International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 1 (2016) pp 592-598
© Research India Publications. http://www.ripublication.com

# Prediction of Compression Index ($C_c$) of Fine Grained Remolded Soils from Basic Soil Properties

**Dr. Rakesh Kumar[2]**
*Assistant Professor, Department of Civil Engineering,*
*M.A.N.I.T., Bhopal – 462003, Madhya Pradesh, India.*
*E-mail – rakesh20777@gmail.com*

**Dr. P. K. Jain[3]**
*Professor, Department of Civil Engineering,*
*M.A.N.I.T., Bhopal – 462003, Madhya Pradesh, India.*
*E-mail –pkjain10@rediffmail.com*

**Pundreek Dwivedi[1]**
*P. G. Scholar,Department of Civil Engineering,*
*M.A.N.I.T., Bhopal – 462003, Madhya Pradesh, India.*
*E-mail – dwivedipundreek@gmail.com*

**Abstract**
Compression Index ($C_C$) is an important parameter for evaluation of settlement due to primary consolidation settlement of clays. Assessment of its value through laboratory test is time consuming, expensive and laborious task. The present study is an attempt to predict it with the help of basic soil properties namelyLiquid Limit (LL), Plasticity Index (PI), Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and Differential Free Swell (DFS). Test data was generated by performing tests in laboratory on 23 clay samples. The single and multiple linear regression analysis were carried out on the results of the tests to correlate Compression Index (Cc) with combination of basic soil parameters. Out of all the correlations, the correlationhaving highest value of correlation coefficient ($R^2$) is also validated from 10 independent test results, which were not included in the determination of correlation and it is found that the predicted values are very close to the reported values of $C_C$.

**Keywords:** Consolidation, Compression Index ($C_C$), Remolded Soils, Correlation, Settlement, Basic Soil Properties, Linear Regression

## Introduction
The determination of settlement of soil under the load of the structure is the most important aspect while checking the integrity of the structure. It is defined as the decrease in volume due to rearrangement of soil particles under the effect of pressure. Compression Index ($C_C$) is one of the parameter that is used in settlement estimation.High value of $C_C$ means large settlement. The compression index ($C_C$) of soils is preferred as its value does not change with the change in confining pressure for normally consolidated clays [1]. It can be obtained either by performing test in the laboratory on soil sample or by using the correlations proposed by various authors [2]. Performing the test takes a lot of time, requires precision, precautions and expertise and therefore is cumbersome. Even a very small disturbance can lead to overestimation or underestimation of value of $C_C$ and hence the settlement. Hence, if correlations are developed, its determination may save a lot of time and laboratory expenditure. Moreover, the settlement of undisturbed soil may be different as compared to remolded soil because compressibility depends on its boundary conditions also and in case of remolded soils, boundary conditions are altered. Practically, Remolded condition occurs where earth-fill is necessary e.g. structure over earth-fill surface, embankment of canal where span of bridge is to be kept etc. Hence, in view of these conditions,this research work is dedicated to remolded soils.

In the literature, various correlations are available, out of which, the correlation given by Skempton (1944), Nishida (1956), Terzaghi and Peck (1967) and Nagaraj and Murthy (1985) are most popular and are given in table 1. Skempton (1944) and Terzaghi and Peck (1967) have given equations correlating compression index with the liquid limit of soils [3]. Skempton proposed the correlation for remolded soils whereas Terzaghi and Peck proposed their equation for undisturbed soils. Nishida (1956) gave the correlation between Compression index and Void ratio but the equation is confined to soils of low sensitivity i.e. Sensitivity < 1.5 [3]. Nagaraj and Murthy (1985) proposed their equation for $C_C$ taking into account the Specific Gravity of solids [3], which is an inherent property. Burland [4] introduced an intrinsic compression line (ICL), which is a line obtained from curve between void index ($I_V$) and effective consolidation pressure.

