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Application of polynomial Regression Analysis in Modelling of the Coefficient of Consolidation of Awka Soil

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ABSTRACT : *The coefficient of consolidation is an important compressibility parameter that can be calculated by plotting the change in height against the logarithm or square root of time obtained from One dimensional consolidation test using Oedometer. This process consumes time and requires great effort. On the other hand, an atterberg limit test costs less and saves time. Hence the need to generate models that can define coefficient of consolidation as a function of atterberg limit (liquid limit, plastic limit, and plasticity index). A total of ten soil samples were gathered from different locations in Awka Anambra State and its environs, and investigated in the laboratory. Subsequently, a sixth degree polynomial regression software using Excel spreadsheet was used to determine three polynomial regression equations relating coefficient of consolidation and liquid limit, coefficient of consolidation and plastic limit, and coefficient of consolidation and plasticity index for the soil. The sixth degree polynomial regression equations obtained for C_v in terms of LL gave coefficient of determination (R^2) equal to 0.9933,while C_v in terms of PL yielded R^2 equal to 0.4759, and C_v in terms of PI gave R^2 equal to 0.9937. Having shown strong correlation, the obtained models relating C_v with LL and C_v with PI can help predict coefficient of consolidation without conducting Oedometer test.*

KEYWORDS: *Coefficient of consolidation, Atterberg limit, Index properties, Regression, Coefficient of determination*

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I. INTRODUCTION

All soils are compressible so deformation will occur whenever stress is applied to soils. The coefficient of consolidation is the parameter used to measure the rate at which saturated clay or other soil compresses when subjected to an increase in pressure. The two elements that influence the coefficient of consolidation are the amount of water squeezed out and the rate at which that water can flow out. The rate and amount of compression in soils varies with the rate at which pore water is lost and therefore depends on permeability. The coefficient of consolidation can be obtained by conducting a One-dimensional consolidation test, also known as Oeodometer test which involves loading of soil sample incrementally while being measured for height change.

Nonetheless, the determination of coefficient of consolidation from Oedometer test is quite expensive, and requires time and effort. In view of he complexity of obtaining C_v from a consolidation test, any attempt to obtain the same from the correlation with the index properties for preliminary design will be most welcome[1].While trying to find an alternative method for the determination of compressibility properties of soil, researchers on numerous occasions have tried to correlate the compressibility parameters with index properties which save time, energy, and cost less. In literature, there have been a number of proposed correlations whereby coefficient of consolidation has been evaluated using Liquid limit(LL), Shrinkage index(I_S), plasticity index(PI), Plastic limit (PL) and several other index properties of soil. Table 1 shows different approximations to predict the coefficient of consolidation as reported in literature.

Sridharan and Nagaraj [1] investigated the coefficient of consolidation and its correlation with Index properties of remoulded soils. Ten soil samples were selected for the study and based on the result; coefficient of consolidation has a better correlation with shrinkage index than liquid limit and plasticity index. The correlation between coefficient of consolidation with plasticity index yielded R^2 value of 0.81, therefore it can be used for prediction purposes in the absence of shrinkage index.

Devi et al.[2] made an attempt to find suitable correlation of C_v with the plasticity property of soil found in Manipur. They found that coefficient of consolidation has better correlation with liquid limit compared to plasticity index and shrinkage index.

Jadhav [3] established a relationship between coefficient of consolidation and index properties of twenty remoulded soil samples from Bagalkot district of Karnataka. He observed that model developed by simple linear regression analysis for correlating coefficient of consolidation with shrinkage index has shown better performance while the model developed by multiple linear regression analysis has significant relation to predict coefficient of consolidation from plastic limit and shrinkage index.

Asma et al. [4] studied the relationship between the liquid limit and coefficient of consolidation of middle and south Iraqi soils. The R^2 value indicates that the coefficient of consolidation of Iraqi soils can be obtained when liquid limit is known.

Solanki et al.[5] found correlations for coefficient of consolidation with liquid limit and plasticity index based on the test data obtained from 10 zones of Surat Municipal Corporation and Surat urban development authority. From their findings, coefficient of consolidation correlates best with Plasticity index.

