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***Journal of Scientific and Engineering Research*, 2018, 5(6):88-96**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Influence of Stabilization on Performance of Udunghwo Dilatant Residual Soils, Akwa Ibom State, Nigeria

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Abstract River sand and lime were utilized for this stabilization experiments. River sand is a sedimentary product of transported soil. It is found in abundance within the tributary of Cross river and the Atlantic coastal plains. This material has a high percentage of fines which ranges from 30% to 35%. Its application increases the CBR values on a range varying between 10%, 20%, 30%, 40% of river sand to the residual soil against 66%, 73%, 114%, 130% CBR contents of Udunghwo residual soils respectively. Further increase in river sand content from 50% to 70% resulted in decreased values of CBR. The samples were equally devoid of plasticity, hence less useful for subbase and base course applications. Lime stabilized soil can be used for both subbase and base course materials. The oxides and hydroxides of calcium and magnesium are considered as lime, but the materials most commonly used for lime stabilization are calcium hydroxide $Ca(OH)_2$ and dolomite $Ca(OH)_2 + MgO$. The dolomite however should not have more than thirty-six percent by weight of magnesium oxide (MgO) to be acceptable as a stabilizing agent. The lime stabilized samples were soaked for ninety-six hours to ascertain the contribution of curing duration on the CBR parameters. Results obtained indicate variations along the range of 2%, 4%, 6%, 8%, 10% against 76%, 92%, 99%, 112%, 121% of lime and CBR values respectively. These values are statistically significant. Finally, multiple nonlinear regressed models were developed to aid prediction and optimization of CBR values of Udunghwo dilatant residual soils at various levels of stabilization.

Keywords Residual soil, River sand, Lime, Compaction, Stabilization

1. Introduction

Udunghwo is located within the tropical zone of Akwa Ibom State along the Coastal plains of the Niger Delta sub – region of Mbo Local Government Area. The topography of proposed road is slightly sloppy towards the Atlantic estuary. The geology of the project area is basically that of the Coastal Plains Sands of the lower Quaternary (Pliocene-Pleistocene) and Alluvium of Upper Quaternary (Recent Sediments) [1]. The soil structure within the area is predominantly dilatant. Improvement or stabilization measures are of essence in order to meet engineering applications.

1.1 River Sand Stabilization

Generally, soil stabilization is designed to improve the physical properties prior to deployment for engineering purposes. Several methods are available for stabilizing dilatant residual soils. These include: compaction, consolidation, admixtures, grouting, stone columns and reinforcement. The ability of any of these methods to improve soil properties depends on several factors, including; soil type, degree of saturation, initial relative density, initial in-situ stresses, initial soil structure and special characteristics of the method used. In most cases the goal of treating the soil is increasing shear strength and loading capacity, increasing stability and settlement control [2]. River sand contains substantial amount of fines. In addition to plasticity reduction river sand provides improved strength and durability. With adequate compaction, the structural composition is rearranged to improve the mobilized stresses, hence a reduction in plastic limit, thus influencing durability.

1.2 Lime Stabilization

This is one of the oldest processes of improving the engineering properties of soils. When lime is added to fine-grained soils, cat-ion exchange takes place, with the calcium and magnesium in the lime replacing the sodium and potassium in the soil. The tendency to swell as a result of increase in moisture content is therefore immediately reduced. The plasticity index value of the soil is also reduced. Pozzolanic reaction may also occur in some resulting in the formation of cementing agent that increase the strength of the soil. When silica or alumina is present in the soil, a significant increase in strength may be observed over a period of time. An additional effect is that lime causes flocculation of the fine particles, thereby increasing the effective grain size of the soil. The percentage of lime used for any project depends on the type of soil being stabilized. The determination of the quantity of lime is usually based on an analysis of the effect that different lime percentages have on the reduction of plasticity and the increase in strength of the soil.

