Empirical Model for Estimating Compression Index from Physical Properties of Weathered Birimian Phyllites

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ABSTRACT

Geotechnical investigation is required for the determination of ground parameters for safe and economic design of civil engineering structures. Compression index is one of the soil parameters that are required for calculation of foundation settlements, however, the determination of compression index is expensive, cumbersome, time consuming and required a lot of experience for obtaining undisturbed soil samples from the field. In order to mitigate these complexities, equations have been developed by many researchers in the past to predict compression index using index properties of soil which are relatively easier to conduct in the laboratory. Linear regression analysis was used to established empirical models relating compression index and index properties of sixty weathered Birimian phyllites samples in the Kumasi area. Based on the analysis, the liquid limit resulted in the model with the highest coefficient of determination compared to the moisture content, plasticity index, and plastic limit. The resulting model was used to predict the compression index of about thirty samples that were not used in the regression analysis; the results showed that, the model is able to predict the compression index with less error. The empirical model (C_c = 0.004LL – 0.03) involving the liquid limit is recommended for prediction of compression index for preliminary design and verification of the laboratory tests soils in Kumasi within the Birimian phyllites.

KEYWORDS: compression index, Liquid limit, linear regression Birimian Phyllites.

INTRODUCTION

Geotechnical investigation is a prerequisite for a safe and economic design of civil engineering structures. The investigations are of prime importance to enable the selection of the salient parameters which affect foundation pressures and constructions operations (Ghartey, 2001). Compression index (Cc) is one of the salient parameters which the geotechnical engineer seeks to unravel to establish the safety of the proposed structure immediately after construction and during the life time of the structure. Compression index is required for computation of the settlements of structures founded on soils. It can be obtained by performing laboratory tests on undisturbed samples using the oedeometer test. It is a conventional test, which is assumed to simulate the compression of the foundation soil when subjected to structural loads. The determination of compression index from consolidation tests is expensive, cumbersome and time consuming since it takes a maximum of three weeks to complete a typical consolidation test including sampling of undisturbed soil samples from the field. A lot of maturity and skill is required on the part of the engineer in interpreting the results of the laboratory tests for application to the conditions in the field (Rani et al, 2013). Because of these factors, several attempts have been made in the past to predict the compression index using index properties which are relatively easier to determine and take lesser time to obtain in the laboratory. Index properties of soil such as Atterberg Limits and moisture content are basic properties of soils; therefore, it is possible to use these index properties to predict the compression index of the soil. Empirical models relating various index properties to the compression index have been presented by many researchers (Terzaghi and Peck (1967), Skempton (1944), Bowles (1979), Wroth and Wood (1978), Park and Lee (2011), Yoon et al (2004), Tiwari and Ajmera (2012), Sridaran and Nagaraj (2003), Abassi et al (2012). Some of the equations relating the compression index to various index properties are presented in Table 1. These equations were obtained by research conducted on soils from the country of origin of the researchers, in most cases and when used in other countries, these equations either overestimate or underestimate the Cc. This paper presents empirical models involving compression index and index properties of Ghanaian soils within the Birimian formation using linear regression analysis. These models can be used to predict the compression index for preliminary design purposes and also ascertain the accuracy of consolidation tests in the study area.

Table 1: Empirical Models relating some physical parameters to the Cc

Reference	Empirical Model
Terzaghi and Peck (1967)	Cc = 0.009(LL – 10)
Bowles (1979)	Cc = 0.0115mc
Skempton (1944)	Cc = 0.007 (LL- 7)
Hong and Onitsuka (1998)	Cc = 0.332LL – 0.390
Sridharan and Nagaraj (2000)	Cc = 0.007(I_s + 18)
	Cc = 0.008(LL – 12)
	Cc = 0.014(PI + 3.6)