Kok Shien Ng et al. [6] studied the prediction of consolidation characteristics from index properties using five cohesive soil samples. The coefficient of consolidation was found to correlate best with plasticity index.

Ntekim and Ike[7] investigated the compressibility properties of ten soil samples from Calabar Municipal, Cross-River State. They obtained exponential models relating coefficient of consolidation with liquid limit, plastic limit, and plasticity index. The result of the analysis indicates that coefficient of consolidation correlates best with plastic limit.

Table 1: Coefficient of consolidation equations proposed by various authors

Author	**Equation**	**Coefficient of determination (R^2)**
Sridharan and Nagaraj[1]	$C_v = [3/(100(I_s)^{3.54}]$ (m^2/s)	0.94
Devi et al. [2]	C_v = -1E-07ln(PI) + 6E-07 (m^2/s)	0.5954
Devi et al. [2]	C_v = 1E-06$e^{-0.064I_s}$ (m^2/s)	0.6132
Devi et al. [3]	C_v = -4E-09LL + 4E-07 (m^2/s)	0.8298
Jadhav [3]	C_v = 128.7/3.54I_s +0,0002 (cm^2/s)	0.715
Jadhav[3]	C_v = 5.4*PL/(I_s)3.54 + 0.0002 (cm^2/s)	0.79
Asma et al. [4]	C_v= 4258.8 $LL^{(-1.75)}$ ($m^2/year$)	0.721
Solanki et al.[5]	C_v =7.7525$PI^{-3.1021}$ (cm^2/s)	0.9156
Solanki et al. [5]	C_v = $10^8LL^{-6.7591}$ (cm^2/s)	0.7806
Kok Shien Ng et al. [6]	C_v = 0.6155 - 0.0183PI ($m^2/year$)	0.9599

Kok Shien Ng et al. [6]	C_v = 0.0451+ 0.011LL - 0.0367PI (m^2/year)	0.8608
Kok Shien Ng et al.[6]	C_v = -0.0202PL+ 0.859 (m^2/year)	0.6505
Ntekim and Ike [7]	C_v (m^2/year) $=0.000215056e^{-0.0323186LL}$	0.97744
Ntekim and Ike [7]	C_v (m^2/year) $=0.000137259e^{-0.0306047PL}$	0.976234
Ntekim and Ike[7]	C_v (m^2/year) $=0.000101356e^{-0.0306516PI}$	0.971964

II. MATERIALS AND METHODS

A. MATERIALS USED

Ten soil samples were collected by disturbed and undisturbed sampling at a depth of 1.5 - 2.0 meters from sites within Awka, Anambra state and its surroundings. Experiments were carried out on these soil samples at the Geotechnical Engineering laboratory of Nnamdi Azikiwe University Awka. Table 2 shows the location of soil samples.

Table 2. Location of soil samples [8]

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

B. EXPERIMENTAL PROCEDURE

In order to determine the compressibility and index properties of the study soils, several tests such as particle size distribution (sieve analysis), specific gravity, Atterberg limit, and consolidation tests were carefully carried out in the laboratory as described by ASTM Standards, as the validity of correlations depends on the accuracy of test procedures used.

One dimensional consolidation tests were carried out on all the soil samples according to ASTM D-2435 [9]. The range of pressure used in this study, are in the following order: 200, 400, 800, 1600, and 3200 kPa. The load increment readings were taken using a time sequence of 0.15, 0.25, 0.36, 1, 2.25, 4, 9, 16, 25, 36, 49, 64, 81, 100, 121, 144, 169, and 1440 minutes. From the plot of dial readings against square root of time, the coefficient of consolidation, C_v was determined using Taylor's method. Atterberg limit test was conducted for the determination of plastic and liquid limit of the study soils in accordance with ASTM D4318-98 [10] (Standard test method for liquid limit, plastic limit and plasticity index of soils). The Plasticity index was obtained by calculating the difference between liquid and plastic limit.