2. Materials Selected

2.1 Udunghwo Residual Soil

Samples of residual soils selected for this research were dug with shovels from four distinct borrow-pits along the proposed road at kilometres 1+000, 2+150, 3+950 and 5+550 respectively. The soil samples were disturbed and at depths varying from 3.0 meters to 5.0 meters of the profile. The samples were excavated bearing in mind the variability of residual soil in its natural composition. Hence the soil samples were excavated both vertically and laterally and thoroughly blended. The samples were conveyed in four, 50kg nylon bags, carefully tagged for identification purpose and transported to the 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 the estuary of the Atlantic ocean in Ebughu. The deleterious and silty substances were thoroughly removed by washing. The material was then air-dried before particle size gradation through sieve analysis. 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 mean diameter D50 equal to 0.630mm and effective diameter D10 of 0.310mm.

2.3 Lime

Lime helps to arrest the shrinkage and swelling behaviour of soil. This is due to the creation of chemical bonds and aggregation [3]. The use of lime to improve the engineering properties of soil had been in practice for long in many parts of the World. The lime used in this work was purchased from Ewet market in Uyo. The primary purpose was to evaluate the behaviour of Udunghwo residual soil on application of various percentages of lime and compactive effort on the maximum dry densities and corresponding optimum moisture contents. Lime stabilized soil is an engineered product that must be properly evaluated, proportioned and constructed in order to obtain the good and long-term performance. Generally, lime reduces the plasticity of highly expansive soils.

3. Preparation and Testing of Samples

3.1 Unstabilized 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 60 minutes 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-Residual Soil Stabilization Tests

Different percentages of river sand varying from 10%, 20%, 30%, 40%. 50%, 60% and 70% were added to air-dried samples 1, 2, 3 and 4. Each of the test samples was thoroughly blended with a trowel, divided into five parts with the aid of a riffle box, moisturized and weighed. Thereafter the Modified Proctor compaction test was carried out to determine the OMC and MDD. Liquid limit and plastic limit tests were conducted on each of the samples. Based on the OMC and MDD results, CBR tests were then conducted on each specimen following five equal layers of compaction with 4.5kg rammer at 61 blows each falling over 450mm height to the top of the mould. Equally the river sand content was varied from 10% to 70% corresponding to the OMC and MDD derived from the compacted tests.

3.3 Lime - Residual Soil Stabilization Tests

One of the oldest processes of improving the engineering properties of soils is by lime stabilization. When lime is added to fine-grained soil, cat-ion exchange takes place, with the calcium and magnesium in the lime replacing the sodium and potassium in the soil. The tendency to swell as a result of increase in moisture content is therefore immediately reduced. The plasticity index value of the soil is also reduced. Pozzolanic reaction may also occur in some resulting in the formation of cementing agents that increase the strength of the soil [4]. When silica or alumina is present in the soil, a significant increase in strength may be observed over a long period of time. An additional effect is that lime causes flocculation of the fine particles, thereby increasing the effective grain size of the soil. The percentage of lime used for any project depends on the type of soil being stabilized. The determination of the quantity of lime is usually based on an analysis of the effect that different lime percentages have on the reduction of plasticity and the increase in strength of the soil.

3.4 California Bearing Ratio Tests

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 six days and thereafter soaked for 24 hours and allowed to drain for 15 minutes. After testing in CBR machine, the average of the two readings was adopted. This procedure meets the provision of clause 6228 design criteria, FMW&H [1997] [5].

4. Presentation of Test Results

Table 1: Udunghwo Residual Soil Compaction at Unstabilized Condition

Sample No	MDD Kg/m3	NMC (%)	Unsoaked CBR (%)	Fines (%)
1	1880	9.3	58	30
2	1870	8.5	53	32
3	1890	10.5	55	35
4	1860	9.6	58	33

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

River sand Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1880	9.3	58	32	20	12	30	A – 2 – 6	SC
10	1990	8.5	56	32	23	9	28.0	A – 2 – 5	SM
20	2010	8.3	71	30	23	7	26	A – 2 – 5	SM
30	2040	8.3	104	29	23	6	25	A – 2 – 4	SM
40	2040	8.2	140	28	22	6	23	A – 2 – 4	SM
50	1910	6.3	99	21	NIL	NIL	30	A –1 – b	SM
60	1960	7.6	64	19	NIL	NIL	19	A –1 – b	SM
70	1820	15.3	43	17	NIL	NIL	15	A – 1 – b	SM

