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Parametric Characterization and Model Prediction of CBR Values of Stabilized Orukim Residual Soils, Akwa Ibom State, Nigeria

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Abstract: *Quarry dust and lime were deployed for this stabilization experiments. Quarry dust is a by-product or sediments derived from the crushing of limestone. This soil modifying agent has a high percentage of fines. Its application increases the CBR values on a range varying from 10%, 20%, 30%, 40% residual soil against 56%, 71%, 104%, 140% CBR contents of Orukim residual soils respectively. Further increase in quarry dust content from 50% to 70% resulted in decreased values of CBR. The samples were equally devoid of plasticity hence less useful in engineering applications. Lime stabilized soil can be used for both base and sub-base 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 indicate variations along the range of 2%, 4%, 6%, 8%, 10% against 80%, 92%, 99%, 110%, 169% of lime and CBR contents respectively.These values are statistically significant. Finally multiple nonlinear regressed models were developed to aid prediction and optimization of CBR values of Orukim residual soils at various levels of stabilization.*

Keywords: *Quarry dust, Lime, Stabilization, Compaction, Residual soil*

I. Introduction

1.1 Quarry Dust Stabilization

Generally stabilization is designed to improve the physical properties of residual soils deployed for engineering applications. Several methods are used to stabilize soils such as: compaction, consolidation, grouting, admixtures, reinforcement and stone column [1]. 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]Quarry dust containssubstantial amount of fines. In addition to plasticity reduction, quarry dust, provides improved strength and durability. The effectiveness of quarry dust stabilization is predicated on the structural composition of the residual soil and the plastic limit which influences durability on compaction.

1.2 Lime Stabilization

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. 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]

II. Materials Selected

2.1 Orukim Residual Soil

Samples of soil selected for this research was dug with shovels at four distinct borrow pits along Orukim-Eto-Essek-Okposo Road. The samples were excavated both vertically and horizontally bearing in mind the variability of residual soil in its natural composition. The samples were conveyed in four, fifty kilogram nylon bags, carefully tagged to ensure proper identification and transported to Mothercat Limited, Materials Testing Laboratory at Uyo.

2.2 Quarry Dust

The quarry dust used in this experiment came from the limestone quarry factory in Akamkpa, Cross River State. This is the by-product or sediments derived from the crushing of limestone. This soil modifying agent has a high percentage of fines, and as expected, the CBR value of quarry dust was the minimum value from both experiments, in that it in fact increased the overall fines content of the Orukim residual soil. The material was purchased from a local supplier at Aka-Itiam street depot in Uyo.

2.3 Lime

Addition of lime helps to arrest the shrinkage and swelling behaviour of soil.[4]. This is due to the creation of chemical bonds and aggregation. 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 Orukim 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.[5] Generally lime reduces the plasticity of a highly expansive

III. Preparation and Testing Of Samples

3.1UnstabilizedMechanical 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 60minutes 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 Quarry Dust–Residual Soil Stabilization Tests

Different percentages of quarry dust 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 quarry dust 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

The percentage of lime used in this study varied from 2%, 4%, 6%, 8% and 10% to the air-dried weight of the residual soil. That decisionwas informed by the fact that Orukim residual soil is highly anisotropic. The percentage of residual soil on corresponding basis varies from 98%, 96%, 94%, 92% and 90% to the weight of hydrated lime. The mixture was thoroughly blended, moisturised and samples taken for liquid limit tests. Similar compaction procedures were adopted for the four soil samples. The modified proctor test was carried out on all the samples uniformly distributed with a 4.5kg rammer and height was 450mm above the soil compacted on five equal layers of 61 blows each. With the OMC and MDD results obtained three samples each of the soil-lime specimen were prepared for CBR test. One sample was tested immediately. The remaining two samples were soaked for 96 hours by complete immersion in water. After the curing duration, the specimen was allowed to drain for 25minutes prior to CBR testing.

