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Comparative Stabilization and Model Prediction of Geotechnical Parameters of Ebekpo Residual Soils, Akwa Ibom State, Nigeria

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Abstract The major objective of stabilizing Ebekpo residual soil was to ascertain the structural response to imposed mechanical systems. The second consideration was to establish levels of improvement of geotechnical properties for engineering applications. River sand and ordinary Portland cement were the two modifiers deployed for this laboratory experiments. Four different soil samples from four distinct borrow pits were utilized. River sand content varied from 10% to 70% while residual soil content complimented with 90% to 30% respectively. CBR results from river sand stabilization based on measured values ranged from 56% to 90% at optimal level. Conversely stabilization with ordinary Portland cement ranged from 2% to 10% and the CBR ranged from 74% to 113% for measured values. From the results cement stabilization tends to generate higher values of CBR. This could be attributed to the contribution of hydrated calcium silicates and calcium aluminates in cement which tend to increase the bonding between particulate structures resulting in plasticity reduction hence gaining in strength propagation. Finally multiple non-linear regressed models were developed to aid prediction and optimization of CBR parameters of Ebekpo residual soils at various levels of stabilization.

Keywords Residual soil, River sand, Cement, Stabilization, Models.

1. Introduction

The topography of Ebekpo area is basically undulating and covered by granitic residual soils. These soils are unique in formation, pleasing in appearance and deceptive in engineering applications. Stabilization is an improvement process designed to achieve a relatively higher shearing resistance, loading capacity, stability and settlement in soils applied for engineering purposes. River sands as a stabilizer will provide sufficient fines to fill the voids thus giving a compact and high load bearing capacity. In all practical cases, the primary ingredient necessary for stabilizing soils is calcium [% of cement]. In addition to plasticity reduction, Portland cement, by its inherent nature of producing strength – developing hydration products, provides improved strength and durability. Therefore the effectiveness of stabilization is based on the number of positions of exchangeable ions – mineralogical composition which is related to liquid limit and the amount of liberated calcium ions from cement [% of cement, % of compaction and curing time] which influences the durability [bonding effect] and unconfined compressive strength [bearing capacity]. Soils most suitable for cement stabilization are mixtures of sand and gravel of good grade, and with less than 10% fines passing 75mm sieve and with coefficient of uniformity of not less than 5. Any type of cement can be used to stabilize soil, but the most commonly used is the ordinary Portland cement. The presence of organic and sulphate materials inside the soil is generally believed to prevent the cement from hardening [1].

2. Materials Selected

2.1 Ebekpo Residual Soil

Four soil samples selected for this research was dug with shovels from four distinct borrow pits. The samples' locations are identified as detailed below:

Sample Identification	Location
1	Km1+250Ebekpo - Ebidang road.
2	Km3+750Ebekpo - Ebidangroad.
3	Km6+250 Ebekpo-Ebidangroad.
4	Km7+000Ebekpo-Ebidang road.

The samples were excavated bearing in mind the variability of residual soil in its natural composition. The soil samples were excavated both vertically and horizontally and thoroughly blended. The samples were conveyed in four, 50 kg nylon bags, carefully tagged for identification purpose and transported to Mothercat Limited, Materials Testing Laboratory at Uyo.

2.2 River Sand

This is one of the most abundant stabilizing materials within the coastal plains and tributaries of the Atlantic. The material was obtained from a tributary of the Atlantic river leading to Onna. The deleterious and silty substances were thoroughly removed by washing. The material was then air-dried before particle size gradation through sieve analysis. The air-dried sample was separated through the riffle box and 1000 g utilized for this experiment. The sample was sieved from 10 mm through 0.075 mm in a mechanical shaker. Sand plays a vital role in enhancing the bond in cementation reactions of soil mixing. It is found that grain size distribution provides a satisfactory skeleton, and the voids are filled with fine sand giving a compact and high load bearing capacity. From analysis the sand is observed to have a d_{50} equal to 0.650 mm, d_{30} equal to 0.445 mm and d_{10} of 0.320 mm.

