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(Research Article)

Exponential Regression Modelling of the Compression Index of Awka Soil

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Abstract

A consolidation (Oedometer) test can be used to measure the soil's compressibility characteristics, which indicate how much settlement will occur. The Atterberg limit test is very simple and quick in comparison to the Oedometer test, which is more expensive and time-consuming. Soil samples from various areas in Awka, Anambra State, and the surrounding area were gathered for this research. Laboratory investigations were carried out on the soil samples in order to determine the Index properties and compressibility parameters namely liquid limit (LL), plastic limit (PL), plasticity index (PI) and compression index (Cc). Based on the outcome of the experiments, non-linear empirical models were subsequently developed using simple regression analysis. This makes it possible to define the compression index as a function of the soil index (Atterberg limit) characteristics viz; LL, PL, and PI in the study area. A good agreement was found between the model's predictions and the actual values of the compression index. The regression models were validated with a 95 percent confidence level based on the coefficient of determination (R^{2}) values, which show a strong link between the variables.

Keywords: Compression index, Liquid limit, Plastic limit, Plasticity index, Regression.

1. Introduction

Among the three most important engineering characteristics of a soil mass (shear strength, compressibility, and permeability), compressibility is the most important parameter when determining how much a soil will settle under the weight of an infrastructure constructed on that soil mass. This factor is applicable in areas like the design and analysis of dams, retaining walls, soil foundation systems, and other applications related to geotechnical engineering practice [1]. Compressibility is a term used to describe a soil mass's susceptibility to volume loss under pressure. Since all soils are compressible, deformation will take place whenever soils are stressed. To build structures for civil engineering that are secure, stable, and cost-effective, it is vital to know the soil's compressibility qualities.

However, obtaining the compressibility properties of soil is relatively expensive and time consuming. Conversely, it's relatively simple and economical to investigate a soil's Atterberg limit (index characteristics). As a result, it would be advantageous to suggest a correlation between compressibility qualities and index properties (Atterberg limit), which can be discovered by an easy and quick testing approach.

In soil mechanics literature, correlations using the Atterberg limits are fairly prevalent and can be very helpful [2].

Researchers have been attempting to associate the value of soil index properties with compressibility characteristics, which take less time and are typically easier to measure. In this article, a thorough investigation of the compressibility characteristics of soil is presented together with statistical predictions made, using nonlinear regression.

2. Literature Review

It has been studied whether there are any correlations between the basic soil qualities and the compressibility parameters. There have been a number of proposed correlations wherein soil variables like specific gravity, liquid limit, and natural moisture content are used to evaluate compressibility parameter like the compression index. Researchers have found a strong correlation between a soil's compressibility properties and its physical qualities. In light of prior research, numerous empirical formulas based on single and multiple linear regression have been created to estimate the compression index from fundamental soil parameters.

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Amardeep and Shahid [3] collected a total number of 23 samples from different Indian hydropower projects and subjected them to laboratory investigation. Based on the experimental results, correlation between the compression index and soil index properties was established.

Nesamatha and Arumairaj [4] carried out a study on Numerical modelling for prediction of Compression Index from Soil index properties. Samples were collected from four different locations in Coimbatore city. An attempt was made to establish a correlation between compression index Vs plasticity index and compression index Vs liquid limit using regression analysis.

Wasif, et al [5] conducted a study on correlation between consolidation properties of soil with liquid limit, in situ water content, void ratio and plasticity index. Total of fourteen (14) soil samples were collected for testing of Dhaka- Chittagong expressway and experimented in the laboratory. The coefficient of deformation R^2 value of 0.9805 was obtained in the relationship between compression index (C_c) and liquid limit (LL) and this verifies that there is a strong correlation between C_c and LL. Also, the relationship between compression index (C_c) and water content, W% was found, with R^2 value of 0.8997 which shows moderate relationship between the two variables. The relationship between compression index (Cc) and void ratio (e_o) was found with R^2 value of 0.8619 which indicates a strong relationship between the variables. Equations derived in terms of liquid limit, water content and void ratio found a basis for the prediction of compression index (C_c).

Kamal, et al [6] carried out a detailed study on correlation of consistency and compressibility properties of soils in Sulaimani city. In their study, sixty undisturbed fine-grained soil samples were collected from twelve different locations at Sulaimani city in Kurdistan region of Iraq. Single and multiple empirical equations were proposed to predict compressibility indices (C_c and C_r) as a function of index properties (LL, PL, PI and SL). The R^2 and Root Mean Square Error RMSE value obtained from the relationship between compression index and liquid limit were 0.74 and 0.026 respectively, the R^2 and RMSE value obtained from the relationship between compression index and plastic limit were 0.75 and 0.016 respectively while R^2 and RMSE value obtained from the relationship between compression index and plasticity index were 0.72 and 0.016. The statistical analysis shows that there is a direct and positive correlation among the selected parameters.

