IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 4 Ver. II (Jul. - Aug. 2015), PP 53-61
www.iosrjournals.org

Comparative Stabilization and Model Prediction of CBR Values of Orukim Residual Soils, AkwaIbom State, Nigeria

Dr.Essien Udo[1], Engr. Charles Kennedy[2], Samuel Assam[3]
[1,2,3]Department of Civil Engineering, University of Uyo, Nigeria

Abstract:*River sand and cement stabilization of Orukim residual soils were essentially designed to improve the engineering properties and to ascertain structural behaviour on engineering applications.The major goal of treating a residual soil is to increase the shear strength and loading capacity. The laboratory stabilization experiments involved four different soil samples from four distinct borrow pits. River sand content varied from 10% to70% and complemented by residual soil which content varied from 90% to 30% respectively. CBR results obtained ranged from 66% to 90%.Conversely cement content utilizedranged from 2% to 10% and the residual soil content varied from 98% to 90% respectively. The CBR values obtained ranged from 70% to 127%. From the results cement stabilization tends to generate optimal values of CBR as compared to river sand stabilization. The contribution of hydrated calcium silicates [$C_2SHx.C_3S_2H_X$] and calcium aluminates [$C_2AH_X.C_4AH_X$] in cement tend to increase the bonding between particulate structures resulting in plasticity reduction hence gaining in strength propagation. Finally multiple non-regressed models were developed to aid prediction and optimization of CBR parameters of Orukim residual soils at various levels of stabilization.*
Keywords*: River Sand, Cement, Residual Soil, Stabilization*

I. Introduction

Most of Orukim Areas are covered by granitic residual soils. These soils are unique in formation, pleasing in appearance and deceptive in engineering applications. Their deployment for both sub base and base course applications on the Orukim-Unyeghe-EtoEssek-Ibeno road project was a failure technically and economically. The predominant aluminium sesquioxide and iron compound montmorillonite [which has the tendency to swell when their moisture content is allowed to increase] could not be curtailed by conventional plain compaction. Residual soils are heterogeneous due to variable weathering of the jointed rock mass [Thurairajah, et.al. 1992][1]. The heterogeneity of residual soils is due to the influence of relict joints, presence of boulders, and variability of the soil matrix. Soil stabilizing agents such as river sand and cement had long been used to improve the handling and engineering characteristics of soils which ensures that the mixture meets certain durability requirements for civil engineering purposes [Al-Aghbari, et.al. 2005][2]. It is also used as stabilizing agent especially for road construction, such as sub-base or base course material, airport runways and earth dams [Van Impe, 1989, Little, 1995][3]. Cement can be used to stabilize sandy and clayey soils. In sediment soils cement has the effect of reducing the liquid limit and increasing the plasticity indexand hence increases the consistency of soil [Huat, 2006]. In theory any soil can be stabilized with cement. However increase in the silt and clay content requires more cement. 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. The mechanism of organic matter interference in strength gain is not completely understood [Janz and Johansson, 2002]

II. Materials Selected

2.1 Orukim Residual Soil

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

Sample Identification Location
Km1+500 Orukim - Unyeghe road.
Km5+250Orukim - Unyegh road.
Km9+500Unyeghe- EtoEssek road.
Km11+00Unyeghe- EtoEssek 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 , 50kg 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 Cross river in Uruan. 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 1000g utilized for this experiment. The sample was sieved from 10mm through 0.075mm 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 0.620mm,d_{30} equal to 0.425mm and d_{10} of 0.300mm.

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, AkwaIbom State. Cement stabilization is mostly applicable to road stabilization and fills especially when the moisture content of the sub-grade is very high [Muntohar, et.al. 2000]. 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), [Lea, 1956]. 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 $Ca(OH)_{2}$., [Bergado, et.al.1996].

III. 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 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 outaccordingly. 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-Residual Soil Stabilization Tests.

Four residual soil samples were utilized in this experiment. The percentage of cement ranged from 2%, 4%, 6%, 8% to 10%. The percentage of residual soil ranged from 98%, 96%, 94%, 92%to 90%. 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.