Table 3: Udunghwo Residual Soil and River Sand Classification – Sample No. 2

River sand Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1870	8.5	53	36	22	14	32	A- 2 -6	SC
10	1900	6.2	54	34	19	15	27	A- 2 – 6	SC
20	2000	8.5	68	29	20	9	30	A- 2 -4	GM
30	1910	6.1	86	27	20	7	29	A- 2 -5	SM
40	1930	6.7	128	26	20	6	28	A- 1 – b	SM
50	1950	6.7	89	25	20	5	17	A- 1 – b	SM
60	1980	8.5	50	18	NIL	NIL	21	A -1 -	SM
70	1780	12.6	45	18	NIL	NIL	16	A – 1 – b	SM

Table 4: Udunghwo Residual Soil and River Sand Classification – Sample No. 3

River sand Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1890	10.5	55	29	25	4	35	A- 2 -4	SM
10	1920	11.5	52	30	20	10	29	A- 2 – 5	SM
20	2010	11.5	83	27	19	8	27	A- 2 -6	SC
30	2020	8.3	81	28	22	6	25	A- 2 -5	SM
40	2070	9.2	117	27	19	8	26	A- 1 – b	SM
50	2030	10.1	83	26	16	10	19	A- 1 – b	SM
60	2080	8.6	56	18	NIL	NIL	17	A -1 - b	SM
70	2040	8.1	42	16	NIL	NIL	14	A – 1 - b	SM

Table 5: Udunghwo Residual Soil and River Sand Classification – Sample No. 4

River sand Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1860	9.6	58	37	21	16	33	A- 2 -6	SC
10	1890	6.2	63	31	23	8	29	A- 2 – 4	SM
20	2010	12.3	98	29	20	9	26	A- 2 – 5	SM
30	2060	7.8	101	27	19	8	29	A- 2 -4	SM
40	2050	8.4	111	20	15	5	23	A- 1 – b	SM
50	2030	11.5	88	26	20	6	21	A- 1 – b	SM
60	1990	8.2	65	16	NIL	NIL	16	A -1 - b	SM
70	1760	12.5	42	19	NIL	NIL	17	A – 1 - b	SM

Table 6: Udunghwo Residual Soil and Lime Classification – Sample No. 1

Lime Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1810	8.4	26	26	21	5	22	A- 2 - 4	SM
2	1940	8.2	76	31	22	9	29	A- 2 - 4	SM
4	2100	8.9	92	28	20	8	29	A- 2 - 4	SM
6	1990	8.5	105	29	23	6	31	A- 2 - 4	SM
8	1980	8.5	98	28	23	5	32	A- 2 – 4	SM
10	1980	8.2	110	19	NIL	NIL	33	A- 2 - 4	SM

Table 7: Udunghwo Residual Soil and Lime Classification – Sample No. 2

Lime Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1950	11.4	26	32	23	9	28	A- 2 - 4	SM
2	1920	12.4	80	30	21	9	31	A- 2 - 4	SM

4	2060	11.5	92	25	18	7	32	A- 2 - 4	SM
6	2090	15.0	99	30	21	9	33	A- 2 - 4	SM
8	2060	14.8	110	26	21	5	34	A- 2 – 4	SM
10	2080	12.1	120	19	NIL	NIL	35	A- 2 - 4	SM

Table 8: Udunghwo Residual Soil and Lime Classification – Sample No. 3

Lime Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1940	10.5	32	29	25	4	35	A- 2 - 4	SM
2	2000	9.3	82	31	21	10	32	A- 2 - 4	SM
4	2050	8.5	86	27	21	6	32	A- 2 - 4	SM
6	1980	11.4	98	28	20	8	34	A- 2 - 4	SM
8	2040	10.3	92	28	21	7	34	A- 2 – 4	SM
10	2130	8.6	149	20	NIL	NIL	38	A- 2 - 4	SM