The lime used in this work was purchased from Ewet market in Uyo. The primary purpose was to evaluate the behaviour of Orukim 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[6]. Generally lime reduces the plasticity of a highly expansive soil, as well as improving the stress-strain behaviour.

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].

IV. Presentation of Test Results

Table 1: Orukim Residual Soil Compaction at Unstabilized Condition

Sample No	MDD Kg/m^3	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: Orukim Residual Soil and Quarry Dust Classification– Sample no. 1

Quarry dust 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: Orukim Residual Soil and Quarry Dust Classification – Sample no. 2

Quarry dust content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve 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 - b	SM
70	1780	12.6	45	18	NIL	NIL	16	A – 1 – b	SM

Table 4: Orukim Residual Soil and Quarry Dust Classification – Sample no. 3

Quarry dust Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve 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: Orukim Residual Soil and Quarry Dust Classification – Sample no. 4

Quarry dust Content (%)	MDD Kg/m^3	OMC (%)	CBR Unsoaked (%)	LL	PL	PI	% passing Sieve 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: Orukim Residual Soil and Lime Classification – Sample no. 1

LIME Content (%)	MDD Kg/m^3	OMC (%)	Soaked CBR (%)	LL	PL	PI	% passing Sieve 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: Orukim Residual Soil and Lime Classification – Sample no. 2

LIME Content (%)	MDD Kg/m^3	OMC(%)	soaked CBR (%)	LL	PL	PI	% passing Sieve 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: Orukim Residual Soil and Lime Classification – Sample no. 3

LIME 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	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	169	20	NIL	NIL	38	A- 2 - 4	SM

Table 9: Orukim Residual Soil and Lime Classification – Sample no. 4

Lime Content(%)	MDD Kg/m^3	OMC (%)	CBR soaked (%)	LL	PL	PI	% passing Sieve 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

V. Discussion of Test Results

Table 1 shows the result of mechanical compaction tests of Orukim residual soil at unstabilized condition. Tables'2 to 5 present Orukim residual soil and quarry dust classification incorporating the plasticity limit as well as the grain-sized distribution based systems. The samples are classified at stabilized conditions. Tables 6 to 9 present Orukim residual soil and lime stabilization. The plasticity index (PI) classification provides a soil profile over depth with the probability of belonging to different soil types, which more realistically and continuously reflects 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 realised 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 1 under unstabilized condition 30% maximum residual soil sample passes the No 200 ASTM sieve, the liquid limit is 32%, plastic limit is 20% maximum and the plasticity index is 12. Based on AASHTO and USCS classifications, this is a composition of clayey sand, A-2-6 and SC respectively or clay sand mixture with appreciable amount of fines. At modified conditions, for example with 20% quarry dust, it is observed that the physical characteristics depreciate gradually to liquid limit, 30%, plastic limit, 23% and plasticity index of 7 with proper compaction.

The CBR values under quarry dust stabilization vary from a minimum of 56% to a maximum of 140% with 10% and40% quarry dust content respectively at location 1. Conversely with lime stabilization the CBR values appreciated considerably from 82% to 169% with lime content of 2% and 10% respectively at location 3.

VI. Multiple Non-Linear Regressed Models

Based on analysis and utilizing multiple nonlinear regressed programs the following models were developed for evaluating CBRvalues of Orukim residual soils at various levels of stabilization with quarry dust 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.

$CBR_{Q1} = 24.896 + 1.974Q - 1.909D + .469M - .028Q^2 + .111D^2 + .747M^2 + .799QD - .373QM - .301DM$……………………………………………………………………………………………..1.1

Where Q=Quarry dust [%], D=Maximum dry density[Mg/m^{3}], M = Optimum moisture content [%]

$CBR_{Q2} = 43.927 + 3.223Q – 1.543D + 3.926M - .051Q^2 + .627D^2 - .122M^2 + .641QD - .197QM - .1O2DM$……………………………………………………………………………………………..1.2

Where Q=Quarry dust [%], D=Maximum dry densty[Mg/m^{3}] , M = Optimum moisture content [%]