Table 1. Literature summary

Equation	Author
$C_c = 0.0082PI + 0.0915$	Solanki [7]
$C_c = 0.006LL - 0.0024$	Solanki [7]
$C_c = 0.0056LL$	Al-Kahdar & Al-Ameri [8]
$C_c = 0.002\ LL + 0.0025PI - 0.005$	Amardeep & Shahid [3]
$C_c = 0.004LL - 0.03$	Akayuli & Ofosu [9]
$C_c = 0.003PL + 0.06$	Akayuli & Ofosu [9]
$C_c = 0.007PI + 0.01$	Akayuli & Ofosu [9]
$C_c = 0.007LL - 0.043$	Abbasi [10]
$C_c = 0.0027\ LL + 0.\ 2$	Dway &Thant [11]
$C_c=0.52 - 0.03LL + 0.03PI$	Dway &Thant [11]
$C_c = 0.004PI + 0.22$	Dway &Thant [11]
$C_c = 0.0026W_L - 1.152$	Nesamatha & Arumairaj [4]
$C_c = 0.026I_P - 0.536$	Nesamatha & Arumairaj [4]
$C_c = 0.5562\ e_o - 0.1453$	Wasif, et al [5]
$C_c = 0.01(LL - 13.61)$	Wasif, et al [5]
$C_c = 0.\ 0158W - 0.179$	Wasif, et al [5]
$C_c = 0.006LL - 0.1$	Kamal, et al [6]
$C_c= 0.007PL - 0.005$	Kamal, et al [6]
$C_c= 0.007PI + 0.036$	Kamal, et al [6]
$C_c= 0.014SL - 0.024$	Kamal, et al [6]

3. Methodology

3.1 Soil samples collection: The ten different soil samples selected for this research were collected by disturbed and undisturbed sampling techniques from different locations in Awka, Anambra state and its surroundings. Awka lies on latitude 6°13′19″N and longitude 7°4′56″E. The details of the sampling locations can be seen in Table 2.

Table 2. Location of soil samples

Sample location	Sample no	Latitude	Longitude
Agu Awka 1	Sample 1	6°12′32″N	7°5′42″E
Agu Awka 2	Sample 2	6°12′32″N	7°5′43.5″E
Agu Awka 3	Sample 3	6°12′33″N	7°5′41″E
Nawfia 1	Sample 4	6°11′49″N	7° 0′46″E
Nawfia 2	Sample 5	6°11′54″N	7°0′42″E
Awkuzu 1	Sample 6	6°13′57″N	6°55′7″E
Awkuzu 2	Sample 7	6°13′59″N	6°54′59″E
Ogbunike	Sample 8	6°10′51″N	6°52′5″E
Nnamdi Azikiwe University 1	Sample 9	6°14′38″N	7°7′30″E
Nnamdi Azikiwe University 2	Sample10	6°14′49″N	7°6′50″E

3.2 Laboratory analysis: The following laboratory tests were carried out on the soil samples, in order to determine the differences in soil properties; Grain size distribution, Specific gravity, Atterberg limit (Liquid limit and Plastic limit), and Consolidation test. Attempts were made to obtain accurate results from the laboratory experiments by following the testing procedures carefully, as outlined by the American Society for Testing and Materials (ASTM).

Table 3. Experimental methods

S/N	Description		ASTM specification
1	Particle size distribution		ASTM D-422 [12]
2	Specific gravity		ASTM D-854 [13]
3	Plasticity characteristics		
	A	Liquid limit	ASTM D-4318 [14]
	B	Plastic limit	
	C	Plasticity index	
4	Compressibility Characteristics		ASTM D-2435 [15]
	A	Compression index	

4. Results

The results obtained from the laboratory experiment, are shown in Table 4 and 5. The soil samples were classified according to Unified Soil Classification System (USCS) [16] and the American Association of State Highway and Transport Officials (AASHTO) [17] Soil Classification.

Table 4. Physical properties of soil samples [18]

Sample no	Specific gravity	Liquid limit	Plastic limit	Plasti-city index	Gravel (%)	Sand (%)	Silt & clay (%)
1	2.58	54.00	23.40	30.60	0.00	47.57	52.43
2	2.58	47.20	25.09	22.11	0.18	50.29	49.53
3	2.58	46.70	21.84	24.86	0.00	49.98	50.02
4	2.54	36.40	16.30	20.10	-	65.83	34.17
5	2.62	30.84	15.39	15.45	0.04	79.67	20.29
6	2.58	35.00	13.67	21.33	0.26	78.64	21.10
7	2.68	31.50	12.69	18.81	0.05	79.32	20.63
8	2.59	42.00	20.17	21.83	6.22	50.40	43.38
9	2.61	20.77	12.73	8.04	1.81	71.86	26.33
10	2.64	20.00	11.03	8.97	13.67	57.86	28.47