Table 9: Udunghwo Residual Soil and Lime Classification – Sample No. 4

Lime Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve No. 200	Classification	
								AASHTO	USCS
0	1960	10.7	26	37	21	16	33	A-2-4	SM
2	2090	6.1	80	30	20	10	33	A-2-4	SM
4	1930	11.5	85	30	22	8	34	A-2-4	SM
6	1930	10.4	98	30	24	6	35	A-2-4	SM
8	1950	12.4	140	21	NIL	NIL	36	A-2-4	SM
10	1970	8.9	145	18	NIL	NIL	39	A-2-4	SM

5. Discussion of Test Results

Table 1 shows the results of mechanical compaction of Udunghwo residual soil at unstabilized condition. Tables 2 to 5 present Udunghwo residual soil and river sand stabilization and classification embodying the plasticity index as well as the grain size distribution based systems. The samples are classified at stabilized condition. Tables 6 to 9 present Udunghwo residual soil and lime stabilization and classification. The plasticity index (PI) classification provides a soil profile over depth with the probability of belonging to different soil types which more realistically reflect the in-situ soil characterization which involves the variability of soil type. The grain size distribution classification emphasizes the certainty of behaviour. The advantage of combining the two classification methods is realized when dealing with the behaviour of the soil water characteristic curve and the variability arising from the application of various percentages of stabilizers. For instance, at location 2 under unstabilized condition 32% maximum residual soil sample passes the No. 200 ASTM sieve, the liquid limit is 36%, plastic limit is 22% and plasticity index is 14. Based on AASHTO and USCS classifications, this this is a composition of clayey sand, A-2-5 and SM respectively or clay sand mixture with appreciable amount of fines. At modified conditions, for example with 30% river sand content, it is observed that the physical characteristics depreciate gradually to liquid limit, 27%, plastic limit 20% and plasticity index of 7 with proper compaction.

The CBR values under river sand stabilization vary from 56% to a maximum of 140% with 10% and 40% river sand content respectively at the first location. On the contrary, the CBR values under lime stabilization vary from a minimum of 82% to a maximum of 149% with lime contents varying from 2% to 10% respectively at the third location.

6. Multiple Nonlinear Regressed Models

Based on analysis and utilizing multiple nonlinear regressed programs, the following models were developed for evaluating the CBR values of Udunghwo dilatant residual soils at various levels of stabilization with river sand

and lime. The models are often used for the purposes of prediction and optimization to determine for what values of the independent variables the dependent variable is a maximum or minimum.

CBR [1] = 2.961 - .708R – 1.818D + 4.348M + .172R2 + 1.096D2 + .401M2 - .528RD - .434RM + 3.048DM………………………………………………………………………………1.1

Where R = River sand content (%), D = Maximum dry density (kg/m^3), M = Optimum moisture content (%)

CBR [2] = 2.175 - .636R – 1.921D + 3.565M + .138R2 + .878D2 + .636M2 - .084RD - .927RM - 1.275DM……………………………………………………………………………...1.2

Where R = River sand content (%), D = Maximum dry density (kg/m^3), M = Optimum moisture content (%)

CBR [3] = 1.051 + 1.246L + 2.374D - .645M + .496L2 - .532D2 + .143M2 + .665LD + 1.658LM + .422DM……………………………………………………………………………..1.3

Where L = Lime content (%), D = Maximum dry density (kg/m^3), M = Optimum moisture content (%)

CBR [4] = 3.551 + 1.079L – 3.777D - .816M - .491L2 - .182D2 + .862M2 + .183LD - .141LM + .353DM……………………………………………………………………………...1.4

Where L = Lime content (%), D = Maximum dry density (kg/m^3), M = Optimum moisture content (%)

Table 10: Multiple Regressed Variables for Measured and Computed CBR Values- Residual Soil and River Sand Stabilization – (Samples 1 & 2)