2.3 Cement

The cement used in this research was the Ordinary Portland cement (OPC). It was purchased from Ewet market in Uyo. This cement is the most widely used in the construction industry in Uyo, Akwa Ibom State. Cement stabilization is mostly applicable to road stabilization and fills especially when the moisture content of the sub-grade is very high [2]. Ordinary Portland Cement particle is a heterogeneous substance, containing minute tri-calcium silicate(C_3S), di-calcium silicate (C_2S), tri-calcium aluminate (C_3A) and solid solution described as tetra calcium alumino-ferrite (C_4A). When the pore water of the soil encounters with cement, hydration of the cement occurs rapidly and the major hydration (primary cementations) produces hydrated calcium silicate (C_2SHx, C_4AHx) and hydrated lime $Ca(OH)_2$ [3].

3. Preparation and Testing of Samples

3.1 Plain Mechanical Compaction tests

This test was conducted to determine the mass of dry soil per cubic meter and the soil was compacted in a specified manner over a range of moisture contents, including that giving the maximum mass of dry soil per cubic meter. For each of the samples, the Modified Proctor Compaction tests were conducted. The air-dried material was divided into five equal parts through a riffle box and weighed to 6000g each. Each sample was poured into the mixing plate. A particular percentage of distilled water was poured into each plate and thoroughly mixed with a trowel. An interval of about 1hour was allowed for the moisture to fully permeate the soil sample. The sample was thereafter divided into five equal parts, weighed and each was poured into the compaction mould, in five layers and compacted at 61 blows each using a 4.5kg rammer falling over a height of 450mm above the top of the mould. The blows were evenly distributed over the surface of each layer. The collar of the mould was then removed and the compacted sample weighed while the corresponding moisture content was noted. The procedure was repeated with different moisture contents until the weight of compacted sample was noted to be decreasing. With the optimum moisture content obtained from the Modified Proctor test, samples were prepared and inserted into the CBR mould and values for the plain mechanical compaction were read for both top and bottom at various depths of penetration.

3.2 River Sand- Ebekpo Residual Soil Stabilization Tests

River sand samples ranging from 10%, 20%, 30%, 40%, 50%, 60% to 70% by weight of the air-dried residual soils were utilized in this stabilization tests. For each of the residual soil samples 1, 2, 3 and 4 different proportions of a 6000g weight ranging from 90%, 80%, 70%, 60%, 50%, 40%, to 30% were correspondingly mixed thoroughly with the river sand to obtain 100% on each sample combination. Liquid limit and plastic limit tests as well as Modified Proctor compaction were carried out on the mixture. With the values of OMC and MDD derived from the Modified Proctor compaction tests, samples were prepared and inserted into the CBR machine and the penetration readings carried out accordingly. It must be noted that on application of 60% to 70% river sand contents the CBR values started falling thus confirming the decreasing to non-plastic nature of the mixture within this range.

3.3 Cement-Ebekpo Residual Soil Stabilization Tests

Four residual soil samples were utilized in this experiment. The percentage of cement ranged from 2%, 4%, 6% to 8%. The percentage of residual soil ranged from 10%, 20%, 30%, 40% to 50%. For each cement content the percentage or proportion of residual soil was varied from 10% to 50%. It is an established fact that the measurement of the strength of soil-cement mixture in laboratory and the determination of the parameters which affect it is very important for the estimation of the strength of mixture *in-situ* [4]. The mixture was thoroughly blended and moisturised and modified proctor compaction test was conducted to establish the OMC and MDD. With the OMC and MDD results, three specimens each were prepared for the CBR test. One specimen was tested immediately while the remaining two were wax-cured for 6days and thereafter soaked for 24 hours, and allowed to drain for 15minutes. After testing in CBR machine, the average of the two readings was adopted. This procedure meets the provision of clause 6228 design criteria [5].

3.4 California Bearing Ratio (CBR) Test

The CBR test (as it is commonly known) involves the determination of the load-deformation curve of the soil in the laboratory using the standard CBR testing equipment. It was originally developed by the California Division of Highways prior to World War 11 and was used in the design of some highway pavements. This test has now been modified and is standardized under the AASHTO designation of T193. With the OMC and MDD results, three specimens each were prepared for the CBR test. One specimen was tested immediately while the remaining two were wax-cured for 6days and thereafter soaked for 24 hours, and allowed to drain for 15minutes. After testing in CBR machine, the average of the two readings was adopted. This procedure meets the provision of clause 6228 design criteria.