LINEAR REGRESSION AND SOIL EMPIRICAL MODELS

Linear Regression is a statistical tool for the investigation of relationships between dependent variable and independent variables. The dependent variables are used to predict the independent variables; the aim of linear regression is to find the value of intercept and slope of the line that best predicts independent variables from dependent variables. The form of the regression equation is commonly written as:

$$Y = MX + C$$

where Y is the independent variable, X is the dependent variable; M and C are the slope and intercept of the regression equation respectively. The regression procedure finds estimates of the C and M by a minimization process. This minimization is done by minimizing the sum of squares of the vertical distances between the data points and the best-fit line in X-Y space (Bartlett and Lee, 2004). Assessment of regression relationships can be done through estimation of coefficient of determination, (R^2). For example an R^2 value of 0.5 means that 50 percent of the variation in the independent variable is being explained by the dependent variable. The values of R^2 range between 0.0 and 1.0. An R^2 value of 0.0 means that there is no correlation between the variables, an R^2 value of 1 means that there is a perfect correlation between the variables. Haan (1994) stated that, the quality of a regression relationship depends on the ability of the relationship to predict the dependent variable for observation on the independent variables that were not used in estimating the regression coefficients.

Many researchers in the field of geotechnical engineering have used linear regression to establish empirical models between soil parameters. Yoon et al. (2004) proposed best regression models for predicting compression index using natural water content, liquid limit and void ratio for Korean coastal area. Recently Abasi et al (2012) used regression analysis to predict the compression behavior of normally consolidated fine grained soil and concluded that, the proposed empirical models predict the compression index accurately in comparison with the existing equations. Yildirim and Gunaydin (2011) also estimated the California Bearing Ratio (CBR) of soils from different parts of Turkey using regression analysis. He concluded that, the correlation equations obtained as a result of regression analyses are in satisfactory agreement with the test results and recommended that the proposed correlations will be useful for a preliminary design of a project where there is a financial limitation and limited time. It is evident in literature that prediction of compression index with regression analysis has proved to be successful and widely accepted.

GEOENVIRONMENTAL CHARACTERISTICS AND GEOLOGY OF THE STUDY AREA

The study area is located in Kumasi within the Birimian Formation. The area falls within the moist semi deciduous forest which occurs in the wet semi – equatorial climate region of Ghana. Annual rainfall is between 125 and 175cm and dry seasons are clearly marked. Relative humidity is low throughout the year and accounts for the heavy rainfall (Dickson and Benneh 2004). According to J. O Kesse (1985), majority of the area is covered by the Birimian Formation. The Birimian has two main divisions, the lower and upper Birimian series, with the lower Birimian series dominating the entire area. The Birimian formation is greatly intruded by large masses of granites and basic intrusive, the supposition is that the granites are of post-Birimian and Pre-Tarkwaian age. Due to the intrusive relationship with granitoids, they are usually strewn with quartz veins. The water-bearing and yielding capacity is high due to the faults, fractures and quartz veins. The major rock type in the formation is the phyllites which form the parent rock of soils in the study area.

MATERIALS AND METHODS

The data used for the study consist of current and past laboratory results of soils sampled during the various geotechnical investigations conducted by Building and Road Research Institute BRRI in different locations within the study area. The data consisted of about 90 laboratory results which were conducted at the Geotechnical Engineering Laboratory of BRRI under the same conditions. The tests included Atterberg Limits (Liquid Limit LL, Plastic Limit PL), moisture content, particle size distribution (hydrometer) and one dimensional consolidation tests

The liquid limit (LL) was determined by the Casagrande method as specified by BS: 1377-Part 2, 1990. The liquid limit tests were carried out to obtain a minimum of five points for plotting the curve, the test was conducted on soil samples passing 425µm. The plastic limit (PL) was determined by the rolling thread method as outlined in BS: 1377-Part 2, 1990. The Plasticity Index (PI) as LL – PL. The Particle size analysis was conducted according to BS: 1377-Part 2, 1990 by combination of sieving and the hydrometer method. The one dimensional consolidation tests were performed in accordance with BS: 1377- Part 5, 1990 with the oedometer equipment. The moisture content (MC) was determined by the oven drying method, the moisture content of the soil sample was express as a percentage of its dry mass. A summary of the laboratory results are presented in Table 1& 2, since the data was from different geotechnical investigation reports; it was carefully scrutinized to eliminate any outliers and errors.