Table 5. Compressibility characteristics and classification of soil samples [18]

Sample no.	C_c	USCS	AASHTO
1	0.27325	CH	A-7-6(12)
2	0.21	SC	A-7-6(7)
3	0.34025	CL	A-7-6(8)
4	0.17275	SC	A-2-6(1)
5	0.133	SC	A-2-6(0)
6	0.14525	SC	A-2-6(0)
7	0.11923	SC	A-2-6(0)
8	0.1275	SC	A-7-6(5)
9	0.091	SC	A-2-4(0)
10	0.428	SC	A-2-4(0)

4.1 Regression analysis: In this investigation, an effort was put forth to determine the relationship between the compression index (C_c) and easily measurably index properties such as liquid limit (LL), plastic limit (PL), and plasticity index (PI) of soil samples. Nonlinear regression models were developed and used to establish the relationship for predicting the compression index of the soil samples.

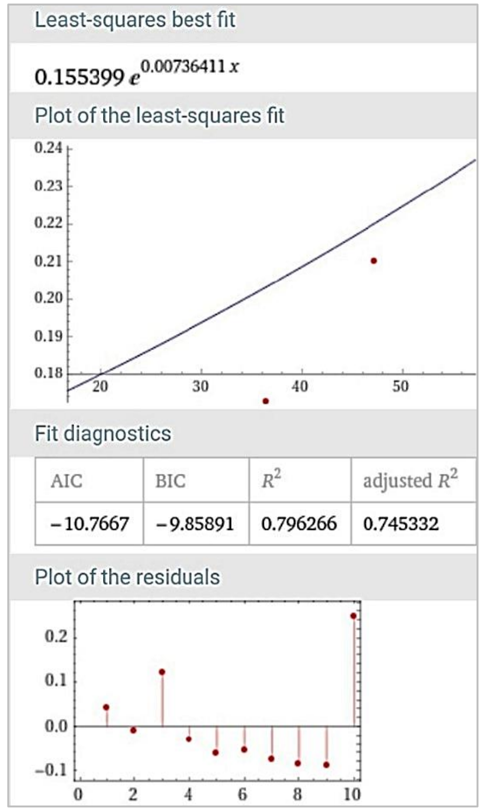

Figure 1. Correlation of compression index with liquid limit

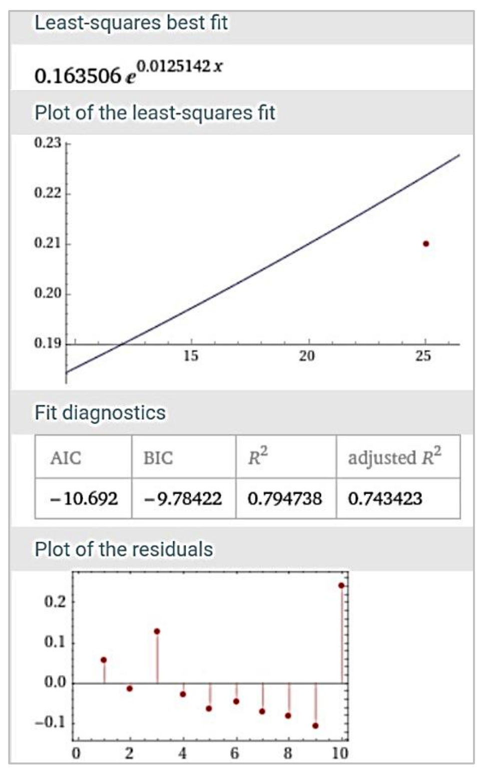

Figure 2. Correlation of compression index with plastic limit

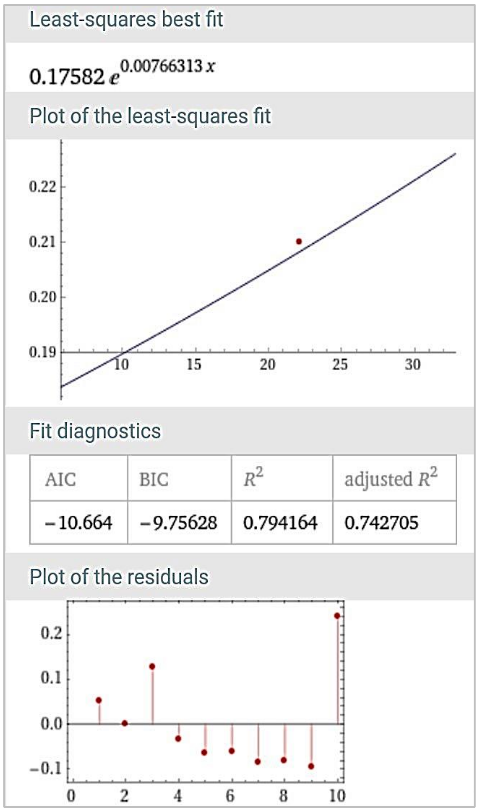

Figure 3. Correlation of compression index with plasticity index

Table 6. Summary of the developed model

Eqn. no.	Developed model	R^2
1	$C_c = 0.155399e^{0.00736411LL}$	0.796266
2	$C_c = 0.163506e^{0.0125142PL}$	0.794738
3	$C_c = 0.17582e^{0.00766313PI}$	0.794164