4. Presentation of Test Results

Table1: Ebekpo Residual SoilCompaction at Plain Condition

Sample No.	MDD (Kg/m^3)	NMC (%)	Unsoaked CBR (%)	Fines (%)
1	1900	12.5	53	33
2	1830	14.6	63	30
3	2010	10.5	59	32
4	1920	14.8	66	29

Table 2: Ebekpo Residual Soil and River Sand Classification – Sample No 1

River sand Content (%)	MDD (Kg/m^3)	OMC (%)	CBR (Unsoaked %)	LL	PL	PI	% passing Sieve 200	Classification	
								AASHTO	USCS
0	1900	12.5	53	35	24	9	31	A- 2 -6	SC
10	1880	14.8	56	36	25	11	33	A- 2 – 4	SM
20	1800	14.0	74	34	23	11	31	A- 2 -5	SM
30	1820	13.5	81	24	15	9	29	A- 2 -4	SM
40	1930	12.2	90	24	19	5	21	A- 1 – b	SM
50	2050	10.4	82	23	20	3	20	A- 1 – b	SM
60	2010	8.0	70	20	NIL	NIL	18	A -1 - b	SM
70	1850	13.1	17	17	NIL	NIL	15	A – 1 - b	SM

Table 3: Ebekpo Residual Soil and River Sand Classification- Sample No 2

River sand Content (%)	MDD (Kg/m^3)	OMC (%)	CBR (Unsoaked %)	LL	PL	PI	% passing Sieve 200	Classification	
								AASHTO	USCS
0	1830	14.6	43	29	19	10	33	A- 2 -6	SC
10	1900	12.5	72	34	25	9	30	A- 2 – 4	SM
20	1990	12.8	74	30	18	12	27	A- 2 -5	SM
30	2010	11.6	83	28	21	7	24	A- 2 -6	SC
40	2060	8.3	95	27	20	7	21	A- 2 – 7	SC
50	1920	11.1	80	25	21	4	19	A- 1 – b	SM
60	1830	11.7	64	20	NIL	NIL	20	A -1 - b	SM
70	850	12.0	57	17	NIL	NIL	14		SM

Table 4: Ebekpo Residual Soil and River Sand Classification-Sample No 3

River sand Content (%)	MDD (g/m^3)	MC (%)	CBR (Unsoaked %)	LL	PL	PI	% passing Sieve 200	Classification	
								AASHTO	USCS
0	2010	10.5	59	29	20	9	32	A- 2 -6	SC
10	2000	10.6	65	33	23	10	30	A- 2 – 6	SC
20	1950	11.2	75	2	23	9	29	A- 2 -4	SM
30	2060	10.8	86	30	18	12	26	A- 2 -4	SM
40	2130	10.8	110	6	22	4	24	A- 2 – 4	SM
50	1960	10.0	71	18	NIL	NIL	22	A- 1 – b	SM
60	1910	9.7	67	19	NIL	NIL	18	A -1 - b	SM
70	1930	11.8	83	17	NIL	NIL	18	A – 1 - b	SM

Table 5: Ebekpo Residual Soil and River Sand Classification-Sample no 4

River sand Content (%)	MDD (Kg/m^3)	OMC (%)	CBR (Unsoaked %)	LL	PL	PI	% passing Sieve 200	Classification	
								AASHTO	USCS
0	1920	14.8	56	32	20	12	29	A- 2 -6	SC
10	2000	10.6	67	37	25	12	29	A- 2 – 6	SC
20	1940	10.4	78	23	15	8	28	A- 2 -4	SM
30	2060	7.6	90	28	20	8	22	A- 2 -4	SM
40	2130	9.6	115	18	NIL	NIL	25	A- 1 – b	SM
50	1960	10.6	82	20	NIL	NIL	25	A- 1 – b	SM
60	1900	6.7	68	14	NIL	NIL	16	A -1 - b	SM
70	1930	8.3	74	18	NIL	NIL	16	A – 1 - b	SM