[Porbala2002]. The mixture was thoroughly blended and moisturised and modified proctor compaction test was conducted to establish the OMC and MDD..With the optimum moisture content (OMC) and maximum dry density (MDD) values obtained, three CBR specimens were prepared for each cement content. One specimen was inserted into the CBR machine and penetration reading carried out to establish a base line. The remaining two specimens were wax cured for 6 days. The specimens were then soaked for 24 hours by complete immersion in water and allowed to drain for 15 minute. This procedure meets the provision of clause 6228 design criteria. FMW & H (1997).

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.

IV. Presentation of Test Results

Table 1: Orukim Residual Soil Compaction at Plain Condition

Sample No	MDD Kg/m^3	NMC %	unsoaked CBR %	Fines %
1	1960	10.7	61	33
2	1940	9.5	64	35
3	1980	10.1	60	30
4	1950	11.4	66	31

Table 2: Orukim Residual Soil and River Sand Classification – Sample no 1

River sand content	MDD	OMC	CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m^3	%	Unsoaked %					AASHTO	USCS
0	1960	10.7	61	37	21	16	33	A- 2 -6	SC
10	1860	9.7	66	31	21	10	33	A- 2 – 4	SM
20	1930	12.5	70	28	19	9	29	A- 2 -5	SM
30	2060	8.2	82	27	21	6	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	2020	8.0	70	20	NIL	NIL	19	A -1 - b	SM
70	1840	13.1	17	17	NIL	NIL	16	A – 1 - b	SM

Table 3: Orukim Residual Soil and River Sand Classification – Sample no 2

River sand content	MDD	OMC	CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m^3	%	Unsoaked %					AASHTO	USCS
	1940	9.5	64	29	25	4	32	A- 2 -6	SC
10	1920	9.5	52	31	23	8	24	A- 2 – 4	SM
20	1990	12.8	74	30	18	12	27	A- 2 -5	SM
30	1910	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	21	A -1 - b	SM
70	1840	12.0	57	17	NIL	NIL	15	A – 1 - b	SM

Table 4: Orukim Residual Soil and River Sand Classification – Sample no 3

River sand content	MDD	OMC	CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m3	%	Unsoaked %					AASHTO	USCS
0	1980	10.1	60	36	22	14	30	A- 2 -6	SC
10	2000	10.6	65	34	23	11	30	A- 2 – 6	SC
20	1940	11.5	75	33	24	9	29	A- 2 -4	SM
30	2060	9.8	86	29	19	10	26	A- 2 -4	SM
40	2130	7.8	110	26	22	4	23	A- 2 – 4	SM
50	1960	10.7	71	18	NIL	NIL	23	A- 1 – b	SM
60	1900	10	67	19	NIL	NIL	19	A -1 - b	SM
70	1930	12.8	83	17	NIL	NIL	17	A – 1 - b	SM

Table 5: Orukim Residual Soil and River Sand Classification – Sample no 4

River sand content	MDD	OMC	CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m^3	%	Unsoaked %					AASHTO	USCS
0	1950	11.4	66	32	20	12	29	A- 2 -6	SC
10	2000	10.6	60	37	25	12	29	A- 2 – 6	SC
20	1940	10.4	75	23	15	8	28	A- 2 -4	SM
30	2060	7.6	86	28	20	8	22	A- 2 -4	SM
40	2130	9.6	110	18	NIL	NIL	25	A- 1 – b	SM
50	1960	10.6	71	20	NIL	NIL	25	A- 1 – b	SM
60	1900	6.7	67	14	NIL	NIL	16	A -1 - b	SM
70	1930	8.3	83	18	NIL	NIL	16	A – 1 - b	SM

Table 6: Orukim Residual Soil and Cement Classification – Sample no 1

Cement content	MDD	OMC	soaked CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m^3	%	%					AASHTO	USCS
0	1960	10.7	26	37	21	16	33	A- 2 - 4	SM
2	2100	11.2	70	28	20	8	40	A- 2 - 4	SM
4	1940	12.3	81	28	21	7	41	A- 2 - 4	SM
6	2040	12.9	87	27	22	5	42	A- 2 - 4	SM
8	2070	13.2	95	17	NIL	NIL	43	A- 2 – 4	SM
10	2060	15.1	110	18	NIL	NIL	44	A- 2 - 4	SM

Table 7: Orukim Residual Soil and Cement Classification – Sample no2

Cement content	MDD	OMC	soaked CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m^3	%	%					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: Orukim Residual Soil and Cement Classification – Sample no3

