, 16.4020%, 17.7670%, 18.7759%, clay + lime + IGF 1.1834% , 3.5573%, 10.0855% , 14.7146% , OMC are clay + cement + IGF 4.7857%, 6.6181%, 8.6469%, 11.9846%, clay + lime + IGF 1.9538%, 4.5062%, 6.0114%, 9.4145%. Chokocho parameters are MDD are clay + cement + IGF 0.2445%, 5.8102%, 8.8072%, 10.7032%, clay + lime + IGF 2.6733%, 5.0586%, 7.4439%, 10.6243% , OMC are clay + cement + IGF 2.4421%, 4.4077%, 5.2676%, 6.5576%, clay + lime + IGF 1.6133%, 3.8688%, 4.4217%, 5.2816%. Ndoni MDD are clay + cement + IGF 3.7073%, 4.7333%, 7.9318%, 13.0012%, clay + lime + IGF 2.1609%, 3.1869%, 5.1784%, 8.0752%, OMC are clay + cement + IGF 3.8263%, 6.1939%, 8.0008%, 9.9946%, clay + lime + IGF 2.4769%, 4.8445%, 6.7759%, 8.0844%. Ogbele stabilized soil parameters are MDD clay + cement + IGF 2.1103%, 4.9388%, 6.8245%, 8.4744%, clay + lime + IGF 1.2922%, ,2.2351%, 5.7118%, 7.5385%, OMC clay + cement + IGF 1.5200% , 3.4272%, 5.9701%, 7.7501%, clay + lime + IGF 2.5269%, 3.9255%, 5.3877%, 7.6128%. Entire compaction test results showed incremental percentile value of maximum dry density (MDD) and optimum moisture content (OMC) of composite stabilized clay soils hybridized with cement / lime + IGF with increase in mix ratio to soils. Comparative results demonstrated in figures 3.1 and 3.2 showed that cement composition are of higher incremental values to lime.

3.2 California Bearing Ratio (CBR) Test

Results obtained from table 3.4 and summarized into 3.4A of California bearing ratio (CBR) test conducted at preliminary state of 100% are unsoaked 4.2789%, 3.8490%, 4.2147%, 3.6713%, and soaked, 3.9843%, 4.0369%, 4.0213%, 3.6713%, of Iwofe, Chokocho, Ndoni, and Ogbele respectively. Results of incremental percentile values recorded from

Iwofe stabilized unsoaked clay + cement + IGF are 404.521%, 706.562%, 1015.405%, 845.337%, clay + lime + IGF; 359.353%, 565.203%, 923.434% , 773.366%, soaked clay + cement + IGF), 373.326%, 741.043%, 1067.027%, 885.452%, clay + lime + IGF 342.212%, 576.543%, 972.134%, 814.653% . Chokocho stabilized unsoaked clay + cement + IGF are 358.923%, 719.826%, 991.439%, 830.407%, clay + lime + IGF, 286.812%, 502.106%, 783.283%, 648.694%, soaked clay + cement + IGF, 378.920%, 766.561%, 1096.416% 964.795%, clay + lime + IGF, 401.005%, 750.924%, 1017.377%, 868.902%. Ndoni unsoaked clay + cement + IGF 397.746%, 704.495%, 987.9301%, 882.409%, clay + lime + IGF, 427.456%, 625.002%, 938.4988%, 758.744%, soaked clay + cement + IGF, 377.260%, 718.111%, 1057.402%, 965.912%, clay + lime + IGF, 414.736%, 668.637%, 1020.410%, 789.913%. Ogbele unsoaked clay + cement + IGF are 339.896%, 577.221%, 908.4308%, 722.443%, clay + lime + IGF are 336.884%, 530.896%, 848.9856%, 723.508%, soaked clay + cement + IGF, 379.783%, 672.035%, 1187.531%, 918.522%, clay + lime + IGF 396.952%, 648.664%, 1054.610%, 938.393%. Stabilized California bearing ratio (CBR) composite materials of cement, lime and IGF showed incremental percentile values with ratio variation and cement composition higher as shown in figure 3.4. Both cementitious materials showed percentile increased to optimum mix ratio of 91.75+0.75+7.5%. Declined percentile values were observed beyond optimum with cracks formation.

3.3 Unconfined Compressive Strength Test

Unconfined compressive strength test results shown in table conducted at preliminary stages of 100% natural soil from sampled roads yielded the following peak percentile results; Iwofe 1.5709%, Chokocho 1.6635%, Ndoni 1.9474% and Ogbele 2.3515%, respectively. Stabilized composite materials Unconfined compressive strength of Iwofe clay + cement + IGF are 121.261%, 270.379%, 328.4326%, 614.147%, clay + lime + IGF 93.427%, 240.268%, 306.2894%, 562.408%. Chokocho clay + cement + IGF are 126.517%, 330.962%, 501.1205%, 710.644%, clay + lime + IGF 106.235%, 276.393%, 444.0125%, 673.854%. Ndoni clay + cement + IGF are 143.394%, 246.438%, 388.2421%, 558.407% clay + lime + IGF 115.197%, 222.968%, 410.1491%, 545.335%. Ogbele clay + cement + IGF are 192.627%, 304.205%, 516.5627%, 695.327%, clay+ lime + IGF 65.498%, 196.510%, 281.953%, 386.384%169.651%, 307.624%, 464.7922%, 631.559%. Unconfined compressive strength results of composite stabilized clay soils with cement / lime + IGF showed incremental percentile values with respect to percentage of composite mix ratio with peak values recorded in cement over lime.