Table 6: Ebekpo Residual Soil and Cement Classification-Sample No 1

Cement Content (%)	MDD (Kg/m^3)	OMC (%)	Soaked CBR (%)	LL	PL	PI	% passing Sieve 200	Classification	
								AASHTO	USCS
0	1960	10.7	14	37	21	16	33	A- 2 - 4	SM
2	2000	10.2	66	28	20	8	39	A- 2 - 4	SM
4	1940	12.2	71	28	21	7	40	A- 2 - 4	SM
6	2030	12.8	87	27	22	5	41	A- 2 - 4	SM
8	2040	13.1	93	17	NIL	NIL	43	A- 2 – 4	SM
10	2050	14.1	113	18	NIL	NIL	43	A- 2 - 4	SM

Table 7: Ebekpo Residual Soil and Cement Classification-Sample No 2

Cement Content (%)	MDD (Kg/m^3)	OMC (%)	soaked CBR (%)	LL	PL	PI	% passing Sieve 200	Classification	
								AASHTO	USCS
0	1940	10.5	32	29	25	4	35	A- 2 - 4	SM
2	2060	11.4	77	29	21	8	33	A- 2 - 4	SM
4	2130	13.1	82	28	22	4	34	A- 2 - 4	SM
6	2050	11.8	87	26	20	6	35	A- 2 - 4	SM
8	2070	13.2	94	26	20	6	36	A – 2 - 4	SM
10	2080	15.4	108	17	NIL	NIL	37	A – 2 - 4	SM

Table 8: Ebekpo Residual Soil and Cement Classification – Sample No 3

Cement Content (%)	MDD (Kg/m^3)	OMC (%)	soaked (%)	CBR	LL	PL	PI	% passing Sieve 200	Classification	
									AASHTO	USCS
0	1930	12.4	36		32	22	10	27	A- 2 - 4	SM
2	2110	12.2	74		29	20	9	28	A- 2 - 4	SM
4	2050	14.8	79		28	20	8	31	A- 2 - 4	SM
6	2050	11.3	84		27	20	7	32	A- 2 - 4	SM
8	2060	15.7	97		27	22	5	30	A- 2 – 4	SM
10	2050	15.2	113		18	NIL	NIL	32	A- 2 - 4	SM

Table 9: Ebekpo Residual Soil and Cement Classification-Sample no 4

Cement Content (%)	MDD (Kg/m^3)	OMC (%)	soaked CBR (%)	LL	PL	PI	% passing Sieve 200	Classification	
								AASHTO	USCS
0	1910	11.4	29	29	21	8	21	A- 2 - 4	SM
2	2130	14.2	76	32	20	12	27	A- 2 - 4	SM
4	2050	13.9	86	28	20	8	28	A- 2 - 4	SM
6	2060	12.5	116	29	21	8	30	A- 2 - 4	SM
8	2060	14.8	120	26	21	5	31	A- 2 – 4	SM
10	2350	13.2	124	18	NIL	NIL	34	A- 2 - 4	SM

5. Discussion of Test Results

Table 1 presents the results of Ebekpo residual soil compaction at plain or unstabilized condition. From the results the MDD varies from 1830kg/m^3 to 2010kg/m^3 within the four locations. NMC fluctuates from 12.5% to 14.8% while the CBR varies from 53% to 66% and Fines from 29% to 33%.

Tables 2 to 5 present the results of residual soil with river sand stabilization from the four distinct borrow pits. The classification method adopts both the plasticity limit and grain size distribution based systems. The advantage of combining the two classification methods is realized when dealing with the behaviour of the soil arising from application of various percentages of stabilizers. From all the samples and deploying 10% river sand and 90% residual soil content, the resulting MDD and CBR values are 1880kg/m^3, 1900kg/m^3, 2000kg/m^3, 2000kg/m^3 and 56%, 72%, 65%, 67% respectively. With increase in river sand content to 30% and reduced residual soil content to 70%, the resulting MDD and CBR values are 1820kg/m^3, 2010kg/m^3, 2060kg/m^3, 2060kg/m^3 and 81%, 83%, 86%, 90% respectively. A further increase above 50% river sand seems to set in a depreciating CBR values in all the samples.

