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Compression Index Prediction Models for Fine-grained Soil Deposits in Nigeria

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ABSTRACT

Compression index prediction models for fine-grained soil deposits in Nigeria are presented. Correlation model equations, each for compression index, in terms of initial void ratio, product of initial void ratio and specific gravity, product of liquid limit and initial void ratio, quotient of percentage fine content and specific gravity, natural moisture content and liquid limit were considered using regression analysis. Values of coefficient of determination (R^2) of the correlation models were used to evaluate the resulting models. The correlation models expressing compression index (c_c) in term of initial void ratio (e_0) and as a function of the product of specific gravity and initial void ratio gave R^2 value of 73.5 and 70.1% respectively. The model expressing c_c as a function of the product of liquid limit and initial void ratio has R^2 value of 53.6%, while that as a function of the quotient of percentage fine content and specific gravity gave R^2 value of 51.3%. Weak correlations exist between compression index and natural moisture content, and between compression index and liquid limit for fine-grained soil deposits in Nigeria.

Keywords: *Coefficient of determination; Compression index; Fine content; Fine-grained soils; Prediction model; Initial void ratio; Specific gravity.*

1 INTRODUCTION

In geotechnical design of foundation for civil engineering structure, safety of the structure is ensured based on the satisfaction of two conditions: 1. the supporting soil is safe against shear failure due to the imposed loads by the superstructure; 2. the settlement of the foundation is within permissible limit. Evaluation of magnitude and rate of settlement of foundation due to structural load is essential for safety and stability of the structure. In evaluation of settlement of foundations on fine-grained soils, compressibility characteristics are used. These characteristics are often described using two coefficients (indices): compression index (c_c) and coefficient of consolidation (c_v). While the latter is used to predict the time required for a given settlement to take place, the former is used for computation of magnitude of the settlement. Compression index is the slope of the straight line portion of the void ratio-effective stress (pressure) curve, on a semi logarithmic plot (virgin curve), which is usually obtained from one-dimensional consolidation test results (Abbasi *et al.*, 2012).

1. LITERATURE REVIEW

Due to the long time and highly undisturbed soil samples required to carry out consolidation test, numerous researchers have evolved empirical relationships to evaluate compressibility indices from other soil parameters. Most of these studies are anchored on finding empirical relationships, using easily determined soil parameters, to evaluate these indices. Azzouz *et al.* (1976) carried out consolidation tests on Chicago clays, organic soils and Brazilian clays. The data obtained was used to derive empirical relationship for c_c each, as a function of natural moisture content (w_n), initial void ratio (e_0) and liquid limit (w_l). Azzouz *et al.* (1976) empirical relationships are presented in equations (1) to (4).

$$c_c = 0.01w_n;\ for\ Chicago\ clay\ deposits \quad (1)$$

$$c_c = 0.208e_0 + 0.0083;\ \ for\ Chicao\ clay\ deposits \quad (2)$$

$$c_c = 0.0115w_n;\ for\ organic\ soils \quad (3)$$

$$c_c = 0.0046(w_l - 9)\ ;\ for\ Brazilian\ clays \quad (4)$$

Wroth and Wood (1978) also carried out study on correlation of compressive index with some basic engineering properties of some soils and evolved an empirical correlation (equation 5) for c_c in terms of specific gravity (G_s) and plasticity index (PI).

$$c_c = 0.5G_s\left(\frac{PI}{100}\right) \quad (5)$$

Rendon-Herrero (1980) investigated a wide variety of clay deposits and developed an equation for c_c, which he called the '*universal compression index equation'*. This equation expresses c_c as a function of G_s and e_0.

$$c_c = 0.141G_s^{1.2}\left(\frac{1+e_0}{G_s}\right)^{2.38} \quad (6)$$

In a similar study by Nagaraj and Murthy (1985), compressive index was expressed (equation 7) as a function of w_l and G_s.

$$C_c = 0.2343\left(\frac{w_l}{100}\right)G_s \quad (7)$$

Lav and Ansal (2001), using index and consolidation parameters, conducted a statistical study to determine suitable correlations for estimating consolidation response. Various linear regression models were adopted and a parametric study was carried out in order to obtain the most suitable and practically applicable relationship. They observed that the void ratio, water content, liquid limit, and dry unit weight yielded sufficiently reliable correlations.