River Sand Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
10	1.99	8.5	66	83.893
20	2.02	8.3	73	79.842
30	2.03	8.3	114	112.195
40	2.04	8.2	130	178.860
50	1.9	6.3	96	290.986
60	1.95	7.6	65	422.001
70	1.92	15.3	44	510.906
10	1.91	6.2	63	55.081
20	2.02	8.5	72	81.554
30	1.92	6.1	88	104.378
40	1.94	6.7	128	179.905
50	1.96	6.7	109	288.233
60	1.99	8.5	60	413.507
70	1.88	12.6	55	535.033

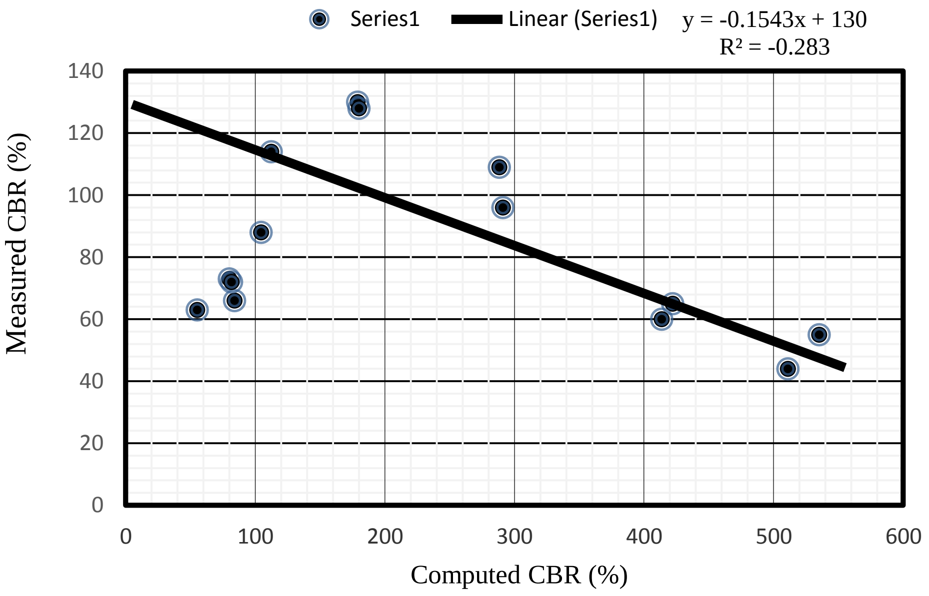

Figure 1: Cross Plot of measured Vs Computed CBR Values using model 1.1

Table 11: Multiple Regressed Variables for Measured and Computed CBR Values – Residual soil and River Sand Stabilization (Samples 3 & 4)

River Sand Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
10	1.93	11.5	62	-2.238
20	2.02	11.5	86	-76.756
30	2.03	8.3	96	-77.004
40	2.07	9.2	122	-88.423
50	2.03	10.1	85	-86.824
60	2.08	8.6	55	26.693
70	2.04	8.1	44	145.522
10	1.99	6.2	62	-19.057
20	2.01	12.3	88	-78.530
30	2.05	7.8	111	-68.923
40	2.05	8.4	121	-68.207
50	2.04	11.5	98	-131.286
60	1.98	8.2	68	45.687
70	1.76	12.5	47	-72.393