Cement content	MDD	OMC	soaked CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m^3	%	%					AASHTO	USCS
0	1950	11.4	26	32	23	9	28	A- 2 - 4	SM
2	2120	11.2	73	28	20	8	29	A- 2 - 4	SM
4	2060	13.8	79	27	20	7	30	A- 2 - 4	SM
6	2050	10.3	83	27	21	6	31	A- 2 - 4	SM
8	2050	14.7	96	26	22	4	32	A- 2 – 4	SM
10	2050	14.2	110	18	NIL	NIL	33	A- 2 - 4	SM

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

Cement content	MDD	OMC	soaked CBR	LL	PL	PI	% passing Sieve 200	Classification	
%	Kg/m^3	%	%					AASHTO	USCS
0	1810	8.4	26	26	21	5	22	A- 2 - 4	SM
2	2120	11.2	82	28	20	8	29	A- 2 - 4	SM
4	2060	13.8	96	27	20	7	30	A- 2 - 4	SM
6	2050	10.3	115	27	21	6	31	A- 2 - 4	SM
8	2050	14.7	121	26	22	4	32	A- 2 – 4	SM
10	2050	14.2	127	18	NIL	NIL	33	A- 2 - 4	SM

V. Discussionof Test Results

Table 1 shows the result of plain mechanical compaction tests of Orukim residual soil devoid of any soil modifier. Tables 2 to 5 present Orukim residual soil and river sand classification for samples 1 to 4 at stabilized condition incorporating the plasticity limit as well as the grain-sized distribution based systems. Tables 6 to 9 present Orukim residual soil and cement 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 plain condition 33% maximum residual soil sample passes the No 200 ASTM sieve, the liquid limit is 37%, plastic limit is 21% maximum and the plasticity index is 16. 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 30% river sand, it is observed that the physical characteristics depreciate gradually to liquid limit, 27%, plastic limit, 21% and plasticity index of 6 with proper compaction.
The CBR values under river sand stabilization vary from a minimum of 66% to a maximum of 90% with 10% and 40% river sand content respectively at location 1. Conversely with cement stabilization the CBR values appreciated considerably from 70% to 110% with cement content of 2% and 10% respectively at same location 1.More appreciable CBR values were observed at location 4 ranging from 82% to 127% with cement content of 2% and 10% respectively.

VI. Multiple Non-Linear Regressed Models

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

$CBR_{R1} = 18.555 - .251S - .245D - .450W - .031S^2 + .984D^2 - .092W^2 + .102SD + .264SW + 1.276DW$……………………………………………………1.1
Where S = river sand content [%], D = maximum dry density [Mg/m^3] W = optimum moisture content [%]
$CBR_{R2} = 53.630 - .115S - .450D - .897W + .077S^2 + .236D^2 - .046W^2 + .121SD + .032SW + .443DW$………………………………………………………1.2
Where S = river sand content [%], D = maximum dry density [Mg/m^3] W = optimum moisture content [%]
$CBR_{C1} = 54.462 - .643C - 1.432D + 2.474W - .583C^2 + .756D^2 + .195W^2 + 3.722CD - .412CW - .142DW$……………………………………………..1.3
Where C = cement content [%], D = maximum dry density [Mg/m^3] W = optimum moisture content [%]
$CBR_{C2} = 22.531 + 2.162C + 1.702D + 3.799W + .548C^2 - .226D^2 + .202W^2 - .821CD - .918CW + .329DW$………………………………………………1.4
Where C = cement content [%], D = maximum dry density [Mg/m^3] W = optimum moisture content [%]
From the models1.1 to 1.4 computed CBR values were generated and tabulatedas shown on Tables 10 to 13.