Linear regression was used to establish empirical models between the compression index and the index properties. A graph of compression index was plotted against the individual index properties and the coefficient of determination R^2 was used to determine the quality of the relationships; the higher the value of R^2, the higher the quality of the relationship between the variables. The data was divided into two, about 60 of the data were used in the regression analysis and the other 30 was used to validate the established relationship.

Table 1: Summary of Laboratory Test Results

No.	SG	MC %	Atterberg Limits %			Particle Size Distribution%				Consolidation		
			LL	PL	PI	Clay	Silt	Sand	Gravel	e_o	e_f	c_c
1	2.67	24.34	55	29.2	25.8	35	27	28	10	0.333	0.287	0.19
2	2.62	26.05	53	30.9	22.1	31	48	11	10	1.32	1.17	0.15
3	2.52	30.29	55.2	34.5	20.7	11	62	24	3	0.437	0.402	0.13
4	2.72	19.6	20.5	12.5	8	35	21	33	11	0.255	0.247	0.02
5	2.68	29.6	60	33.9	26.1	8	61	18	13	0.764	0.616	0.2
6	2.7	16.4	27.5	18.2	9.3	35	22	31	12	0.476	0.399	0.02
7	2.64	17.2	26.3	19	7.3	56	30	12	2	0.53	0.423	0.03
8	2.71	21.6	36.4	18.6	17.8	21	34	40	5	0.623	0.487	0.12
9	2.68	13.4	14.6	4.4	10.2	8	70	22	0	0.523	0.51	0.08
10	2.68	12.5	56.4	34.1	22.3	0	68	16	16	0.33	0.302	0.19
11	2.67	16.5	64.2	25.5	38.7	18.6	53.6	13.7	14.1	0.487	0.387	0.2
12	2.67	12.6	67.6	22.9	44.7	18	46	6	30	0.523	0.465	0.21
13	2.69	19.07	20.9	12.1	8.8	10	74	12	4	0.57	0.46	0.01
14	2.65	17.05	24.4	12.5	11.9	16	58	24	2	0.67	0.56	0.01
15	2.7	17.05	24.4	12.5	11.9	4	78	7	11	0.56	0.45	0.01
16	2.64	18.94	53	37.8	15.2	2	51	43	4	0.853	0.803	0.175