3.4 Consistency Limits Test

Consistency limits (Plastic index) at preliminary tests of 100% natural and at composite stabilized states from tables 3.4, 3.5 and 3.6 developed summarized percentile values of tables 3.4A, 3.5A into 3.6A are iwofe 0.995%, Chokocho 0.989%, Ndoni 0.988% and Ogbele 0.987%. Composite stabilized Iwofe clay + cement + IGF -8.2069%, -9.4931%, -10.7471%, -11.101%, clay + lime + IGF -7.8719%, -10.3886%, -13.9609%, -15.3114%. Chokocho stabilized parameters are clay + cement + -3.2028%, -4.0175%, -4.9136%, -6.3800%, clay + lime + IGF -1.6360%, -2.8173%, -3.6319%, -4.8132%. Ndoni clay + cement + IGF clay + cement + IGF -10.043%, -7.0475%, -8.3679% , -12.909%, clay + lime + IGF -7.8848%, -8.6578%, -9.9460%, -11.105%. Ogbele clay + cement + IGF -1.4977%, -2.3991%, -3.7669%, -4.6062%, clay + lime + IGF -1.9994%, -3.0563%, -3.9267%, -4.8592%. Consistency limit test of plastic index indicated decreased in values with respect to increase in percentile values of composite materials to soil ratio with peak reduction values in cement.

Table 3.1: Engineering Properties of Soil Samples Iwofe, Chokocho, Ndoni and Ogbele Town Roads

Location Description	Iwofe Rd Obio/Akpor L.G.A	Chokocho Rd Etche L.G.A	Ndoni Rd Ogba/Egbema/Ndoni L.G.A	Ogbele Rd Ahoda East L.G.A
Depth of sampling (m)	1.2	1.2	1.2	1.2
Percentage(%) passing BS sieve #200	76.35	80.25	83.65	78.25
Colour	greenish	Greenish	greenish	greenish
Specific gravity	2.52	2.58	2.45	2.44
Natural moisture content (%)	42.58	48.35	44.65	44.30
Consistency Limits				
Liquid limit (%)	68.35	53.85	62.40	58.75
Plastic limit (%)	37.25	29.30	31.35	26.58
Plasticity Index	31.10	24.55	31.05	32.17
AASHTO soil classification Unified Soil Classification System	A-7-6 CH	A-7-6 CH	A-7-6 CH	A-7-6 CH
Optimum moisture content (%)	15.28	16.28	16.05	15.73
Maximum dry density (kN/m$^{3)}$	1.685	1.635	1.657	1.697
Compaction Characteristics				
Gravel (%)	0.0	0	0	0
Sand (%)	13.18	12.3	12.8	16.5
Silt (%)	42.3	48.5	42.3	48.2
Clay (%)	44.6	38.2	44.9	35.3
Unconfined compressive strength (kPa)	87.85	78.75	105.75	85.35
California Bearing Capacity (CBR)				
Unsoaked (%) CBR	7.35	7.75	8.15	7.85
Soaked (%) CBR	6.35	6.23	7.05	5.55

Table 3.2: Results of Maximum Dry Density (MDD) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0+10%
MDD (Clay + Cement + IGF) IWOFE TOWN ROAD	1.69	1.77	1.89	1.91	1.93
MDD (kN/m3) (Clay + Lime + IGF) IWOFE TOWN ROAD	1.69	1.70	1.74	1.85	1.92
MDD (Clay + Cement + IGF) CHOKOCHO TOWN	1.64	1.64	1.73	1.78	1.81

ROAD					
MDD (kN/m3) (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	1.64	1.66	1.70	1.74	1.79
MDD (Clay + Cement + IGF) NDONI TOWN ROAD	1.66	1.69	1.71	1.76	1.84
MDD (kN/m3) (Clay + Lime + IGF) NDONI TOWN ROAD	1.66	1.68	1.69	1.73	1.77
MDD (Clay + Cement + IGF) IWOFE TOWN ROAD	1.70	1.72	1.76	1.80	1.82
MDD (kN/m3) (Clay + Lime + IGF) IWOFE TOWN ROAD	1.70	1.71	1.72	1.78	1.81

Table 3.2A: Results of Maximum Dry Density (MDD) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
MDD (Clay + Cement + IGF) IWOFE TOWN ROAD	1.05%	9.28%	16.40%	17.77%	18.78%
MDD (kN/m3) (Clay + Lime + IGF) IWOFE TOWN ROAD	1.01%	1.18%	3.56%	10.09%	14.71%
MDD (Clay + Cement + IGF) CHOKOCHO TOWN ROAD	1.00%	0.24%	5.81%	8.81%	10.70%
MDD (kN/m3) (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	1.01%	2.67%	5.06%	7.44%	10.62%
MDD (Clay + Cement + IGF) NDONI TOWN ROAD	1.02%	3.71%	4.73%	7.93%	13.00%
MDD (kN/m3) (Clay + Lime + IGF) NDONI TOWN ROAD	1.01%	2.16%	3.19%	5.18%	8.08%
MDD (Clay + Cement + IGF) IWOFE TOWN ROAD	1.01%	2.11%	4.94%	6.82%	8.47%
MDD (kN/m3) (Clay + Lime + IGF) IWOFE TOWN ROAD	1.01%	1.29%	2.24%	5.71%	7.54%

Table 3.3: Results of Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
OMC%(Clay + Cement+ IGF) IWOFE TOWN ROAD	15.28	15.65	15.93	16.24	16.75
OMC%(Clay + Lime + IGF) IWOFE TOWN ROAD	15.28	15.43	15.82	16.05	16.57
OMC%(Clay + Cement+ IGF) CHOKOCHO TOWN ROAD	16.28	16.48	16.80	16.94	17.15
OMC%(Clay + Lime + IGF) CHOKOCHO TOWN ROAD	16.28	16.33	16.86	16.95	17.09
OMC%(Clay + Cement+ IGF) NDONI TOWN ROAD	16.05	16.36	16.74	17.03	17.35
OMC%(Clay + Lime + IGF) NDONI TOWN ROAD	16.05	16.25	16.63	16.94	17.15
OMC%(Clay + Cement+ IGF) IWOFE TOWN ROAD	15.73	15.85	16.15	16.55	16.83
OMC%(Clay + Lime + IGF) IWOFE TOWN ROAD	15.73	15.93	16.15	16.38	16.73