Sieve analysis and specific gravity tests were conducted in accordance with ASTM D6913M[11]and ASTM D845-98[12] standards respectively.

C. REGRESSION ANALYSIS

Regression analysis utilizes a number of approaches for modelling and evaluating multiple variables when analyzing the relationships between dependent variables and one or more independent variables. Nonlinear regression employs a variety of fitting techniques, including Lorenz curves, power functions, Gaussian functions, exponential functions, logarithmic functions, trigonometric functions and other fitting methods.

In this study, liquid limit, plastic limit, and plasticity index were correlated with coefficient of consolidation,C_v to determine the best correlated parameter using polynomial regression.

III. RESULTS AND DISCUSSION

Index properties of the study soils in terms of liquid limit, plastic limit, and plasticity index are shown in Table 3, while the oedometer test results in terms of coefficient of consolidation are shown in Table 4. The coefficient of consolidation ranges from 0.5828 to 1.9924 cm^2/sec.

Table 3: **Physical properties of soil samples** [13]

Sample no.	Specific gravity	Liquid limit	Plastic limit	Plasticity 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	15.73	5.04	1.81	71.86	26.33
10	2.64	20.00	11.03	8.97	13.67	57.86	28.47

Table 4. **Coefficient of consolidation and classification of soil samples** [13]

Sample no.	**C_v (cm^2/sec)**	**USCS**	**Group Name**
1	0.5828	CH	Clay of High Plasticity
2	0.71522	SC	Clayey Sand
3	0.6878	CL	Clay of Low Plasticity
4	0.6282	SC	Clayey Sand
5	0.7104	SC	Clayey Sand
6	0.7766	SC	Clayey Sand
7	0.6776	SC	Clayey Sand
8	0.6364	SC	Clayey Sand

9	1.9924	SC	Clayey Sand
10	1.6404	SC	Clayey Sand

A. RELATIONSHIP BETWEEN COEFFICIENT OF CONSOLIDATION AND INDEX PROPERTIES

Polynomial regression analysis has been carried out using Microsoft Excel software in order to develop correlations between compressibility and index parameters. The coefficient of determination, R^2 was used as an evaluation criteria to check the best fit of the curves.

In Fig.1, the graph showing the relation of coefficient of consolidation, C_v with liquid limit, LL has been plotted. The value of coefficient of determination, R^2 has been found 0.9933 which indicates strong correlation between C_v and LL.