17	2.61	33.24	43.8	25.9	17.9	38	49	4	9	0.348	0.312	0.126
18	2.61	21.93	56	36.2	19.8	1	60	39	0	0.523	0.498	0.127
19	2.61	16.48	60.5	33.3	27.2	1	62	31	6	0.613	0.587	0.26
20	2.65	24.2	48	28.6	19.4	15	68	12	5	1.014	0.859	0.12
21	2.62	15.17	49.2	30.5	18.7	22.2	58.8	15	4	0.82	0.627	0.13
22	2.61	13.48	51.8	32.1	19.7	20	61	19	0	1.27	1.098	0.26
23	2.6	13.48	49.2	24.9	24.3	22	31.2	43	3.8	1.43	1.17	0.12
24	2.6	13.48	47.2	24.3	22.9	26.8	30.8	42	0.4	0.569	0.503	0.126
25	2.62	13.48	60	37.3	22.7	24	53	21	2	0.533	0.468	0.21
26	2.6	13.48	51.8	25.7	26.1	4	60	36	0	0.486	0.372	0.2
27	2.6	13.48	50.9	33.3	17.6	3	66	31	0	0.598	0.487	0.128
28	2.7	22.8	41.2	23	18.2	3	75	22	0	0.808	0.649	0.14
29	2.7	22.8	41.2	21.1	20.1	8	62	30	0	0.745	0.628	0.13
30	2.72	16.2	30.8	22.8	8	30	33	30	7	0.81	0.736	0.09
31	2.65	29.8	48	34.6	13.4	3	71	26	0	0.719	0.671	0.12
32	2.64	34.2	51	26	25	2	76	22	0	0.82	0.736	0.26
33	2.69	38.9	39.8	27.4	12.4	2	76	22	0	0.874	0.757	0.124
34	2.68	15.8	28.5	19.3	9.2	10	71	15	4	0.81	0.721	0.07
35	2.67	26.8	50	24.1	25.9	29	47	14	10	0.72	0.691	0.18
36	2.7	25.4	53.5	33.1	20.4	31	44	23	2	0.739	0.681	0.17
37	2.6	30.2	36.4	25.2	11.2	2	72	26	0	0.731	0.665	0.09
38	2.84	19.45	50.5	26.8	23.7	16	21	63	0	0.885	0.751	0.28
39	2.89	23.15	58.2	37.9	20.3	21	45	34	0	1.105	0.972	0.19
40	2.63	24.35	65.5	40.6	24.9	10	54	30	6	0.858	0.7	0.2
41	2.8	27.18	60.22	43	17.22	37	24	29	10	0.8	0.7	0.26
42	2.58	37.8	55.2	34.1	21.1	2	72	26	0	0.891	0.753	0.28
43	2.86	33.3	59	40	19	28	43	29	0	1.2	0.94	0.18
44	2.58	30.7	50.5	31.7	18.8	13	47	40	0	1.047	0.858	0.19
45	2.79	29.6	52.1	26	26.1	10	47	43	0	1.143	0.92	0.22