Crumley *et al.* (2003), studied alluvial and residual soils from Puerto Rico, and reported R^2 values for correlations of c_c with compression ratio, w_n and e_0, at various ranges of *PI* values, and also at various ranges of w_l values. Using artificially prepared soil samples, Nath and DeDalal (2004) developed and an expression (equation 8) for c_c as a function of I_p.

$$c_c = 0.015I_p - 0.0198 \quad (8)$$

Rao *et al.* (2006) investigated the choice of liquid limit, plasticity index, initial moisture content and dry density for prediction of compression index. The authors carried out study on fifteen soil samples with wide ranges of liquid limit, plasticity index, dry density and initial moisture content. Regression models, relating compression index with liquid limit, plasticity index, initial moisture content and dry density were developed separately and also for various combinations of these parameters. The applicability of the proposed regression models were tested by comparing predicted and observed compression index values for 180 test existing data. Their results showed regression models relating compression index with liquid limit, dry density and moisture content as better models.

Singh and Noor (2012) used regression analysis to develop prediction models for estimation of compression index from index properties (LL and PI). The result of their study showed that compression index correlated well with liquid limit and plasticity. Nader *et al.* (2012), using soils collected from different part of Iran, proposed a prediction model for compression index with dry unit weight γ_d, while study by Widodo and Ibrahim (2012), using soil from Pontianak, Indonesia, showed low R^2 values for correlation between c_c and moisture content w_n.

Study carried out by Mustapha and Alhassan (2013a) on preconsolidation pressure and overconsolidation ratio of some selected soil deposits in Nigeria, showed the studied soil deposits to be generally overconsolidated, with the exception of soil deposit from Northwestern part of the country, which is under-consolidated. Using values of compressive index (c_c), obtained from laboratory test results and those obtained, using some existing correlations, Mustapha and Alhassan (2013b), showed that the correlation, proposed by Azzouz *et al.*(1976) for Chicago clays, compared to other correlations in literature, best (R^2 *of 66.25 %*) fits clay depositsin Nigeria.

Compression index prediction models for soil deposits in Nigeria have not been reported in literature. In this study, prediction models for compression index (c_c), as a function of some index properties of fine-grained soil deposits in Nigeria are proposed.

2. MATERIALS AND METHOD

Thirty eight (38) undisturbed fine-grained soil samples were collected from different part of Nigeria (Figure 1), at depth ranging between 0.5 and 10.0 m. Tests conducted on the samples included soil identification and classification tests in accordance with B. S. 1377-2 (1990), while one-dimensional consolidation test was conducted in accordance with B. S. 1377-5 (1990). The tests were carried out in the geotechnical laboratories of the Department of Civil Engineering, Federal University of Technology, Minna, and Dadson Engineering Services, Minna, all in Nigeria.

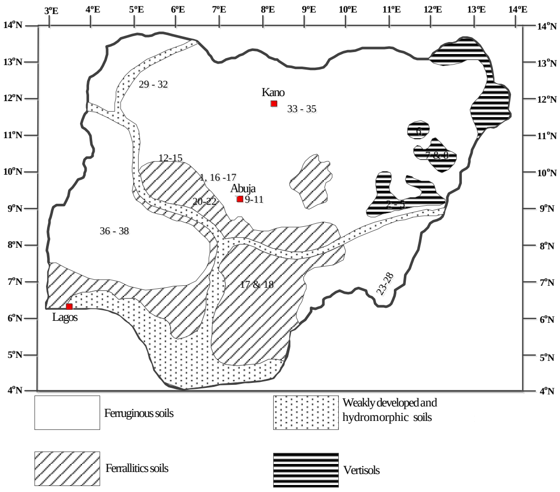

Figure 1: Distribution of the soil sampling points

Laboratory results from the one-consolidation test were used to evaluate the compression index (c_c), using Terzaghi's void ratio-effective stress relationship (curve). These results are presented on Table 1. The resulting compression indices were then correlated with some of the determined soils index properties, using regression analysis (Figs 1-6).