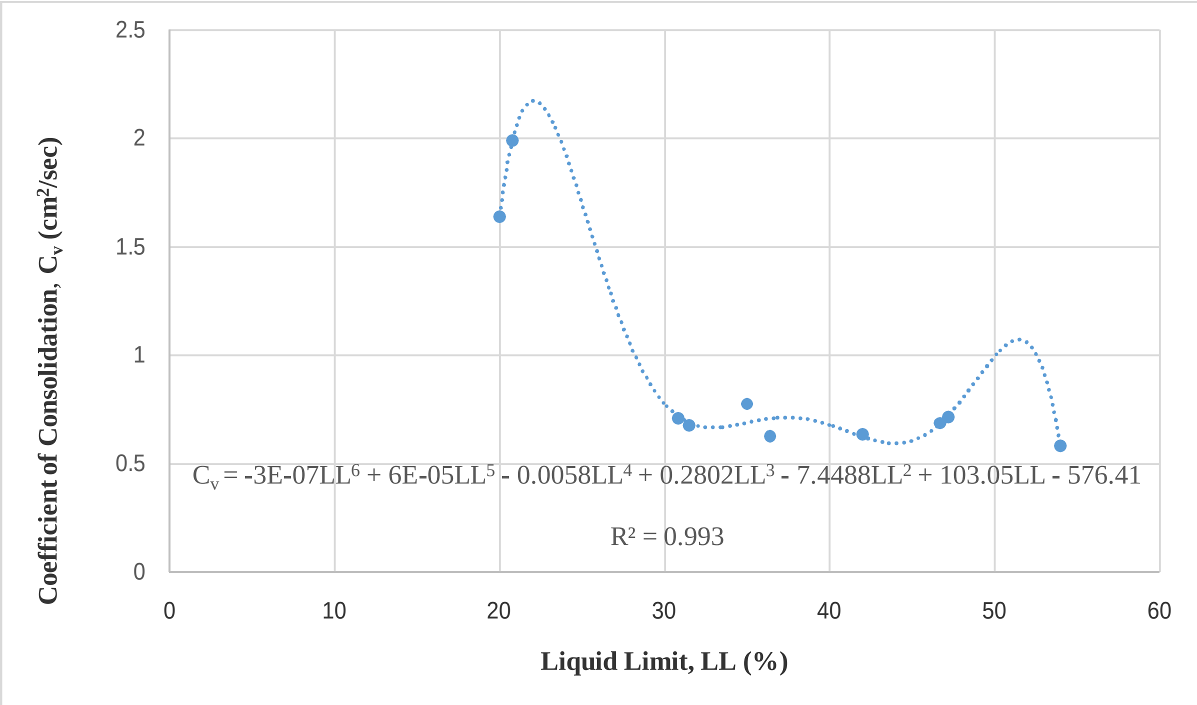

Fig. 1. Relationship between Liquid limit and Coefficient of Consolidation

In Fig.2, the graph showing the correlation between coefficient of consolidation, C_v and plastic limit, PL has been plotted. It has been observed that correlation of C_v with plastic limit has the most scatter. Again, the value of coefficient of determination, R^2 has been found 0.4759 which shows that their is no significant correlation between the two variables.

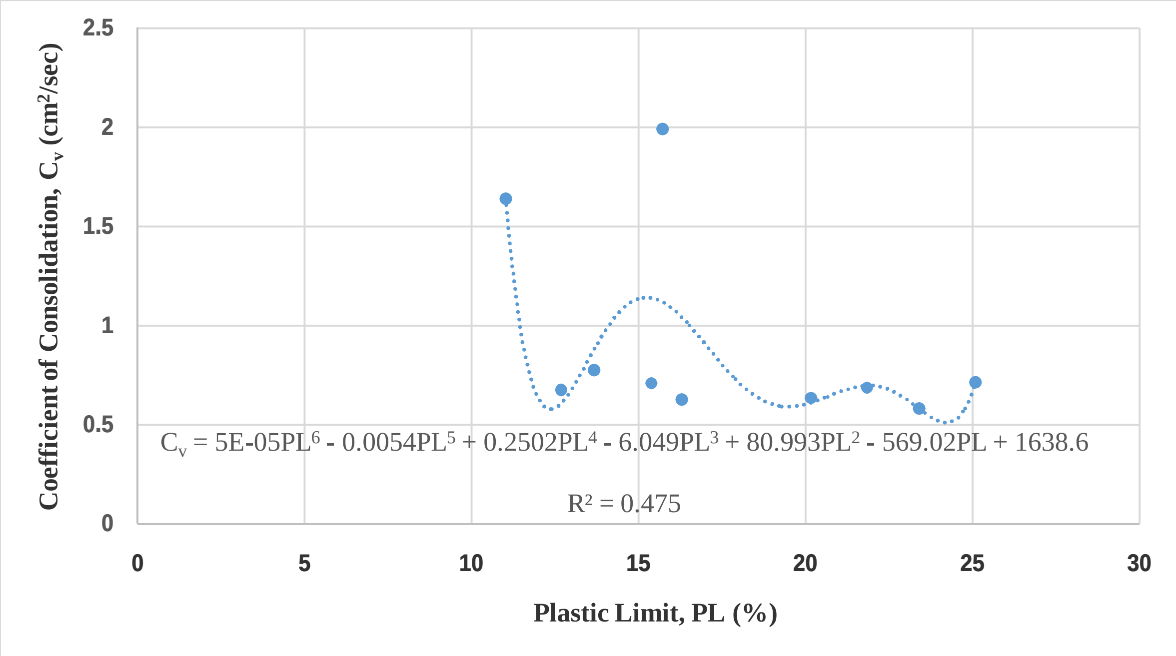

Fig. 2: Relationship between Plastic Limit and Coefficient of Consolidation

In Fig.3, the graph showing the correlation between coefficient of consolidation, C_v and plasticity index, PI has been plotted. The value of coefficient of determination, R^2 has been found 0.9937 which verifies that there is strong correlation between C_v and PI .