$CBR_{L1} = 89.318 – 2.448L + 1.199D + .669M - .538L^2 + .573D^2 + .479M^2 + .135LD - .197LM - .837DM$……………………………………………………………………………………………1.3

Where L=lime [%], D=Maximum dry density [Mg/m^{3}], M= Optimum moisture content [%]

$CBR_{L2} = 108.171 - 3.977L + 7.717D + 1.233M - .211L^2 + .346D^2 - .141M^2 - .209LD +,191LM +.464DM$……………………………………………………………………………………………..1.4

Where L=lime [%], D=Maximum dry density [Mg/m^{3}], M= Optimum moisture content [%]

Table 10: Multiple Regressed Variables for Measured and Computed CBR Values – Residual Soil and Quarry Dust Stabilization (Samples1&2)

Quarry Dust Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
10	1.99	8.5	56	75.538
20	2.01	8.3	71	70.321
30	2.04	8.3	104	61.762
40	2.04	8.2	140	47.517
50	1.91	6.3	99	38.145
60	1.96	7.6	64	5.323
70	1.82	15.3	43	-101.262
10	1.9	6.2	54	58.741
20	2	8.5	68	71.192
30	1.91	6.1	86	60.348
40	1.93	6.7	128	50.287
50	1.95	6.7	89	35.986
60	1.98	8.5	50	-3.226
70	1.78	12.6	45	-88.849

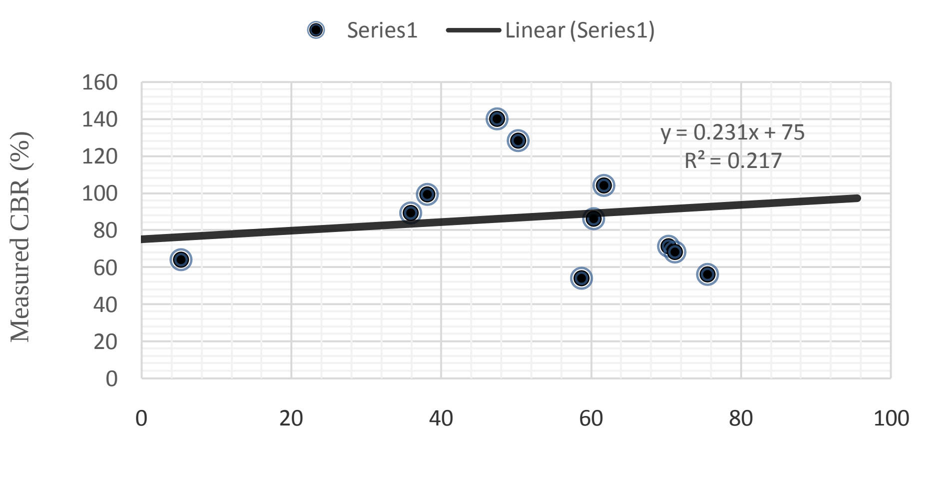

Fig.1: Cross Plot of Measured Vs Computed CBR Values Using Equation 1.1

Table 11: Multiple Regressed Variables for Measured and Computed CBR Values – Residual Soil and Quarry Dust Stabilization. (Samples 3&4)

Quarry Dust Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
10	1.92	11.5	52	119.089
20	2.01	11.5	83	126.803
30	2.02	8.3	81	123.230
40	2.07	9.2	117	115.821
50	2.03	10.1	83	92.612
60	2.08	8.6	56	72.517
70	2.04	8.1	42	37.054
10	1.89	6.2	63	98.117
20	2.01	12.3	98	128.950
30	2.06	7.8	101	124.121
40	2.05	8.4	111	116.919
50	2.03	11.5	88	87.717
60	1.99	8.2	65	71.463
70	1.76	12.5	42	-8.647