3. RESULTS AND DISCUSSION

Results of the index properties test is presented on Table 1, while the regression analysis plot correlating compression index with some of the properties are presented in Figures 2-7. Figure 2 presents correlation between compression index and initial void ratio. From the regression analysis equation (9) relating c_c with initial void ratio was evolved. This model has value of coefficient of determination (R^2) of 73.5%, indicating a relatively strong correlation. This model is similar to the correlation model developed by Azzouz *et al.* (1979) for Chicago clay.

$$c_c = 0.245e_0 + 0.011; \qquad R^2 = 0.735 \quad (9)$$

TABLE 1: PROPERTIES OF THE SOILS

Sample No.	Natural moisture content (%)	Percentage fine content (%)	Initial void ratio (e_o)	Specific gravity Gs	Liquid limit (%)	Plasticity index (%)	Bulk unit weight (kN/m^3)	Dry unit weight (kN/m^3)	Compressive index (c_c)	Final moisture content (%)
1	32.8	58	0.882	2.28	57.4	25.8	17.5	13.4	0.254	33.8
2	22.4	80.9	0.669	2.26	57.8	32.9	19.6	16	0.163	25
3	25	68	0.806	2.41	57.5	33.2	19.4	15.5	0.216	23.7
4	22	74.1	0.611	2.35	57.6	33.6	19.5	16	0.189	20
5	22.8	81.4	0.704	2.24	56	33.4	19.1	15.6	0.141	27.7
6	20.8	72	0.571	2.32	58.2	29.4	19.6	16.2	0.143	24.2
7	22.6	58	0.821	2.24	57.2	28.5	18.2	14.8	0.246	27.7
8	21.8	75	0.656	2.26	51.9	21.7	19.4	15.9	0.179	21.5
9	12.4	67.7	0.747	2.49	45.6	22.6	19.3	17.2	0.188	20.1
10	16.7	72.7	0.663	2.46	40.5	20.9	19.9	17.1	0.188	21.8
11	11.2	51.8	0.872	2.54	40.9	23.2	17.1	15.4	0.206	18.6
12	19	75.2	0.671	2.52	50.2	23.5	20.6	17.3	0.194	21.6
13	17.2	75.6	0.612	2.54	47.6	25.6	17.8	20.9	0.158	21.3
14	24.3	76	0.782	2.49	50.4	26	19.5	15.7	0.176	26.6
15	24.9	68	0.844	2.43	48.7	24.1	18.7	15	0.221	26.4
16	19.7	59	0.845	2.66	50.5	25.2	18.9	15.8	0.184	22.7
17	17.7	67.2	0.644	2.57	40.2	18	20.2	17.2	0.15	19.3
18	18.6	70.9	0.714	2.54	44.6	15.5	20	16.9	0.198	25.6
19	21.9	65.9	0.52	2.48	34.8	14.7	20.4	16.7	0.135	16.5
20	17.7	74.9	0.56	2.41	44	24.3	20.3	17.2	0.176	14.1
21	16.2	83.4	0.511	2.39	49.1	30	20.6	17.7	0.123	15.8
22	13.3	55.5	0.78	2.67	41.1	22.1	19.9	17.6	0.228	18.8
23	33.3	68	0.968	2.56	49.8	18.7	19	14.3	0.241	26.6
24	37	49.2	0.786	2.7	52.3	11.7	19.2	14	0.211	23.5
25	27.6	75	0.745	2.71	42.7	9.2	20	15.7	0.158	22.6
26	31.2	57.9	0.938	2.47	61.4	19.8	18.6	14.2	0.199	27.1
27	29.2	68	1.06	2.51	50.9	17	18.6	14.4	0.236	32.3
28	31.3	71.8	0.797	2.51	42.9	8.4	19.1	14.6	0.176	27.7
29	10.9	45.3	1.243	2.69	46.5	18.7	14.4	13	0.317	20
30	13	61.5	0.886	2.66	48.7	20.2	18.2	16.1	0.231	22.4
31	17.8	67	0.796	2.74	50.5	14	20.5	17.4	0.183	24.2
32	23.2	59.4	0.859	2.61	50.2	14.1	19.1	15.5	0.248	23
33	16.6	53.9	0.813	2.61	46.9	10.5	18	15.4	0.199	23.8
34	17.9	54.7	0.9	2.61	46.5	11.5	18.1	15.3	0.241	24.5
35	21	51.4	0.771	2.61	48.2	12.4	19.5	16.2	0.219	22.7
36	22.9	52.2	0.995	2.69	46.1	10.4	18.3	14.9	0.284	26.1
37	22.5	50	0.966	2.68	47.9	11	18.7	15.3	0.287	25.4
38	19.8	49.7	0.94	2.69	46.5	9.8	19.4	16.2	0.253	25.7