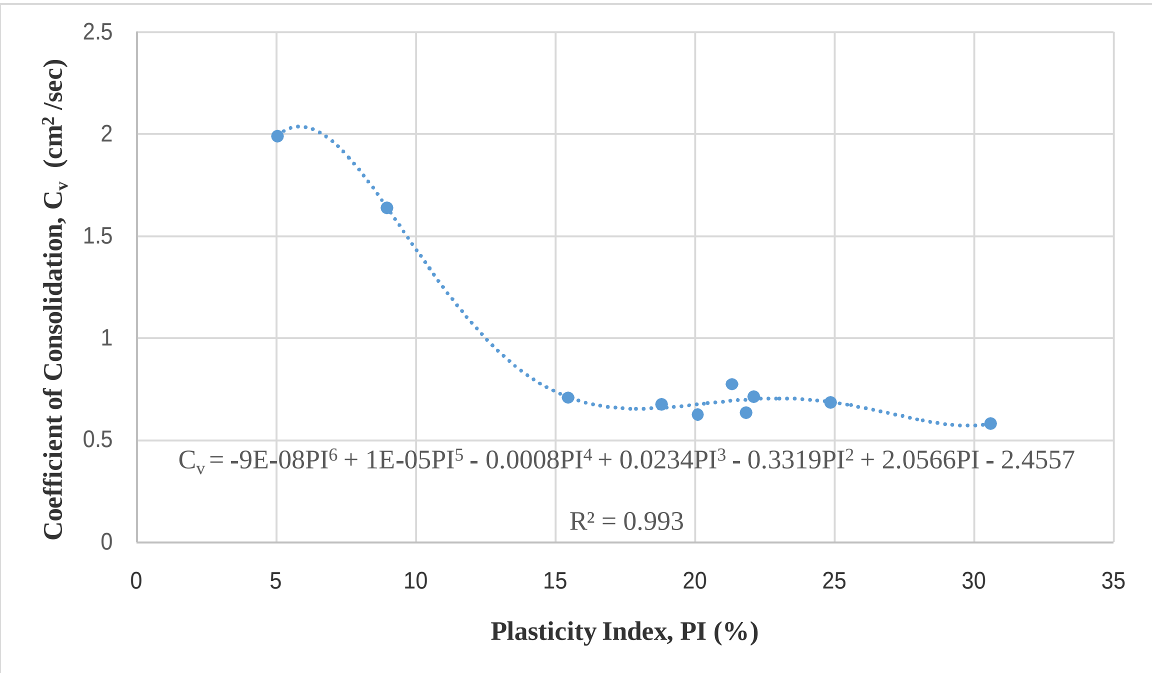

Fig. 3: Relationship between Plasticity index and Coefficient of Consolidation

The regression analysis shows that coefficient of consolidation correlates best with plasticity index. Similar findings have been reported by Solanki et al.[5] and Kok Shien Ng [6]. Although the present study shows that coefficient of consolidation has a better correlation with plasticity index , the relation between coefficient of consolidation and liquid limit can also be used for predicting coefficient of consolidation.

Table. 5. Summary of the developed models

EQUATION NO	DEVELOPED MODEL	R^2
1	$C_v = -3E\text{-}07LL^6 + 6E\text{-}05LL^5 - 0.0058LL^4 + 0.2802LL^3 - 7.4488LL^2 + 103.05LL - 576.41$	0.9933
2	$C_v = 5E\text{-}05PL^6 - 0.0054PL^5 + 0.2502PL^4 - 6.049PL^3 + 80.993PL^2 - 569.02PL + 1638.6$	0.4759
3	$C_v = -9E\text{-}08PI^6 + 1E\text{-}05PI^5 - 0.0008PI^4 + 0.023PI^3 - 0.3319PI^2 + 2.0566PI - 2.4557$	0.9937