Table 3.3A: Results of Optimum Moisture Content (OMC) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0+10%

OMC%(Clay + Cement+ IGF) IWOFE TOWN ROAD	1.0242%	4.7857%	6.6181%	8.6469%	11.985%
OMC%(Clay + Lime + IGF) IWOFE TOWN ROAD	1.0098%	1.9538%	4.5062%	6.0114%	9.4145%
OMC%(Clay + Cement+ IGF) CHOKOCHO TOWN ROAD	1.0123%	2.4421%	4.4077%	5.2676%	6.5576%
OMC%(Clay + Lime + IGF) CHOKOCHO TOWN ROAD	1.0031%	0.6133%	3.8688%	4.4217%	5.2816%
OMC%(Clay + Cement+ IGF) NDONI TOWN ROAD	1.0193%	3.8263%	6.1939%	8.0008%	9.9946%
OMC%(Clay + Lime + IGF) NDONI TOWN ROAD	1.0125%	2.4769%	4.8445%	6.7759%	8.0844%
OMC%(Clay + Cement+ IGF) IWOFE TOWN ROAD	1.0076%	1.5200%	3.4272%	5.9701%	7.7501%
OMC%(Clay + Lime + IGF) IWOFE TOWN ROAD	1.0127%	2.5269%	3.9255%	5.3877%	7.6128%

Table 3.4: Results of California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
UNSOAKED CBR (Clay + Cement + IGF) IWOFE TOWN ROAD	7.35	31.45	53.65	76.35	63.85
UNSOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	7.35	28.32	43.45	69.78	58.75
SOAKED CBR(Clay + Cement+ IGF) IWOFE TOWN ROAD	6.35	25.30	48.65	69.35	57.82
SOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	6.35	23.45	38.33	63.45	53.45
UNSOAKED CBR (Clay + Cement + IGF) CHOKOCHO TOWN ROAD	7.75	29.83	57.80	78.85	66.37
UNSOAKED CBR (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	7.75	31.45	50.85	71.35	64.32
SOAKED CBR(Clay + Cement+ IGF) CHOKOCHO TOWN ROAD	6.23	25.15	49.30	69.85	61.65
SOAKED CBR (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	6.23	26.45	48.25	64.85	55.60
UNSOAKED CBR (Clay + Cement + IGF) NDONI TOWN ROAD	8.15	34.35	59.35	82.45	73.85
UNSOAKED CBR (Clay + Lime + IGF) NDONI TOWN ROAD	8.15	36.65	52.75	78.30	63.65
SOAKED CBR(Clay + Cement+ IGF) NDONI TOWN ROAD	7.05	28.35	52.38	76.30	69.85
SOAKED CBR (Clay + Lime + IGF) NDONI TOWN ROAD	7.05	30.85	48.75	73.55	57.30
UNSOAKED CBR (Clay + Cement + IGF) IWOFE TOWN ROAD	7.85	28.82	47.45	73.45	58.85
UNSOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	7.85	28.60	43.83	68.80	58.95
SOAKED CBR(Clay + Cement+ IGF) IWOFE TOWN ROAD	5.55	22.45	38.67	67.28	52.35
SOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	5.55	23.35	37.32	59.85	53.40

Table 3.4A: Results of California Bearing Ratio (CBR) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
UNSOAKED CBR (Clay + Cement + IGF) IWOFE TOWN ROAD	4.2789%	404.52%	706.56%	1015.41%	845.34%
UNSOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	3.8531%	359.35%	565.20%	923.43%	773.37%
SOAKED CBR(Clay + Cement+ IGF) IWOFE TOWN ROAD	3.9843%	373.33%	741.04%	1067.03%	885.45%
SOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	3.6929%	342.21%	576.54%	972.13%	814.65%
UNSOAKED CBR (Clay + Cement + IGF) CHOKOCHO TOWN ROAD	3.8490%	358.92%	719.83%	991.44%	830.41%
UNSOAKED CBR (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	4.0581%	381.16%	631.49%	896.00%	805.29%
SOAKED CBR(Clay + Cement+ IGF) CHOKOCHO TOWN ROAD	4.0369%	378.92%	766.56%	1096.42%	964.80%
SOAKED CBR (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	4.2456%	401.00%	750.92%	1017.38%	868.90%
UNSOAKED CBR (Clay + Cement + IGF) NDONI TOWN ROAD	4.2147%	397.75%	704.49%	987.93%	882.41%
UNSOAKED CBR (Clay + Lime + IGF) NDONI TOWN ROAD	4.4969%	427.46%	625.00%	938.50%	758.74%
SOAKED CBR(Clay + Cement+ IGF) NDONI TOWN ROAD	4.0213%	377.26%	718.11%	1057.40%	965.91%
SOAKED CBR (Clay + Lime + IGF) NDONI TOWN ROAD	4.3759%	414.74%	668.64%	1020.41%	789.91%
UNSOAKED CBR (Clay + Cement + IGF) IWOFE TOWN ROAD	3.6713%	339.90%	577.22%	908.43%	722.44%
UNSOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	3.6433%	336.88%	530.90%	848.99%	723.51%
SOAKED CBR(Clay + Cement+ IGF) IWOFE TOWN ROAD	4.0450%	379.78%	672.04%	1187.53%	918.52%
SOAKED CBR (Clay + Lime + IGF) IWOFE TOWN ROAD	4.2072%	396.95%	648.66%	1054.61%	938.39%

Table 3.5: Results of Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
LL(Clay + Cement+ IGF) IWOFE TOWN ROAD	68.35	68.52	68.75	69.05	69.38
LL (Clay + Lime + IGF) IWOFE TOWN ROAD	68.35	68.45	67.45	67.78	67.91