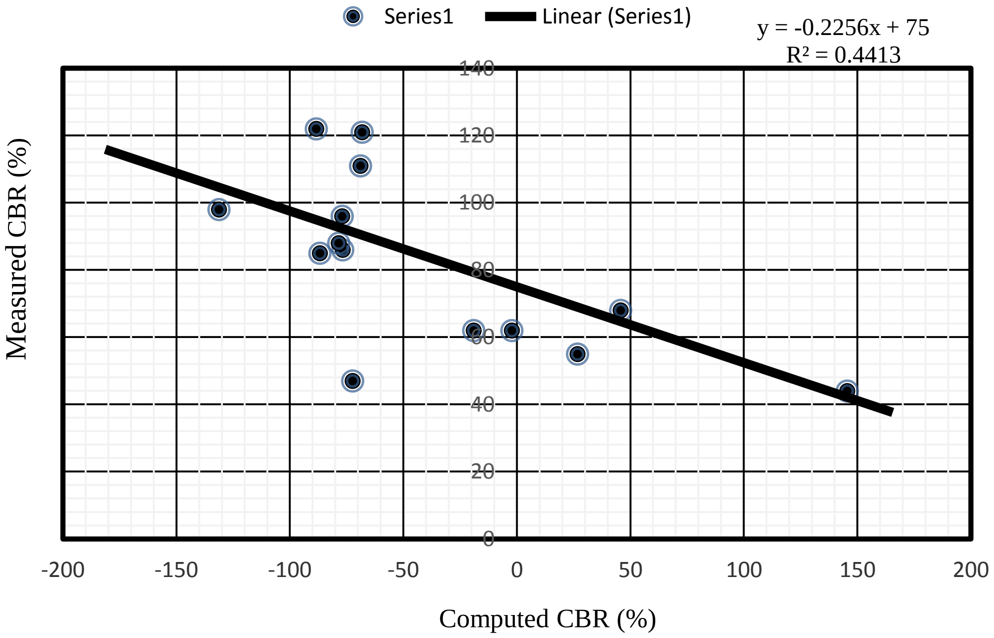

Figure 2: Cross plot of measured vs computed cbr values using model 1.2

Table 12: Multiple Regressed Variables for Measured and Computed CBR Values – Residual soil and Lime Stabilization (Samples 1 & 2)

Lime Content (%)	MDD (kg/m3)	OMC (%)	Soaked CBR (%)	Computed CBR (%)
2	1.95	8.2	76	48.992
4	2.11	8.9	94	94.760
6	1.97	8.5	105	133.329
8	1.98	8.5	111	180.607
10	1.98	8.2	116	226.027
2	1.92	12.4	76	75.833
4	1.96	11.5	92	119.068
6	1.99	15	99	221.257
8	2.05	14.8	112	287.187
10	2.07	12.1	121	303.831

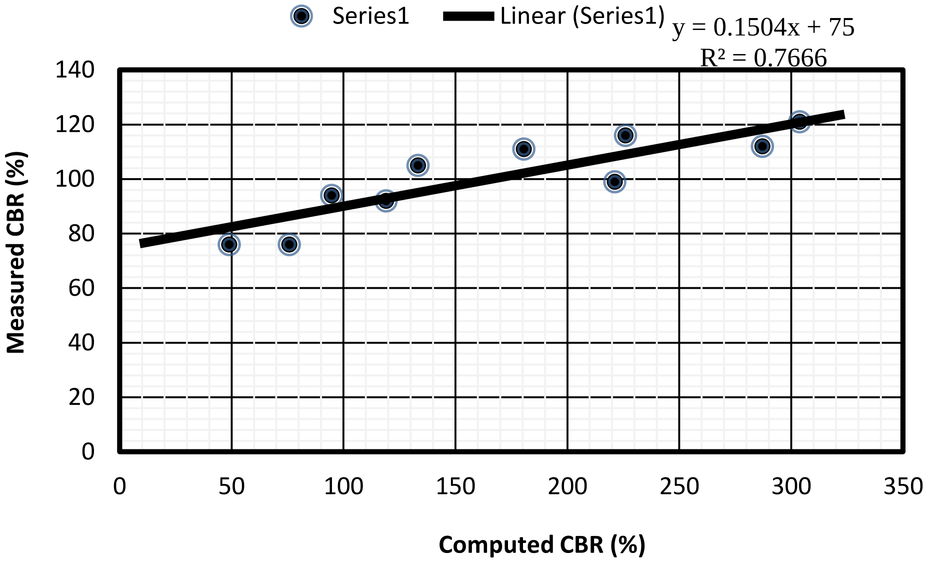

Figure 3: Cross plot of measured vs computed cbr values using model 1.3

Table 13: Multiple Regressed Variables for Measured and Computed CBR Values – Residual soil and Lime Stabilization (Samples 3 & 4)