Table 2: Summary of Laboratory Test Results

No.	SG	MC %	Atterberg Limits %			Particle Size Distribution%				Consolidation		
			LL	PL	PI	Clay	Silt	Sand	Gravel	e_o	e_f	c_c
46	2.87	39	48.4	21.1	27.3	8	45	43	4	0.75	0.686	0.23
47	2.72	21.04	50	25	25	32	48	20	0	0.78	0.732	0.25
48	2.78	22.85	53.8	25.6	28.2	24	49	27	0	1.2	0.99	0.21
49	2.76	25.8	57	33.1	23.9	4	59	37	0	1.1	0.93	0.26
50	2.76	27.25	56.5	32.7	23.8	21	42	37	0	1	0.862	0.26
51	2.66	27.85	57	39.1	17.9	18	42	40	0	1.06	0.822	0.18
52	2.66	31.21	56.5	49.7	6.8	10	72	18	0	1.02	0.824	0.086
53	2.69	29.4	55.2	33.3	21.9	15	63	22	0	0.973	0.802	0.18
54	2.83	27.2	53	41.9	11.1	15	43	42	0	1	0.08	0.092
55	2.78	32.65	47.3	38.9	8.4	42	35	23	0	0.866	0.714	0.063
56	2.67	20.3	48.2	39	9.2	15	43	42	0	0.7	0.594	0.09
57	2.62	21.3	53	28	25	21	69	10	0	0.297	0.231	0.18
58	2.62	19.6	37	29.8	7.2	42	43	15	0	0.456	0.395	0.08
59	2.61	21	50.2	40	10.2	35	43	17	5	0.482	0.454	0.13
60	2.58	28.21	55	33	22	25	53	22	0	0.253	0.2	0.19
61	2.6	29.35	55	43	12	25	38	26	11	0.428	0.399	0.18
62	2.56	42.21	63	42	21	0	56	40	4	0.287	0.231	0.25
63	2.59	45.74	53	39	14	2	58	35	5	0.523	0.491	0.175
64	2.58	32.84	57	35	22	14	31	51	4	0.333	0.31	0.22
65	2.6	35.27	60	43	17	46	39	15	0	0.289	0.232	0.24
66	2.63	36.28	53	26	27	22	52	18	8	0.422	0.382	0.18
67	2.64	19.00	45.00	23	22.00	30	57	12	1	1.251	1.11	0.163
68	2.65	23.00	50.00	29	21.00	31	35	23	11	0.526	0.487	0.182
69	2.63	26.00	48.00	40	8.00	29	39	25	7	0.477	0.345	0.155
70	2.67	19.00	43.00	28	15.00	19	54	24	3	0.712	0.598	0.152
71	2.68	17.00	41.00	27	14.00	40	44	15	1	0.523	0.478	0.142
72	2.67	21.00	44.00	32	12.00	28	47	19	6	0.632	0.589	0.146
73	2.68	15.00	43.00	19	24.00	12	60	20	8	0.429	0.41	0.138
74	2.68	17.00	41.00	22	19.00	17	65	13	5	0.832	0.628	0.13
75	2.64	19.20	48.00	30.8	17.20	26	61	12	1	0.544	0.376	0.162
76	2.62	20.20	48.40	37.9	10.50	10	70	20	0	0.238	0.222	0.162
77	2.60	21.40	44.80	34.8	10.00	11	75	14	0	0.628	0.577	0.142
78	2.63	24.40	46.00	34.3	11.70	7	75	18	0	0.389	0.311	0.151
79	2.65	18.70	43.00	23	20.00	3	79	18	0	0.444	0.427	0.142
80	2.68	20.00	43.00	23	20.00	7	63	30	0	0.634	0.519	0.14
81	2.70	22.50	46.00	31.2	14.80	34	40	26	0	0.298	0.199	0.147
82	2.60	23.40	46.00	31.2	14.80	4	66	30	0	0.433	0.288	0.154
83	2.63	24.50	44.00	37.2	6.80	4	72	24	0	0.587	0.5	0.146
84	2.61	26.60	42.00	33.6	8.40	2	70	28	0	0.821	0.753	0.132
85	2.60	18.10	47.50	24.3	23.20	5	55	40	0	0.432	0.421	0.16
86	2.72	19.60	20.50	17.3	3.20	24	46	15	15	0.329	0.287	0.045
87	2.60	29.00	60.00	29.3	30.70	35	33	21	11	0.527	0.488	0.23
88	2.68	15.50	28.00	26.2	1.80	8	61	18	13	0.436	0.411	0.082
89	2.70	16.40	27.50	18.2	9.30	40	20	20	20	0.589	0.499	0.08
90	2.70	17.20	38.50	19.8	18.70	13	46	35	6	0.555	0.532	0.082

RESULTS AND DISCUSSIONS

Linear regression analysis of the compression index and the index properties are presented in a graphical form in Figure 1 – 4.The graphs indicate the relationship between the variables and the coefficient of determination R^2 of the relationships. Table 2 shows a summary of the regression analysis.