Tables 6 to 9 present the results of residual soil and Portland cement stabilization. With 2% cement and 98% residual soil the resulting MDD and CBR are 2000kg/m^3, 2060kg/m^3, 2110kg/m^3, 2130kg/m^3 and 66%, 77%, 74%, 76% respectively. An increase in cement content to 6% and residual soil content set at 94% shows the MDD and CBR results as 2030kg/m^3, 2050kg/m^3, 2050kg/m^3, 2060kg/m^3 and 87%, 87%, 84%, 116%

respectively. The CBR values obtained with 30% river sand stabilization and with 6% stabilization are reasonably above the recommended minimum of 80% by the FMW&H(1997) specification.

6. Multiple Non-Linear Regressed Models

A model is essentially an idealized formulation designed to fit into a mathematical description. Based on analysis and utilizing multiple nonlinear regressed programs the following models were developed for evaluating the CBR values of Ebekpo residual soils at various levels of stabilization with river sand and cement. The models are developed for the purpose of prediction and optimization to determine for what values of the independent variables the dependent variable will be a maximum or minimum.

$CBR_{\{SI\}} = 57.291 + .303S - .261D - 3.809W + .021S^2 + 1.487D^2 + .034W^2 + .138SD + 0.183SW - 0.216DW$ ……………………………………………………………………….……….1.1

Where S = river sand content [%], D = maximum dry density [Mg/m^3], W = optimum moisture content [%]

$CBR_{\{S2\}} = 55.668 + .521S - 0.431D - 7.861W + 0.138S^2 + 2.538D^2 + 0.031W^2 + 0.224SD + 0.256SW + 0.482DW$ ………………….…………………………………………………….…..1.2

Where S = river sand content [%], D = maximum dry density [Mg/m^3], W = optimum moisture content [%]

$CBR_{\{C1\}} = 28.041 - 0.899C - 0.401D - 0.698W - 0.357C^2 + 0.191D^2 + 0.607W^2 + 0.124CD - 0.126CW - 0.293DW$ ……..1.3

Where C = cement content [%], D = maximum dry density [Mg/m^3], W = optimum moisture content [%]

$CBR_{\{C2\}} = 38.156 - 0.133C - 0.181D - 0.227W + 0.342C^2 - 0.873D^2 + 0.381W^2 + 0.553CD - 0.104CW - 0.113DW$ …………………….…………………………………………...…….1.4

Where C = cement content [%], D = maximum dry density [Mg/m^3], W = optimum moisture content [%]

Table 10: Multiple Regressed Variables for Measured and Computed CBR Values-Ebekpo Residual Soil and River Sand Stabilization Sample Location 1 & 2

River Sand Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
10	1.88	14.8	56	41.929
20	1.8	14	74	80.202
30	1.82	13.5	81	120.849
40	1.93	12.2	90	161.509
50	2.05	10.4	82	199.419
60	2.01	8	70	229.268
70	1.85	13.1	17	322.391
10	1.9	12.5	72	45.360
20	1.99	12.8	74	80.774
30	2.01	11.6	83	118.124
40	2.06	8.3	95	147.945
50	1.92	11.1	80	202.040
60	1.83	11.7	64	254.656
70	1.85	12	57	311.991

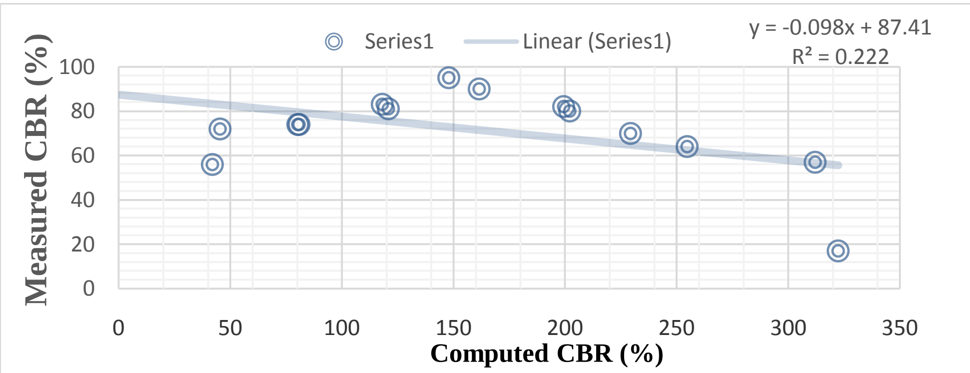

Figure 1: Ebekpo Residual Soil and River Sand Clasification (location 1& 2)

Table 11: Multiple Regressed Variables for Measured and Computed CBR Values – Ebekpo Residual Soil and River Sand Stabilization Sample Location Sample Location 3 & 4.