LL(Clay + Cement+ IGF) CHOKOCHO TOWN ROAD	53.85	54.06	54.35	54.62	54.95
LL (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	53.85	53.90	54.25	54.75	54.85
LL(Clay + Cement+ IGF) NDONI TOWN ROAD	62.40	62.78	63.98	63.63	63.28
LL (Clay + Lime + IGF) NDONI TOWN ROAD	62.40	62.65	62.85	63.08	63.38
LL(Clay + Cement+ IGF) IWOFE TOWN ROAD	58.25	58.53	58.72	58.93	59.20
LL (Clay + Lime + IGF) IWOFE TOWN ROAD	58.25	58.48	58.81	59.05	59.14

Table 3.5A: Results of Liquid Limit (LL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
LL(Clay + Cement+ IGF) IWOFE TOWN ROAD	1.0025%	0.4968%	0.8333%	1.2722%	1.7551%
LL (Clay + Lime + IGF) IWOFE TOWN ROAD	1.0015%	0.2924%	-1.1707%	-0.6892%	-0.498%
LL(Clay + Cement+ IGF) CHOKOCHO TOWN ROAD	1.0039%	0.7784%	1.3170%	1.8184%	2.4312%
LL (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	1.0009%	0.1856%	0.8356%	1.7641%	1.9498%
LL(Clay + Cement+ IGF) NDONI TOWN ROAD	1.0061%	1.2143%	3.1373%	2.5764%	2.0155%
LL (Clay + Lime + IGF) NDONI TOWN ROAD	1.0040%	0.7997%	1.1202%	1.4888%	1.9696%
LL(Clay + Cement+ IGF) IWOFE TOWN ROAD	1.0048%	0.9591%	1.2853%	1.6458%	2.1093%
LL (Clay + Lime + IGF) IWOFE TOWN ROAD	1.0039%	0.7881%	1.3547%	1.7667%	1.9212%

Table 3.6: Results of Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
PL(Clay + Cement + IGF) IWOFE TOWN ROAD	37.25	38.67	39.30	39.99	40.43
PL (Clay + Lime + IGF) IWOFE TOWN ROAD	37.25	38.55	38.65	38.95	39.12
PL(Clay + Cement + IGF) CHOKOCHO TOWN ROAD	29.30	29.90	30.39	30.88	31.57
PL (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	29.30	29.55	30.19	30.89	31.28
PL (Clay + Lime + IGF) NDONI TOWN ROAD	31.35	32.80	33.24	33.87	34.53
PL (Clay + Cement + IGF) NDONI TOWN ROAD	31.05	29.53	30.46	30.05	28.64
PL(Clay + Cement + IGF) IWOFE TOWN ROAD	26.58	26.60	27.08	27.29	28.27
PL (Clay + Lime + IGF) IWOFE TOWN ROAD	26.58	26.63	27.31	27.82	28.21

Table 3.6A: Results of Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
PL(Clay + Cement + IGF) IWOFE TOWN ROAD	1.0381%	7.4842%	9.1755%	11.0278%	12.21%

PL (Clay + Lime + IGF) IWOFE TOWN ROAD	1.0349%	6.8622%	7.1306%	7.9360%	8.3924%
PL(Clay + Cement + IGF) CHOKOCHO TOWN ROAD	1.0205%	4.0545%	5.7268%	7.3992%	9.7541%
PL (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	1.0085%	1.6993%	3.8836%	6.2726%	7.6037%
PL (Clay + Lime + IGF) NDONI TOWN ROAD	1.0463%	9.05%	10.45%	12.46%	14.56%
PL (Clay + Cement + IGF) NDONI TOWN ROAD	0.9510%	6.043%	7.047%	8.3679%	12.909%
PL(Clay + Cement + IGF) IWOFE TOWN ROAD	1.0008%	0.1504%	1.9563%	2.7464%	6.4334%
PL (Clay + Lime + IGF) IWOFE TOWN ROAD	1.0019%	0.3759%	2.9342%	4.8529%	6.3202%

Table 3.7: Results of Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
IP (Clay + Cement + IGF) IWOFE TOWN ROAD	31.10	29.85	29.45	29.06	28.95
IP (Clay + Lime + IGF) IWOFE TOWN ROAD	31.10	29.90	29.00	28.80	28.62
IP (Clay + Cement + IGF) CHOKOCHO TOWN ROAD	24.55	24.16	23.96	23.74	23.38
IP (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	24.55	24.35	24.06	23.86	23.57
IP (Clay + Cement + IGF) NDONI TOWN ROAD	31.05	29.53	30.46	30.05	28.64
IP (Clay + Lime + IGF) NDONI TOWN ROAD	31.05	29.85	29.61	29.21	28.85
IP (Clay + Cement + IGF) IWOFE TOWN ROAD	32.17	31.93	31.64	31.20	30.93
IP (Clay + Lime + IGF) IWOFE TOWN ROAD	32.17	31.85	31.51	31.23	30.93

Table 3.7A: Results of Plastic Limit (PL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
IP (Clay + Cement + IGF) IWOFE TOWN ROAD	0.9598%	-8.2069%	-9.4931%	-10.7471%	-11.101%
IP (Clay + Lime + IGF) IWOFE TOWN ROAD	0.9614%	-7.8719%	-10.766%	-11.4089%	-11.988%
IP (Clay + Cement + IGF) CHOKOCHO TOWN ROAD	0.9841%	-3.2028%	-4.0175%	-4.9136%	-6.3800%
IP (Clay + Lime + IGF) CHOKOCHO TOWN ROAD	0.9919%	-1.6360%	-2.8173%	-3.6319%	-4.8132%
IP (Clay + Cement + IGF) NDONI TOWN ROAD	0.9510%	-10.043%	-7.0475%	-8.3679%	-12.909%
IP (Clay + Lime + IGF) NDONI TOWN ROAD	0.9614%	-7.8848%	-8.6578%	-9.9460%	-11.105%
IP (Clay + Cement + IGF) IWOFE TOWN ROAD	0.9925%	-1.4977%	-2.3991%	-3.7669%	-4.6062%
IP (Clay + Lime + IGF) IWOFE TOWN ROAD	0.9901%	-1.9994%	-3.0563%	-3.9267%	-4.8592%