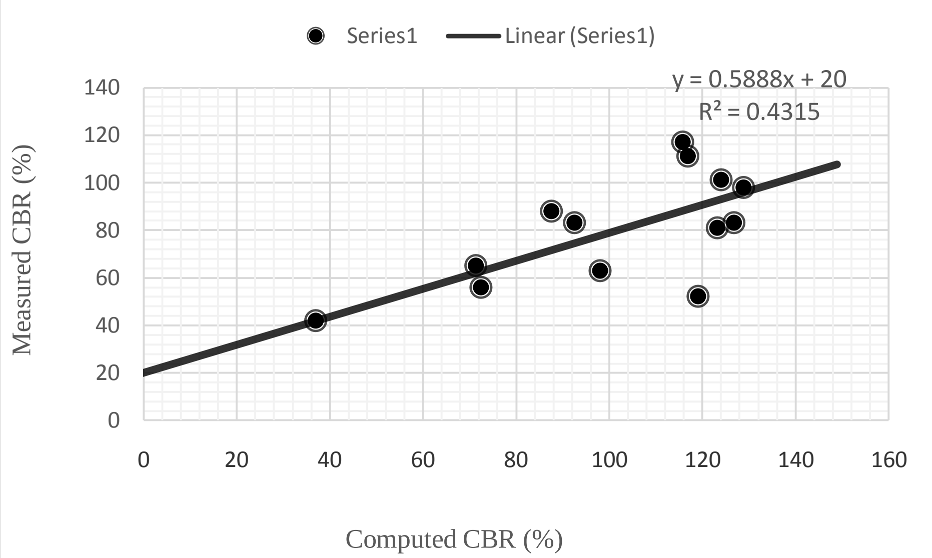

Fig.2: Cross Plot of Measured Vs Computed CBR Values Using Equation 1.2

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

Lime Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
2	1.94	8.2	76	108.424
4	2.1	8.9	92	98.336
6	1.99	8.5	105	77.618
8	1.98	8.5	98	54.872
10	1.98	8.2	110	26.282
2	1.92	12.4	80	144.337
4	2.06	11.5	92	119.083
6	2.09	15	99	135.804
8	2.06	14.8	110	108.406
10	2.08	12.1	120	52.142

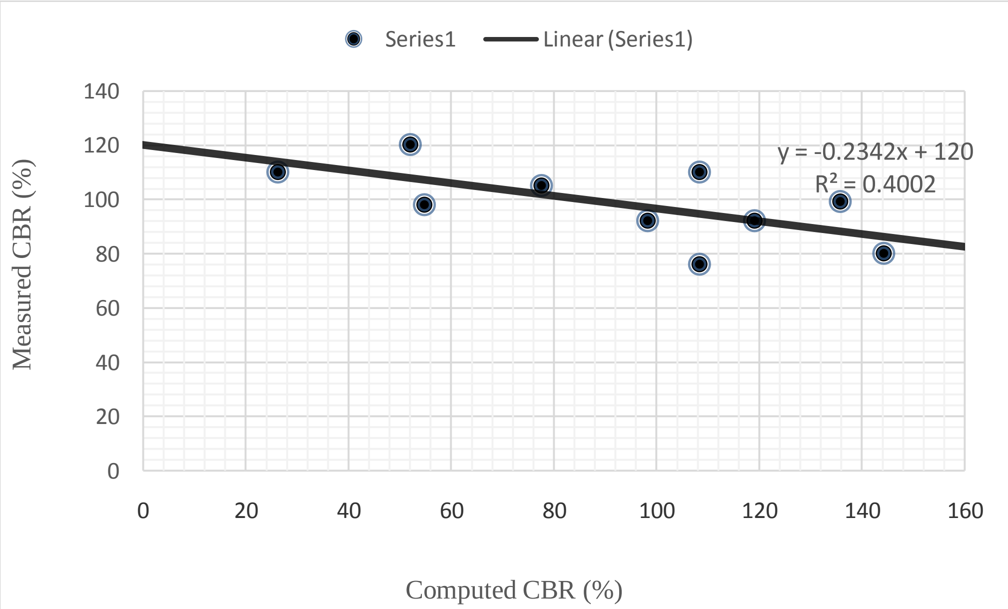

Fig.3: Cross Plot of Measured Vs Computed CBR Values Using Equation 1.3

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

Lime Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
2	2	9.3	82	128.482
4	2.05	8.5	86	122.747
6	1.98	11.4	98	115.102
8	2.04	10.3	92	106.674
10	2.13	8.6	169	94.861
2	2.09	6.1	80	128.407
4	1.93	11.5	85	121.300
6	1.93	10.4	98	114.120
8	1.95	12.4	140	106.251
10	1.97	8.9	145	92.903