IV. CONCLUSION

The outcome of the experiment for the study soils shows that liquid limit, plastic limit, and plasticity index are within the range of 20% to 54%, 11.03 to 25.09%, and 8.04% to 30.6 %, respectively. Again, specific gravity varies between 2.54 to 2.64 while coefficient of consolidation varies between 0.5828cm^2/sec to 1.99249cm^2/sec. The coefficient of determination (R^2) values show that the models obtained by correlating coefficient of consolidation with index properties(Liquid limit and Plasticity index) have significant relation to predict coefficient of consolidation unlike the empirical relation between coefficient of consolidation and plastic limit which shows less significance to predict coefficient of consolidation. The coefficient of consolidation has been found to correlate best with plasticity index.

This study has provided polynomial regression models that can reliably predict coefficient of consolidation within the study area using soils' index properties. Furthermore, this study has revealed that coefficient of consolidation correlates best with plasticity index.

REFERENCES

[1]. Sridharan, A and Nagaraj, H. B.(2004). " Coefficient of Consolidation and its Correlation with Index Properties of Remolded Soils''. Geotechnical Testing Journal, 27(5), 1-6 (2004).

[2]. Devi, S. P., Devi, K. R., Prasad, D.S.V., and Prasada Raju, G.V. R. (2015), Study on Consolidation and Correlation with Index Properties of Different Soils in Manipur Valley, International Journal of Engineering Research and Development, 11(5), PP. 57–63.

[3]. Jadhav, G. (2016). ''Establishing Relationship between Coefficient of Consolidation and Index Properties/Indices of Remoulded Soil Samples''. International Journal of Advanced Research in Science and Engineering, 5(12), 299-309(2016). .

[4]. Asma Y. A-Tae'e and Abbas F. Al-Ameri(2011). ''Estimation of Relation between Coefficient of Consolidation and Liquid Limit of Middle and South Iraqi Soils''. Journal of Engineering, 17(2), 430-440.

[5]. Solanki, C. H., Desai, M. D., and Desai, J. A.(2010). ''Quick Settlement Analysis of Cohesive Alluvium Deposits using New Empirical Correlations''. Journal of Civil Engineering Research and Practice. 7(2),49-58.

[6]. Kok Shien Ng, Yee Ming Chew, and Nur Izzati Ahmad Lazim (2018). ''Prediction of Consolidation Characteristics from Index Properties''.E3S Web of Conferences 65, 06004(2018).

[7]. Ntekim, G. F. and Ike, C. C.(2022). ''Non-Linear Regression Modeling of the Compressibility Properties of Soil in Calabar Municipal, Cross River State''. International Journal of Darshan Institute on Engineering Research and Emerging Technologies. 11(2), 45-53.

[8]. Ukeje, E.C. and Ike, C. C. (2022). ''Exponential Regression Modelling of the Compression Index of Awka Soil''. International Journal of Darshan Institute on Engineering Research and Emerging Technologies. 11(2), 54-59.

[9]. ASTM D 2435-90. "Test Method for One-dimensional Consolidation Properties of Soils", Annual Book of ASTM Standards, 1994, 04.08, 96-205.

[10]. ASTM D 4318-94. "Standard Test Method for Liquid limit, Plastic limit and Plasticity index of Soils", Annual Book of ASTM Standards, 1994, 04.08, 69-76.

[11]. ASTM D6913M -17 (2017).“Standard test Method for Particle-Size Distribution(Gradation) of Fine-Grained Soils Using Sieve Analysis”. ASTM International, West Conshohocken, PA (2017).
[12]. ASTM D 854-92. “Standard Test Method for Specific Gravity of Soils” , Annual Book of ASTM Standards, 04.08, 1994, ASTM, Philadelphia, USA, PP. 80-83.
[13]. Ukeje, E.C. (2022), “Nonlinear Regression Modelling of the compressibility properties of soil in Awka, Anambra state”, Master’s thesis, Department of Civil Engineering, Enugu State University of Science and Technology, Agbani, Enugu State, 2022.