Table 3.8: Results of Unconfined Compressive Strength (UCS) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5+ 5.0%	91.75+0.75 +7.5%	89+1.0 +10%

UCS(KPA) (CLAY + CEMENT + IGF) IWOFE TOWN RD	87.85	156.00	287.00	338.00	589.00
UCS(KPA) (CLAY + LIME + IGF) IWOFE TOWN RD	87.85	138.00	267.00	325.00	550.00
UCS(KPA) (CLAY + CEMENT + IGF) CHOKOCHO TOWN RD	78.75	143.00	304.00	438.00	603.00
UCS(KPA) (CLAY + LIME + IGF) CHOKOCHO TOWN RD	78.75	131.00	265.00	397.00	578.00
UCS(KPA) (CLAY + CEMENT + IGF) NDONI TOWN RD	105.78	206.00	315.00	465.00	645.00
UCS(KPA) (CLAY + LIME + IGF) NDONI TOWN RD	105.78	183.00	297.00	495.00	638.00
UCS(KPA) (CLAY + CEMENT + IGF) OGBELE TOWN RD	83.35	196.00	289.00	466.00	615.00
UCS(KPA) (CLAY + LIME + IGF) OGBELE TOWN RD	83.35	180.00	295.00	426.00	565.00

Table 3.8A: Results of Unconfined Compressive Strength (UCS) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	97.25+0.25 +2.5%	94.5+ 0.5 + 5.0%	91.75+0.75 +7.5%	89+1.0 +10%
UCS(KPA) (CLAY + CEMENT + IGF) IWOFE TOWN RD	1.7758%	121.26%	270.38%	328.43%	614.15%
UCS(KPA) (CLAY + LIME + IGF) IWOFE TOWN RD	1.5709%	93.43%	240.27%	306.29%	562.41%
UCS(KPA) (CLAY + CEMENT + IGF) CHOKOCHO TOWN RD	1.8159%	126.52%	330.96%	501.12%	710.64%
UCS(KPA) (CLAY + LIME + IGF) CHOKOCHO TOWN RD	1.6635%	106.23%	276.39%	444.01%	673.85%
UCS(KPA) (CLAY + CEMENT + IGF) NDONI TOWN RD	1.9474%	143.39%	246.44%	388.24%	558.41%
UCS(KPA) (CLAY + LIME + IGF) NDONI TOWN RD	1.7300%	115.20%	222.97%	410.15%	545.34%
UCS(KPA) (CLAY + CEMENT + IGF) OGBELE TOWN RD	2.3515%	192.63%	304.21%	516.56%	695.33%
UCS(KPA) (CLAY + LIME + IGF) OGBELE TOWN RD	2.1596%	169.65%	307.62%	464.79%	631.56%

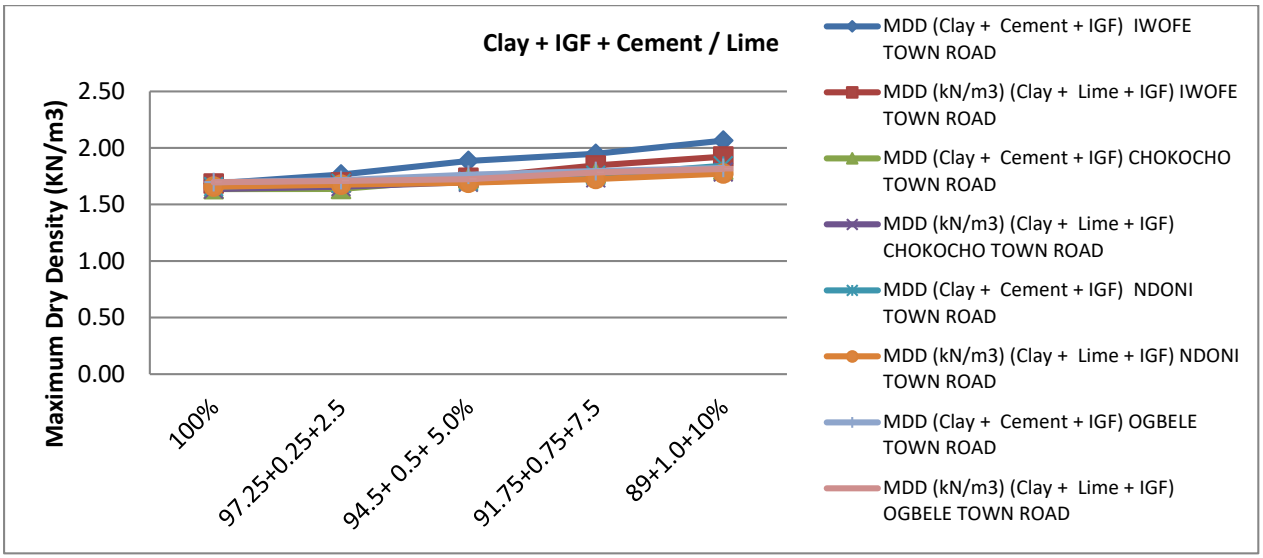

Figure 3.1: Maximum Dry Density (MDD) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