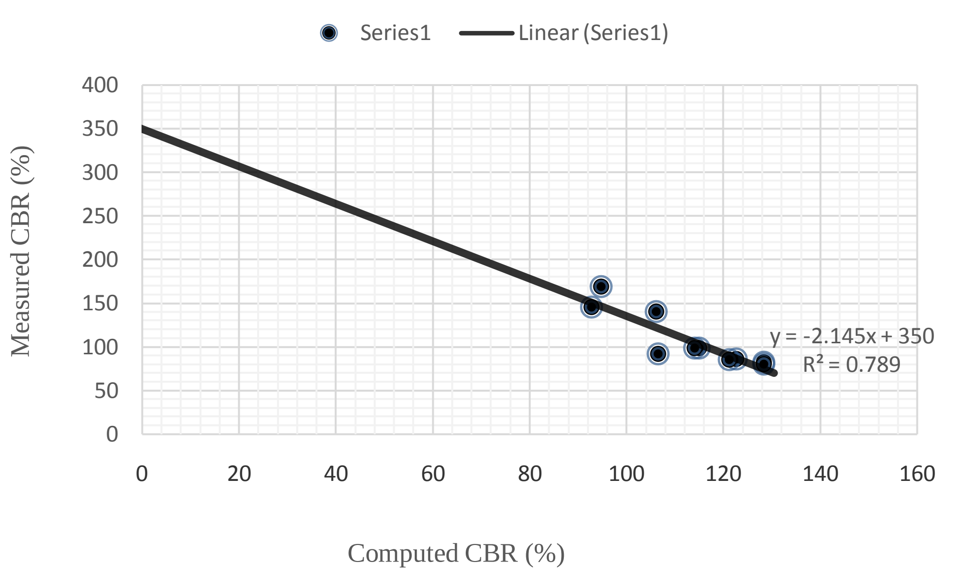

Fig.4: Cross Plot of Measured Vs Computed CBR Values Using Equation 1.4

VII. Conclusion

Tables 10 and 11 present the multiple regressed variables for measured and computed CBR values resulting from quarry dust stabilization. Results vary from 56KPa – 140KPa and 75KPa – 129KPa for measured and computed values respectively. Tables 12 and 13 present similar values resulting from lime stabilization. Results vary from 76KPa -169KPa and 108KPa – 144KPa for the measured and computed CBR values respectively.

The models 1.1 and 1.3 do not seem to generate higher correlations between the measured and computed values hence could further be optimized by subjecting the coefficients of the input variables to basic iteration.

The models 1.2 and 1.4 are adequate for this research. Model 1.2 revealed that with quarry dust content ranging from 10% - 30% of residual soil the measured and computed values vary from 63% - 101% and 98% - 124% respectively. With regards to model 1.4 it is observed that lime stabilization varying from 2% - 6% of residual soil content yielded measured and computed CBR values varying from 82% - 98% and 128% - 115% respectively. These values are adequate for both sub base and base course applications because they areabove recommended minimum specified by FMW&H [1997] 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 I to IV illustrate the measured and computed values based on non- linear regressed models. The straight line in the figure represents the line of perfect equality where the values being compared are exactly equal.

The correlation coefficients R^2 at 95% confidence interval are 0.2175,0.4315 and 0.4002,0.7899 for CBR with quarry dust content from 10% - 70% and lime content from 2% - 10%. These values are significant statistically and suggest that the measured and computed values are compatible.

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