Table 10: Multiple Regressed Variables for Measured and Computed CBR Values-Orukim Residual Soil and River Sand Stabilization – Sample no 1 & 2

Sample Location	River sand Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
1	0	1.96	10.7	61	33.267
	10	1.86	9.7	66	53.399
	20	1.93	12.5	70	85.048
	30	2.06	8.2	82	99.722
	40	1.93	12.2	90	109.675
	50	2.05	10.4	82	92.447
	60	2.02	8	70	45.630
	70	1.84	13.1	17	116.265
2	0	1.94	9.5	64	32.722
	10	1.92	9.5	52	53.837
	20	1.99	12.8	74	87.857
	30	1.91	11.6	83	94.635
	40	2.06	8.3	95	70.383
	50	1.92	11.1	80	98.838
	60	1.83	11.7	64	100.731
	70	1.84	12	57	96.389

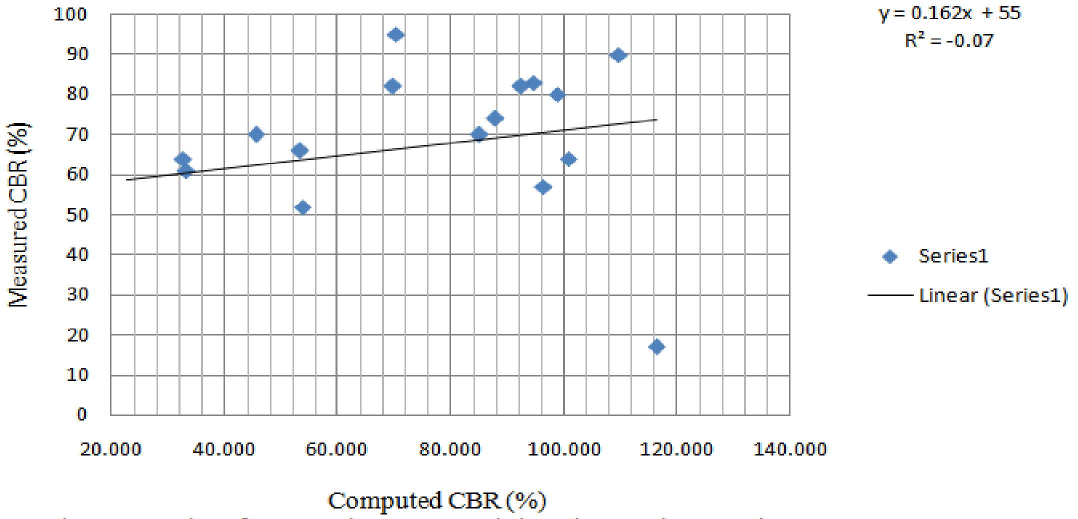

Fig I: cross plot of measured vs computed cbr values– using equation 1.1

Table 11:Multiple Regressed Variables for Measured and Computed CBR Values-Orukim Residual Soil and River Sand Stabilization – Sample no 3 & 4

Sample Location	River sand Content (%)	MDD (kg/m³)	OMC (%)	Measured CBR (%)	Computed CBR (%)
3	0	1.98	10.1	60	48.771
	10	2	10.6	65	60.751
	20	1.94	11.5	75	87.684
	30	2.06	9.8	86	132.175
	40	2.13	7.8	110	190.200
	50	1.96	10.7	71	263.809
	60	1.9	10	67	351.768
	70	1.93	12.8	83	459.835
4	0	1.95	11.4	66	47.294
	10	2	10.6	60	60.751
	20	1.94	10.4	75	88.130
	30	2.06	7.6	86	131.790
	40	2.13	9.6	110	191.147
	50	1.96	10.6	71	263.750
	60	1.9	6.7	67	348.150
	70	1.93	8.3	83	454.312