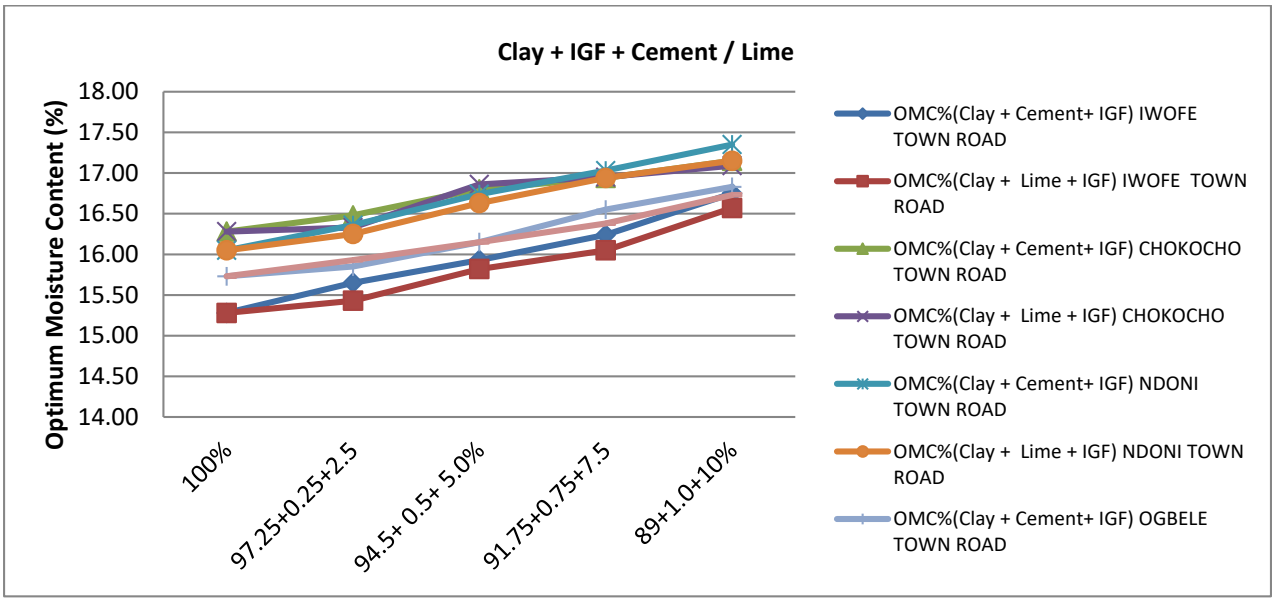

Figure 3.2: Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

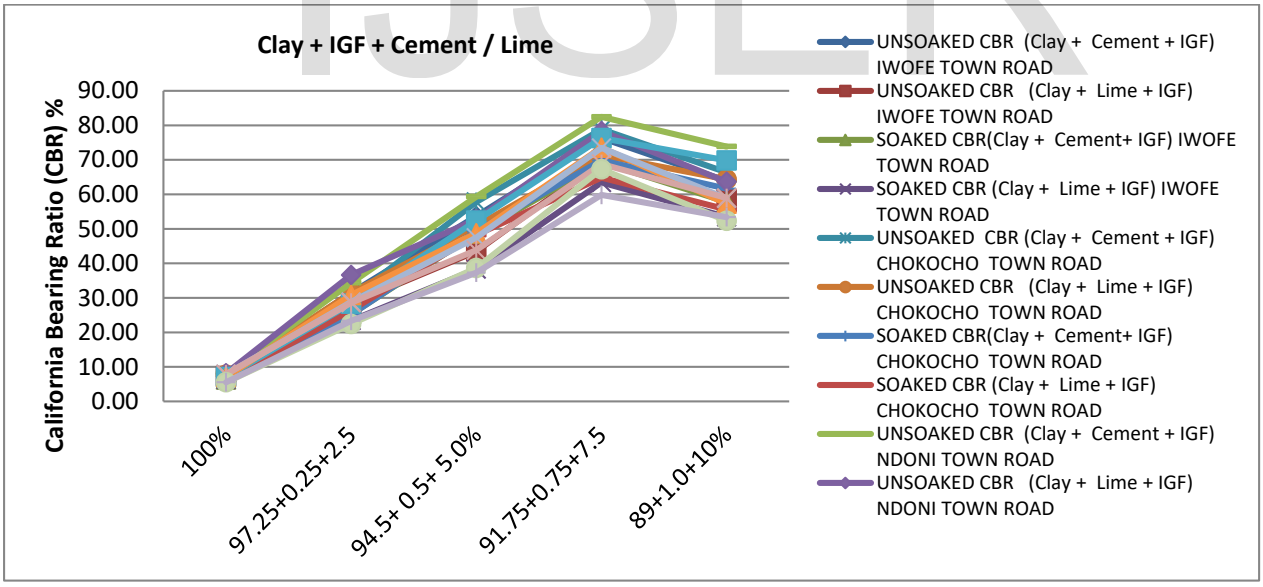

Figure 3.3: California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

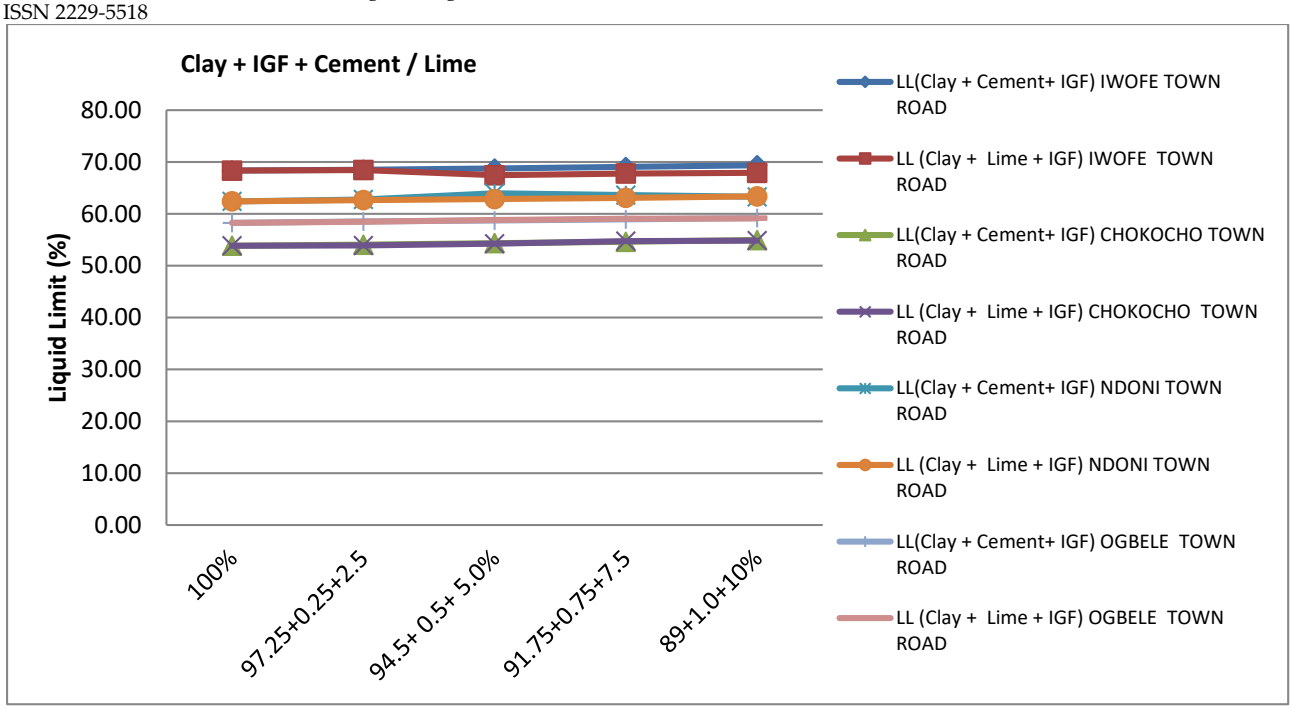

Figure 3.4: Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

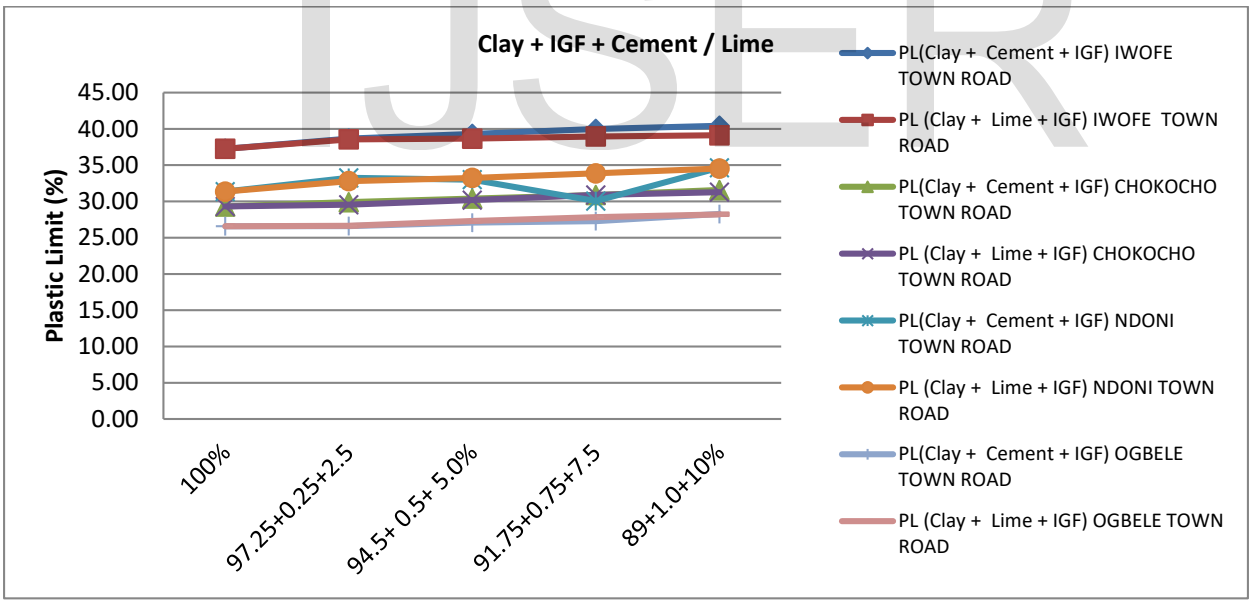

Figure 3.5: Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

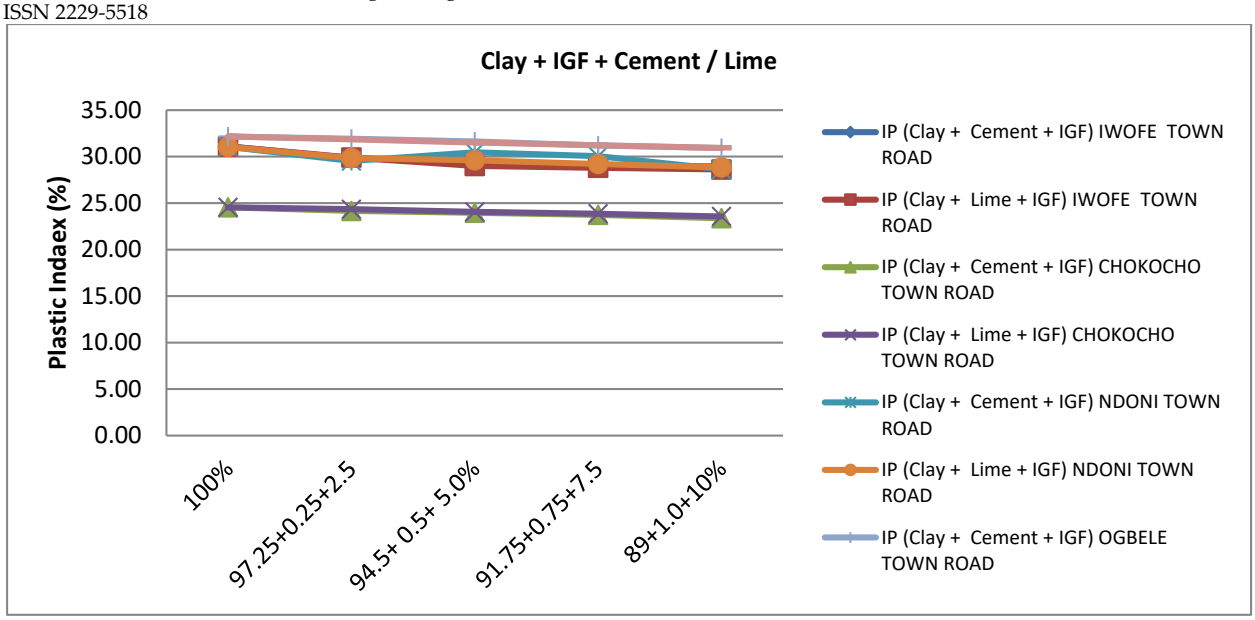

Figure 3.6: Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

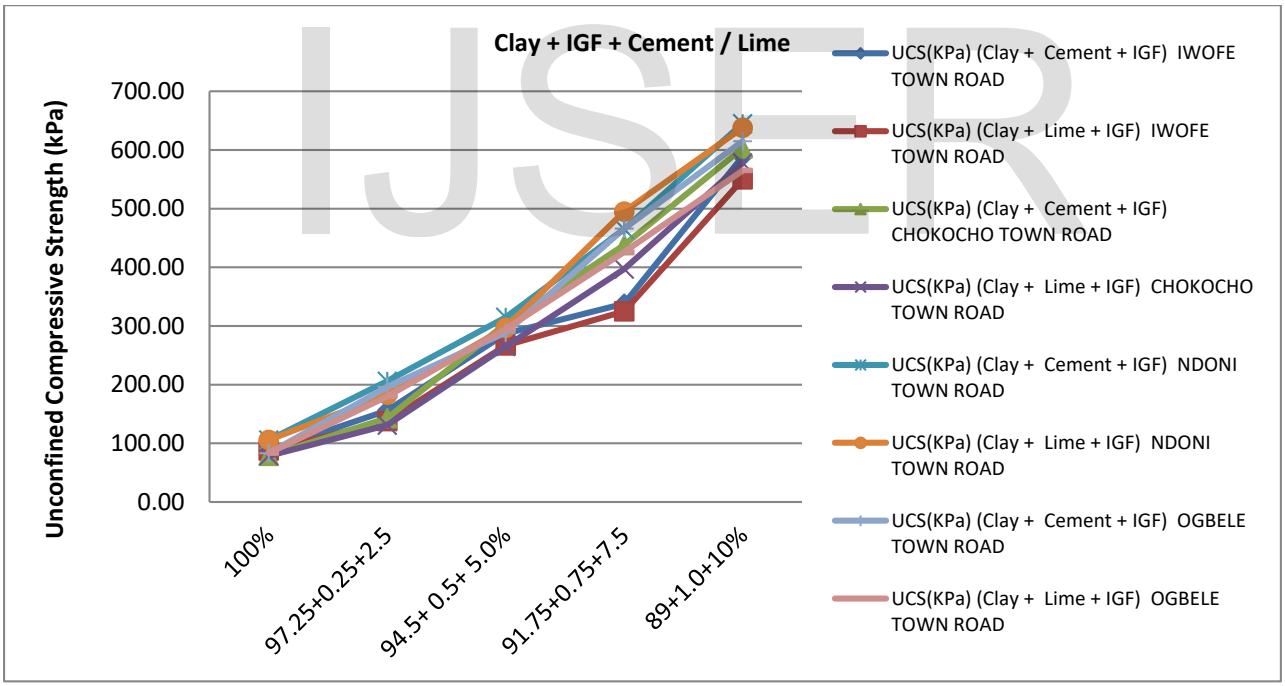

Figure 3.7: Unconfined Compressive Strength (UCS) of Niger Deltaic Clay Soils Subgrade with IGF + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

4.0 Conclusions

The following conclusions were made from the experimental research results.