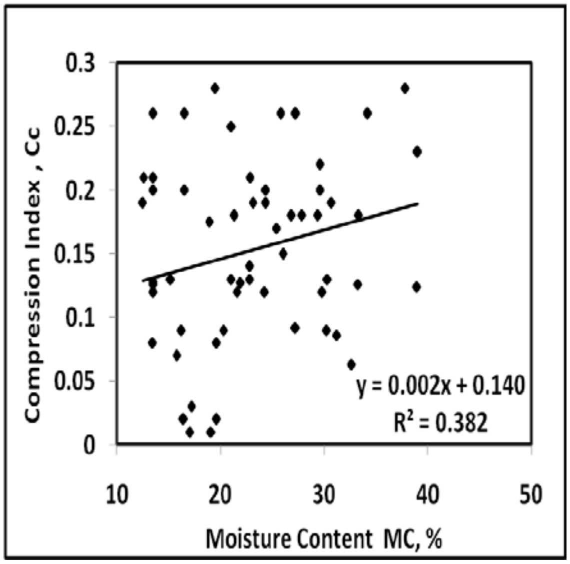

Figure 1: Compression Index and MC

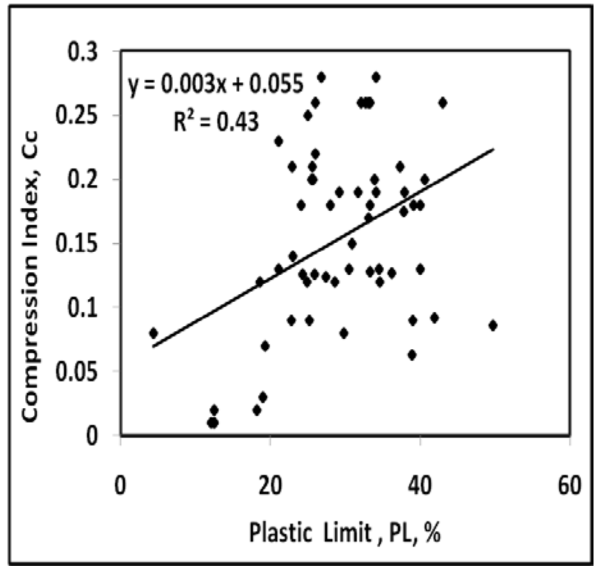

Figure 2: Compression Index and PL

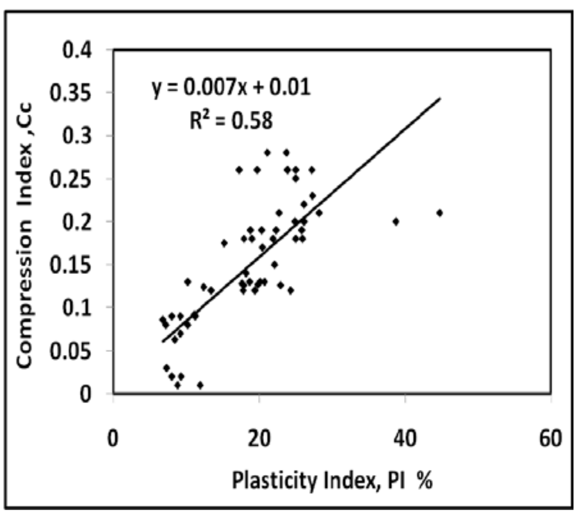

Figure 3: Compression Index and PI

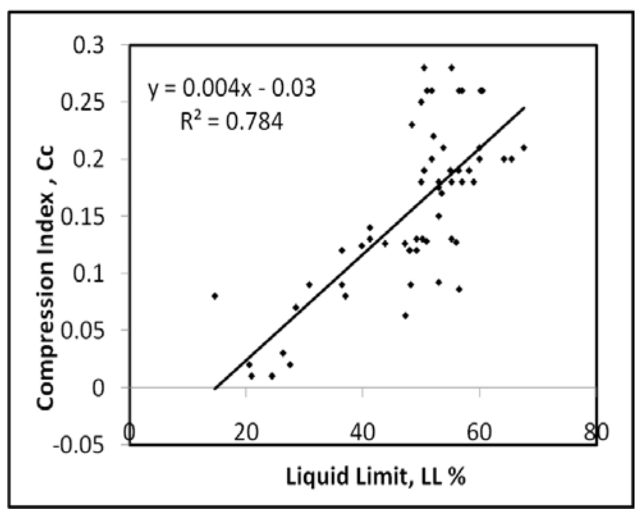

Figure 4: Compression Index and LL

Table 3: Summary of Regression Analyses

Independent Variable	Empirical Model	Coefficient of Determination R^2
Moisture Content - MC	$C_c = 0.002MC + 0.14$	0.382
Plastic Limit – PL	$C_c = 0.003PL + 0.055$	0.430
Plasticity Index – PI	$C_c = 0.007PI + 0.01$	0.580
Liquid Limit - LL	$C_c = 0.004LL - 0.03$	0.784