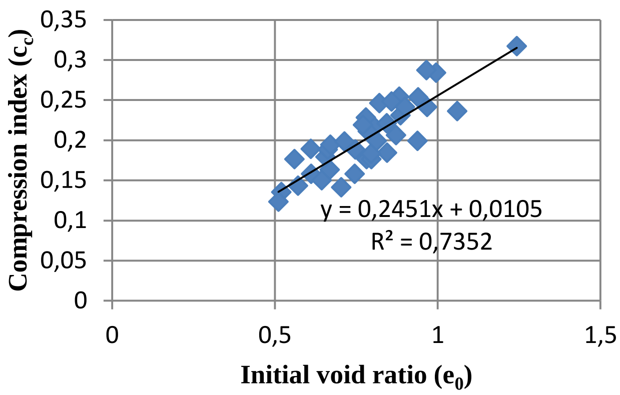

Figure 2: Relationship between Compression index and initial void ratio

Figure 3 presents correlation between compression index and the product of specific gravity and initial void ratio. Regression analysis of this relationship yielded equation (10). The model has R^2 value of 70.1%, also indicating a relatively strong correlation. This model is slightly different the '*universal compression index equation'* developed by Rendon-Herrero (1980).

$$c_c = 0.081(G_s e_0) + 0.042; \qquad R^2 = 0.701 \qquad (10)$$

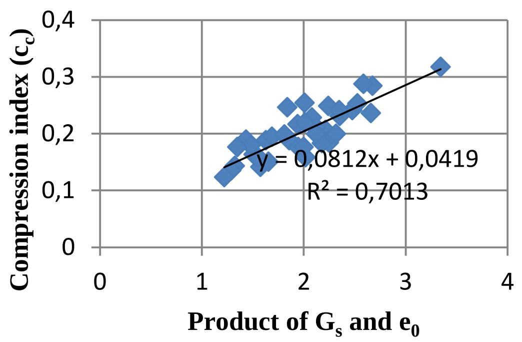

Figure 3: Relationship between Compression index and product of G_s and e_0

Figure 4 shows correlation between compression index and the product of liquid limit and initial void ratio. Equation (11) presents resulting equation from the regression analysis of the relationship. R^2 value of this correlation is 53.6%.

$$c_c = 0.0036(w_l e_0) + 0.0642; \qquad R^2 = 0.536 \qquad (11)$$

Figure 5 presents correlation between compression index and the quotient of fine content and specific gravity. Regression analysis of this relationship yielded equation (12), with R^2 value of 51.3%. Model relating compression index with fine content of soils have not been well reported in literature.

$$c_c = -0.006\left(\frac{Fine\ content\ (\%)}{G_s}\right) + 0.363; \quad R^2 = 0.513 \quad (12)$$