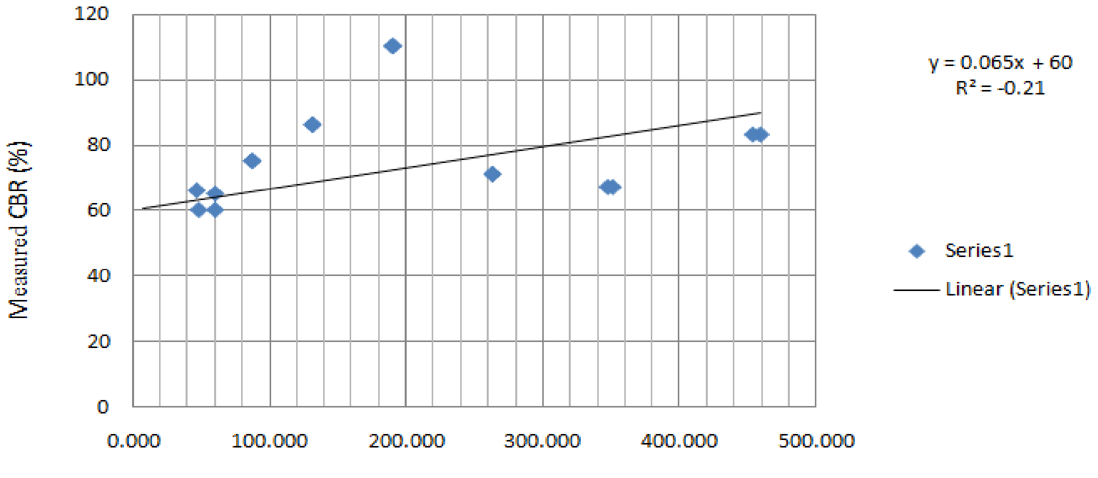

Fig.II: CrosS Plot of Measured VS Computed CBR Values using equation 1.2

Table 12: Multiple Regressed Variables for Measured and Computed CBR ValuesOrukimResidual Soil and Cement Stabilization – Sample no 1 & 2

Sample Location	Cement Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
1	0	1.96	10.7	26	106.140
	2	2.1	11.2	70	88.401
	4	1.94	12.3	81	80.462
	6	2.04	12.9	87	69.738
	8	2.07	13.2	95	62.013
	10	2.06	15.1	110	66.285
2	0	1.94	10.5	32	104.763
	2	2.06	11.4	77	89.974
	4	2.13	13.1	82	82.518
	6	2.05	11.8	87	63.896
	8	2.07	13.2	94	62.013
	10	2.08	15.4	108	66.929

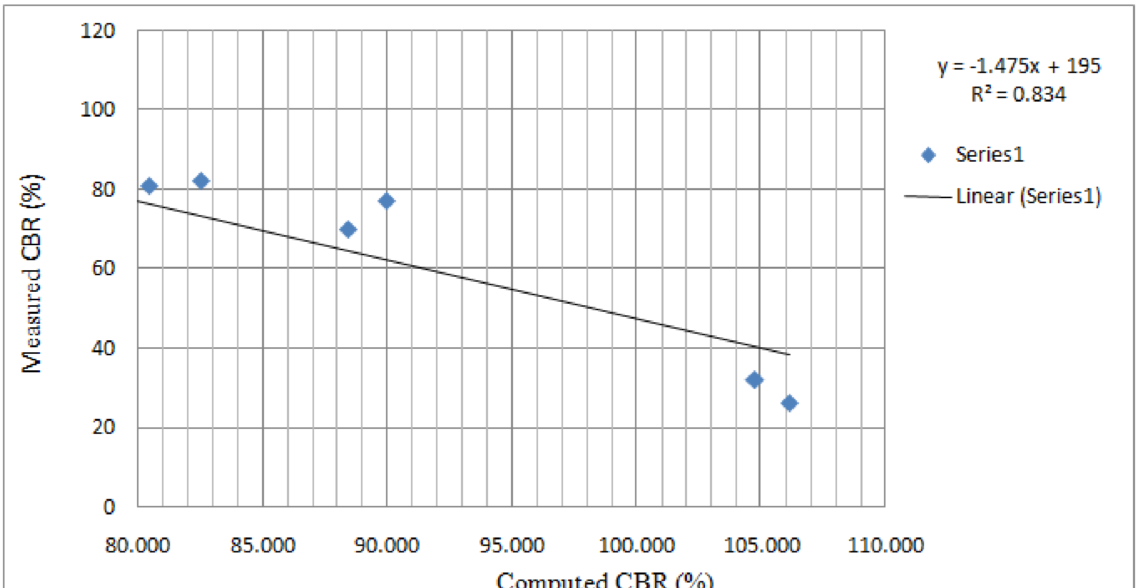

Fig.III: Cross Plot of Measured vs Computed CBR values using equation 1.3

Table 13: Multiple Regressed Variables for Measured and Computed CBR Values-Orukim Residual Soil and Cement Stabilization – Sample no 3 & 4

Sample Location	Cement Content (%)	MDD (kg/m^3)	OMC (%)	Measured CBR (%)	Computed CBR (%)
3	0	1.95	11.4	26	87.237
	2	2.12	11.2	73	86.174
	4	2.06	13.8	79	112.193
	6	2.05	10.3	83	95.599
	8	2.05	14.7	96	142.736
	10	2.05	14.2	110	156.696
4	0	1.81	8.4	26	66.034
	2	2.12	11.2	82	86.174
	4	2.06	13.8	96	112.193
	6	2.05	10.3	115	95.599
	8	2.05	14.7	121	142.736
	10	2.05	14.2	127	156.696