The graphs indicate that there is a significant level of correlation between the compression index and the other parameters; however, it is the coefficient of determination (R^2) that differentiates the level of correlation. The values of R^2 for the moisture content and plastic limit are very low, this can be attributed to the fact that, majority of the points in the graphs are further away from the regression line. The R^2 values means that the variables MC and PL cannot predict about 50% of the compression index in the regression analysis therefore cannot be used to accurately predict the compression index in the study area. However, the equations relating the compression index to the plasticity index and the liquid limit shows an improved value for the R^2. This means that, there is a high correlation between the compression index, the plasticity index and the liquid limit. It is clear from the graphs represented in Figure 3 &4 that, liquid limit and the plasticity index increases with an increase in compression index. The liquid limit can be considered as a measure of the quantity of water attracted by the soil particles, thus making it possible to correlate well with compression index. Plasticity is the property by which the material can undergo large amount of deformation; clayey soil exhibits this property to a greater degree with high liquid limit. That is why soil containing high liquid limit, posses high compression index. Similar observations were made by Terzaghi and Peck (1967), Sridharan and Nagaraj (2000). The equation for the liquid limit has a R^2 of 0.784 and that of the plasticity index is 0.580. More than 50% of the compression index can be predicted by the LL and the PL but is clear from the values that the liquid limit can predict the compression index with less uncertainty.

In order to verify the equation between the liquid limit and the compression index, the equation was used to predict the compression index of the remaining 30 results which were not used in the regression analysis. The predicted values were plotted against the observed laboratory results; Figure 5 shows the graph of predicted values against observed values. The R^2 for the relationship between the predicted values and the observed laboratory is 0.96, this indicates that the established equation can predict compression index using the liquid limits of the soils in the study area.

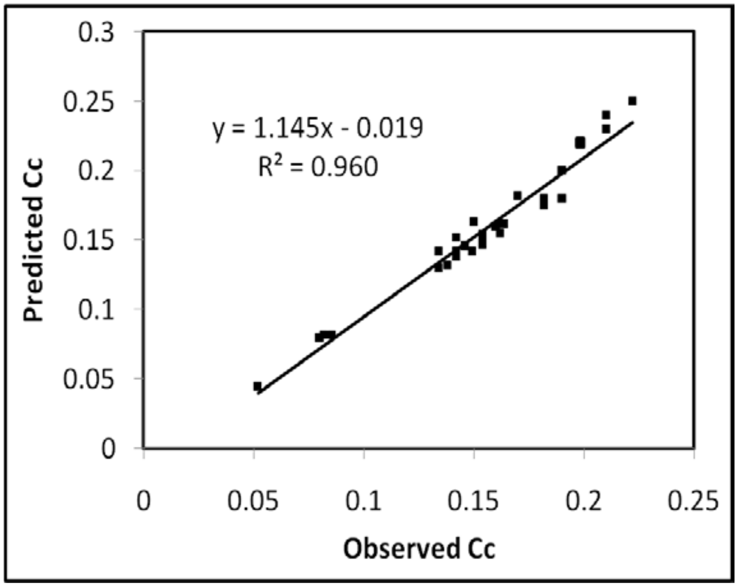

Figure 5: Graph of Predicted Cc and Observed C_c

CONCLUSIONS

The study has successfully demonstrated that index properties which are simple to perform can be used to predict compression index. Based on the regression analysis conducted on the variables, the moisture content resulted in R^2 of 0.38 , the PL resulted in R^2 of 0.43 , PI resulted in R^2 of 0.58 and LL resulted in R^2 0.78. The liquid limit resulted in the highest coefficient of determination and therefore can be used to predict the compression index in the study area. Currently a lot of infrastructural development is ongoing in the study area, the developed equation between the C_c and LL can be use for preliminary estimates of compression index of weathered Birimian phyllites in the study area before extensive exploration and testing is undertaken for a final design. This will facilitate the determination of ground parameters related to settlements for foundation design of structures. It should be recognized that any correlation between a particular soil property and the index properties can only be approximate, therefore should not be used as an alternative to detail determination of compression index.

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