4.2 T-test validation: Using this T-Test program to confirm the relationship between Compression Index and Liquid limit, the model's accuracy was further examined. Test results are so visible.

Table 7. Analysis of variance for obtained values of compression index

Treatment 1(X)	Diff(X −M)	Sq. Diff(X − M)^2
0.27325	0.07	0.00
0.21	0.01	0.00
0.34025	0.14	0.02
0.17275	– 0.03	0.00
0.133	– 0.07	0.01
0.14525	– 0.06	0.00
0.119225	– 0.08	0.01
0.1275	– 0.08	0.01
0.091	– 0.11	0.01
0.428	0.22	0.05
	M: 0.204	SS: 0.11

Table 8. Analysis of variance for predicted values of compression index

Treatment 2(X)	Diff(X −M)	Sq. Diff(X −M)^2
0.268346177	0.07	0.00
0.238644533	0.04	0.00
0.236595027	0.03	0.00
0.198079965	– 0.01	0.00
0.179964316	– 0.02	0.00
0.193353526	– 0.01	0.00
0.182024966	– 0.02	0.00
0.218169668	0.02	0.00
0.151267087	– 0.05	0.00
0.149271121	– 0.05	0.00
	M: 0.2016	SS: 0.04

Calculations:

Treatment 1

N_1: 10

$$df_1 = N-1 = 10-1 = 9 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

M_1: 0.204

SS_1: 0.11

$$S_1^2 = SS_1/(N-1) = 0.11/(10-1) = 0.012 \quad \ldots\ldots\ldots (2)$$

Treatment 2

N_2: 10

$$df_2 = N-1 = 10-1 = 9 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

M_2 : 0.2016

SS_2 : 0.04

$$S_2^2 = SS_2/(N-1) = 0.04/(10-1) = 0.004 \quad \ldots\ldots\ldots\ldots (4)$$

T- Value Calculation

$$S^2M_1 = S_p^2/N_1 = 0.008/10 = 0.0008 \quad \ldots\ldots\ldots\ldots (5)$$

$$S^2M_2 = S_p^2/N_2 = 0.008/10 = 0.0008 \quad \ldots\ldots\ldots\ldots (6)$$

$$t = \frac{(M_1 - M_2)}{\sqrt{(S^2M_1 + S^2M_2)}} = \frac{0.0024}{\sqrt{0.0016}} = 0.07 \quad \ldots\ldots\ldots\ldots (7)$$

Where:

SS = Sum of squares
M = Mean
df = Degree of freedom
S^2 = Variance
N = Number of data points in the set
X = Each individual value in the data set

5. Discussion

From Table 5, the Unified Classification System (UCSC) shows that most of the soil samples are classified as SC (Clayey Sand) which shows that the samples contain both clay and sand particles while those classified according to AASHTO shows that most of the soil samples are silty or clayey gravel and sand. Clayey and Silty soils have low hydraulic conductivity, thereby causing the consolidation settlement to take longer time.

The T-test result shows that there is no significant difference between the predicted and actual values of the compression index thereby validating the obtained models.

6. Conclusions

The results of the laboratory tests and the statistical correlations for this study can be used to derive the following conclusions:

- The liquid limit, plastic limit, and plasticity index of the soil samples fall between 20 and 54%, 11.03 to 25.09%, and 8.04% to 30.6%, respectively.
- The empirical relationships for the compression index (C_c) have been derived as a function of the index parameters viz; LL, PL, and PI.
- The coefficient of determination (R^2) values range from 0.794164 to 0.796266. This suggests that there is a high correlation between the variables.
- The compression index correlates best with liquid limit (LL).
- The T-test result indicates that the compression index actual and predicted values do not differ significantly, and the regression model equation is confirmed with a 95% confidence level.
- The obtained models can be applied to predict the compressibility parameters of the soil in the study locations, by using the Atterberg limits.

Nomenclature

Cc Compression index
LL Liquid limit
PL Plastic limit
PI Plasticity index
SS Sum of squares
M Mean
df Degree of freedom
S2 Variance
N Number of data points in the set
X Each individual value in the data set
SC Clayey sand
CL Low plasticity clays
CH Medium and high plasticity clays

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