Lime Content (%)	MDD (kg/m3)	OMC (%)	Soaked CBR (%)	Computed CBR (%)
2	2.02	9.3	81	67.087
4	2.05	8.5	85	49.704
6	1.99	11.4	88	87.384
8	2.03	10.3	112	54.121
10	2.15	8.6	119	11.351
2	2.01	6.1	70	25.859
4	2.03	11.5	87	99.450
6	2.15	10.4	96	69.590
8	2.15	12.4	138	92.791
10	2.17	8.9	146	15.444

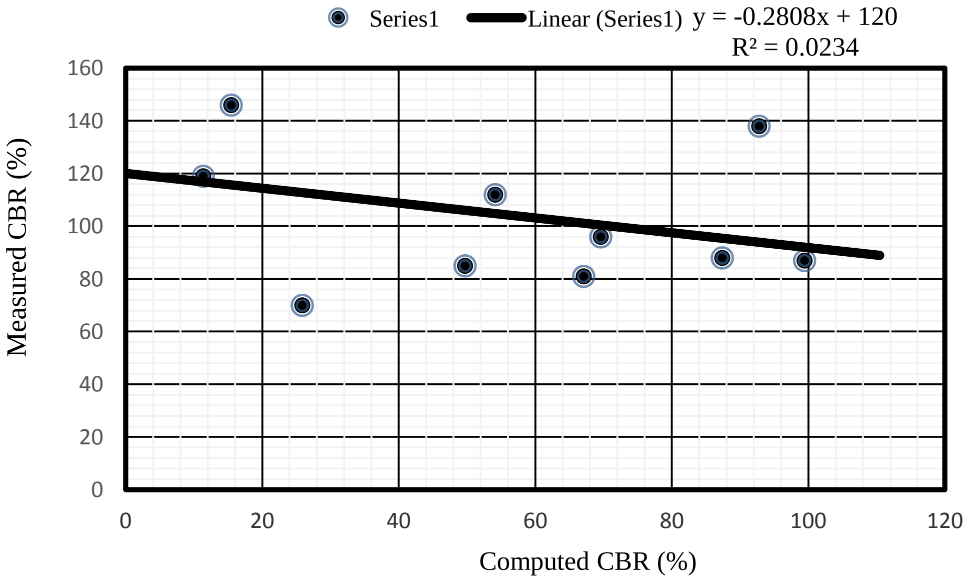

Figure 4: Cross Plot of measured vs computed cbr values using model 1.4

7. Conclusion

Tables 10 and 11 present the multiple regressed variables for measured and computed CBR values resulting from river sand stabilization. Results vary from 66% - 130% and 83% -178% for measured and computed values respectively. Tables 12 and 13 present results from lime stabilization. Results vary from 76% - 121% and 48% - 303% for both measured and computed values respectively.

The models 1.2 and 1.4 do not seem to generate higher correlations between the measured and computed values hence could be further optimized by subjecting the input variables to some basic iterations.

The models 1.1 and 1.3 could be considered adequate for this research. Model 1.1 revealed that with river sand content ranging from 20% - 40% of residual soil the measured and computed values vary 73% - 130% and 79% - 178% respectively. With regards to model 1.3, it is observed that lime stabilization varying from 2% - 10% of residual content yielded measured and computed CBR values ranging from 76% - 121% and 75% - 303% respectively. These values are adequate for both sub base and base course applications because they are above the recommended minimum specified by FMW&H [5] code.

The accuracy and reliability of the models were checked by comparing the measured and computed values of CBR and computing the correlation coefficients. The figures 1 to 4 illustrate the measured and computed values based on non-linear regressed models. The straight line in the figure represents the line of best fit where the values being compared are exactly equal.

The correlation coefficients R2 at 95% confidence interval are 0.283, 0.4413 and 0.7666, 0.0234 for CBR with river sand content from 10% -70% and lime content from 2% - 10%. These values are statistically significant and suggest that the measured and computed values are compatible.

Acknowledgement

The author would like to acknowledge the contribution of Esudo Engineering Ventures for support rendered in the course of this research.

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