i. Preliminary results on clay soils as seen in detailed test results given in Tables: 3.1 showed that the physical and engineering properties fall below the minimum requirement for such application and needs stabilization to improve its properties

ii. The soils classified as A - 7 - 6 / CH on the AASHTO classification schemes / Unified Soil Classification System as shown in table 3.

iii. The soil has unsoaked CBR values of 7.35%, 7.75%, 8.15%, and 7.85% and soaked CBR values of 6.35%, 6.23%, 7.05% and 5.55%, unconfined compressive strength values of 87.85kPa , 78.75kPa, 105.75kPa and 85.35kPa.

iv. Entire compaction test results showed incremental percentile value of maximum dry density (MDD) and optimum moisture content (OMC) of composite stabilized clay soils hybridized with cement / lime + IGF with increase in mix ratio to soils

v. Stabilized California bearing ratio (CBR) composite materials of cement, lime and IGF showed incremental percentile values with ratio variation. Both cementitious materials showed percentile increased to optimum mix ratio of 91.75+0.75+7.5%. Declined percentile values were observed beyond optimum with cracks formation.

vi. Unconfined compressive strength results of composite stabilized clay soils with cement / lime + IGF showed incremental percentile values with respect to percentageof composite mix ratio.

vii. Consistency limit test of plastic index indicated decreased in values with respect to increase in percentile values of composite materials to soil ratio.

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