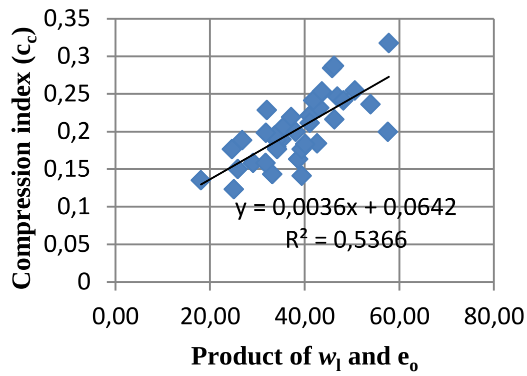

Figure 4: Relationship between Compression index and product of w_l and e_0

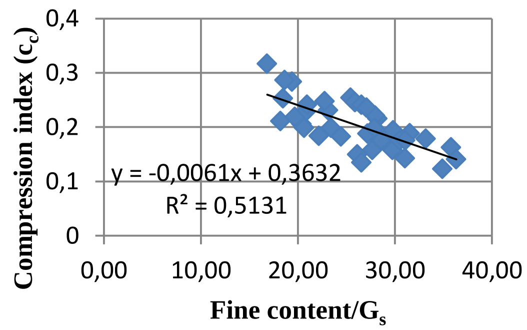

Figure 5: Relationship between Compression index and $\frac{Fine\ content\ (\%)}{G_s}$

Figure 6 presents correlation between compression index and natural moisture content (w_n), while Figure 7 shows correlation between compression index and liquid limit (w_l). The trends and the resulting equations (equations 13 and 14) are those that yielded the best R^2 values. From the R^2 values, it can be observed that for fine-grained soil deposits in Nigeria, relatively weak correlation exist between compression index and natural moisture content and liquid limit. This is different from what was reported by Azzouz *et al.* (1979) for Chicago clay deposits and Brazilian clays respectively, for natural moisture content and liquid limit.

$$c_c = 0.0002(w_n)^2 - 0.01w_n + 0.306; \quad R^2 = 0.063 \quad (13)$$

$$c_c = -0.0003(w_l)^2 + 0.0312w_l - 0.565; \; R^2 = 0.111 \quad (14)$$

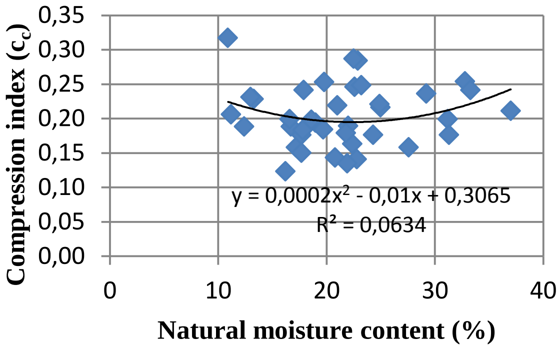

Figure 6: Relationship between Compression index and product of natural moisture content

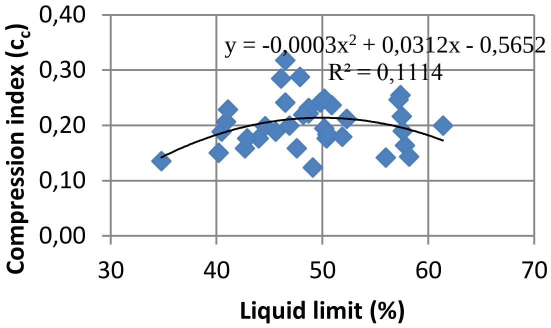

Figure 7: Relationship between Compression index and product of liquid limit (%)

4. CONCLUSION

Correlation model equations each for compression index in terms of initial void ratio, product of initial void ratio and specific gravity, product of liquid limit and initial void ratio, quotient of percentage fine content and specific gravity, natural moisture content and liquid limit were considered using regression analysis. Values of coefficient of determination (R^2) of the correlation models were used to evaluate the resulting model equations. The correlation models expressing compression index (c_c) in term of initial void ratio (e_0) and that expressing c_c as a function of the product of specific gravity and initial void ratio gave R^2 value of 73.5 and 70.1% respectively. The model expressing c_c as a function of the product of liquid limit and initial void ratio has R^2 value of 53.6%, while that it as a function of the quotient of percentage fine content and specific gravity gave R^2 value of 51.3%. For fine-grained soil deposits in Nigeria, weak correlations exist between compression index and natural moisture content, and liquid limit.

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