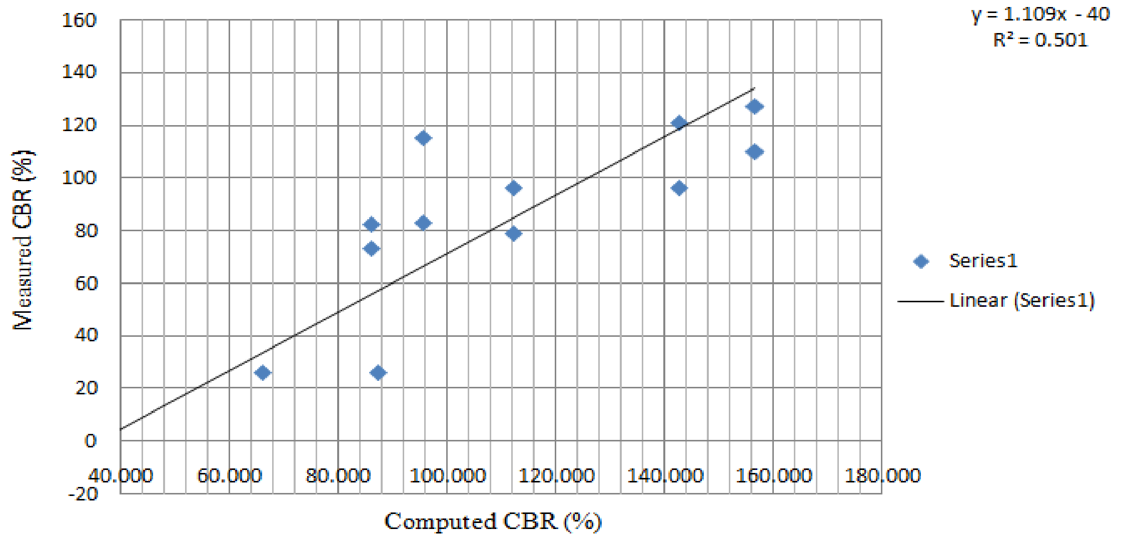

Fig.IV: Cross Plot of Measured VS Computed CBR Values– using eqution 1.4

VII. Conclusion

Tables 10, 11 and 12, 13 present multiple regressed variables for measured and computed CBR values resulting from river sand and cement stabilizations respectively. Results from river sand stabilization vary from 66% to 90% and 53% to 110% for measured and computed CBR values. River sand content ranged from 10% to 40%. Generally it is noted that river sand content exceeding 40% results in decreasing CBR value.

With cement stabilization the measured and computed CBR values ranged from70% to 127% and 86% to 156% respectively. Cement content varies from 2% to 10%. In comparative terms cement stabilization tends to optimize both measured and computed CBR values. The technical basis is simple. The calcium silica hydrate [C-S-H] gel or the hydrated calcium silicates [$C_2SHx.C_3S_2H_X$] and calcium aluminates [$C_2AH_X.C_4AH_X$] in cement tend to increase the bonding between particulate structures resulting in plasticity reduction hence gaining in strength propagation.The models 1.1 to 1.2 revealed that with 30%, river sand and 70% residual soil stabilization the measured and computed CBR values are 82%/99% and 86%/132% at locations 1&2. These values are above recommended minimum by the FMW & H [1997] specifications.

The model 1.3 could be further optimized by subjecting the coefficients of the input variables to basic iteration.The model 1.4 is adequate for cement stabilized Orukim residual soil. Results show that with 6% cement and 94% residual soil the measured and computed CBR values are 83% and 95%. These values are above accepted minimum of 80% by the code. Direct inference is that the curing duration influences strength development.The accuracy and reliability of the models 1.1 to 1.4 were checked by comparing the computed and measured CBR values and computing the correlation coefficients. Figures I to IV illustrate the computed and measured values based on non-linear regressed models.

The correlation coefficients R^2 at 95% confidence interval are .078, .218, .838, and .5014. These values are statistically significant and therefore suggest that the measured and computed values of CBR are compatible.

Acknowledgement

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

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