River Sand Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
10	2	10.6	65	25.522
20	1.95	11.2	75	101.497
30	2.06	10.8	86	210.161
40	2.13	10.8	110	345.211
50	1.96	10	71	500.618
60	1.91	9.7	67	684.561
70	1.93	11.8	83	919.258
10	2	10.6	83	25.522
20	1.94	10.4	128	103.817
30	2.06	7.6	136	212.092
40	2.13	9.6	110	342.829
50	1.96	10.6	117	503.398
60	1.9	6.7	129	663.106
70	1.93	8.3	140	885.126

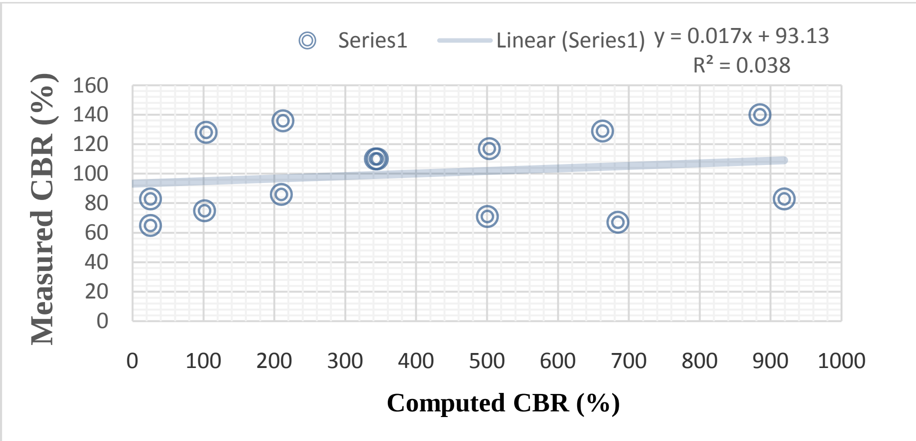

Figure 2: Ebekpo Residual Soil and River Sand Classification (location 3 & 4)

Table 12: Multiple Regressed Variables for Measured and Computed CBR Values-Ebekpo Residual Soil and Cement Stabilization Sample Location 1 & 2

Cement Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
2	2	10.2	66	72.758
4	1.94	12.2	71	88.383
6	2.03	12.8	87	84.505
8	2.04	13.1	93	73.990
10	2.05	14.1	113	70.474
2	2.06	11.4	77	86.485
4	2.13	13.1	82	100.047
6	2.05	11.8	87	71.575
8	2.07	13.2	94	75.281
10	2.08	15.4	108	90.340

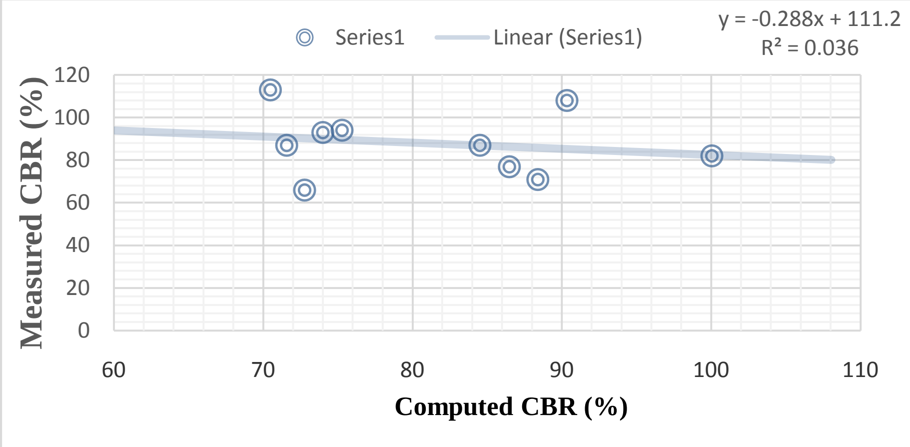

Figure 3: Ebekpo Residual Soil and Cement Clasification (location 1 & 2)

Table 13: Multiple Regressed Variables for Measured and Computed CBR Values-Ebekpo Residual Soil and Cement Stabilization Sample Location 3 & 4

Cement Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
2	2.11	12.2	74	85.815
4	2.05	14.8	79	114.100
6	2.05	11.3	84	88.848
8	2.06	15.7	97	137.648
10	2.05	15.2	113	143.569
2	2.13	14.2	76	104.498
4	2.05	13.9	86	105.046
6	2.06	12.5	116	98.412
8	2.06	14.8	120	128.352
10	2.35	13.2	124	124.931

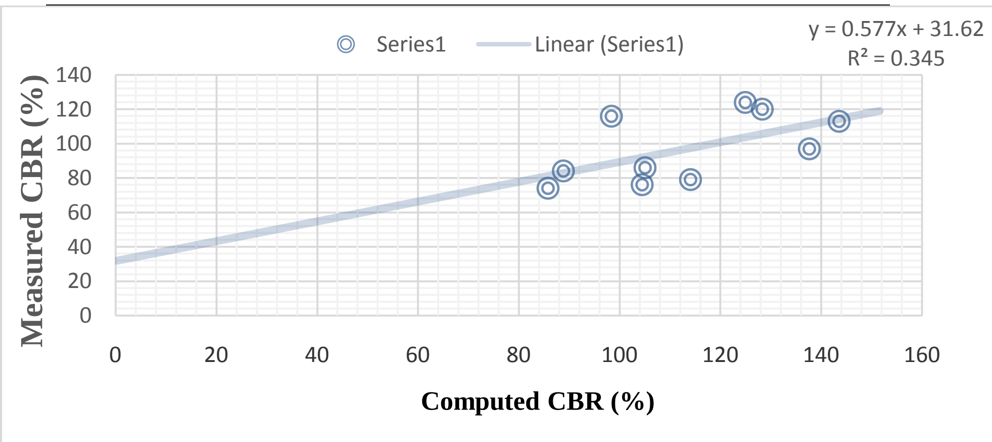

Figure 4: Ebekpo Residual Soil and Cement Clasification(location 3 & 4)

Conclusion

The multiple regressed variables for measured and computed CBR values resulting from river sand and cement stabilization are presented on Tables 10, 11, 12 and 13. Results from river sand stabilization involving samples from locations 1 & 2- Table 11-show variations from 56% to 80% and 42% to 199% for measured and computed CBR values with river sand content varying from 10% to 50%. The second location varied from 72% to 80% and 45% to 202% for measured and computed CBR values respectively with river sand content equally varying from 10% to 50%.

From Tables 2 & 3 it is observed that when river sand content exceeds 50% the sample is devoid of plasticity hence less useful in engineering applications.

From Table 13 samples from locations 3&4 are presented. Cement stabilization results varied from 74% to 97% and 85% to 137% for measured and computed CBR values at location 3 and 76% to 120% and 104% to 128% for measured and computed values at location 4. In both locations the cement content varied from 2% to 8%. Above 8% the sample is devoid of plasticity as reflected in tables 8 & 9.

The model 1.1 revealed that with 30% river sand and 70% residual soil stabilization, the measured and computed values are 81% and 120% respectively. These values are above recommended minimum of 80% by the FMW&H Specification [5]. Model 1.2 tends to generate higher computed CBR values. Models 1.3 though acceptable could further be optimized by subjecting the coefficients of the input variables to basic iteration. The models 1.1 and 1.4 are adequate for this research. The accuracy and reliability of models 1.1 to 1.4 were checked by comparing the measured and computed CBR values and computing the correlation coefficients. Figures 1 to 4 present the measured and computed values based on non-linear regressed models.

The correlation coefficients of recommended models R^2 at 95% confidence interval are 0.2228 and 0.3458. These values have statistical significance and therefore suggest compatibility of both the measured and computed CBR values.

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