**Table 1:** Popular Correlations Given by Various Authors [1]

| **Author** | **Equation** | **Condition of applicability** |
|---|---|---|
| Skempton (1944) | $C_C = 0.007(LL - 10)$ | Remolded Clays |
| Nishida (1956) | $C_C = 1.15(e - 0.35)$ | Clays having low sensitivity |
| Terzaghi and Peck (1967) | $C_C = 0.009(LL - 10)$ | Normally Consolidated, Moderate sensitivity |
| Nagaraj and Murthy (1985) | $Cc = 0.2343(\frac{L.L.}{100}) G_S$ | Normally Consolidated Clays |

Burland [4] also summarized the overall work done on consolidation parameters till 1990. Wroth and Wood [5] showed the compression index of a soil as an exclusive function of its plasticity index and specific gravity through the concept of critical state soil mechanics. The work of Wroth and Wood [5] was also justified by Sharma and Bora [6].Wroth [7] also developed a theoretical estimate through critical state soil mechanics of the major vertical principal stress for a soil of very low sensitivity. Author concluded, when soil is one dimensionally normally consolidated and the water content is equal to the liquid limit then it is experiencing a major principal effective stress of about 6.3 $kN/m^2$. Solanki, C. H. [8] also correlated $C_C$ with liquid limit, void ratio, porosity and water content etc. Tiwari and Ajmera [9] conducted a research by using different proportions of montmorillonite, Illite, kaolinite and quartz at an initial water content equal to liquid limit. They proposed two different sets of equations for correlating Cc with initial void ratio and liquid limit; one for the soils having "activity" less than 1 and one for the soils having "activity" greater than 1.Akayuli and Ofosu [10] used linear regression analysis to establish empirical correlations relating Compression Index (Cc) and Index properties of soil, using Birimian phyllites samples found in Kumasi city, Ashanti region (Ghana). About 90 samples were tested, out of which 60 samples were used in regression analysis and 30 samples were used to validate the obtained correlation.Singh & Noor [11] developed a model to estimate the Compression Index ($C_C$) as a function of liquid limit and plasticity index using multiple linear regression analysis on the testing data of 23 soil samples and the root mean square error (RME) for the proposed model was found to be 0.035 as compared to Skempton's 0.131 and Terzaghi and Peck's 0.211.Abbasi, Javadi & Bahramloo [12] discussed about the effect of physical and index properties on the Compression Index ($C_C$) for the soil samples of Iran. The correlations were obtained using statistical analysis software, SPSS.Kalantary, F. and Kordnaei, A. [13] used the same database of already available correlations to predict new correlations from Artificial Neural Network. Yoon, Kim and jeon [14] proposed empirical equations using natural water content, initial void ratio, liquid limit and plasticity index for clayey soils in the coastal zone of Korea.

On plotting the predicted values from existing correlations with reported values of $C_C$, it was found that different correlations give different values of $C_C$. We can also see in the existing correlations that they rely upon one or two parameters only, whereas, the compressibility depends on other factors also, e.g. two different types of soil may have same value of liquid limit but different compressibility character.Also, the use of empirical correlations to find consolidation parameters cannot be generalized for all regions and all soils [8]. So, in the present study other basic soil properties are tried to correlate with $C_C$ to see whether combination of parameters like LL, PI, OMC, MDD and DFS affect the $C_C$ or not. The locally available samples are taken in the study to also see that which already available correlation gives the nearest values of $C_C$ for the study region. It is found that correlation using other basic soil properties like OMC, MDD and DFS also give very good coefficient of determination ($R^2$).

Consistency limits represent the resistance of a soil at various moisture contents to mechanical stresses or manipulations [2]. Hence, applicability of LL and PI to compression index has been taken in the study.Since the key reason for compacting soil is to reduce subsequent settlement under working loads [15]. So OMC and MDD are taken in the study to see their contribution in the correlation.Differential free swell value signifies the degree of expansiveness and possible damage to lightly loaded structures [2] and Swelling affects compressibility parameters to a large extent and hence, its effect on compression Index (Cc) has been studied.

## Soil Characteristics

In the present study, the study area is divided into 16 zones of Bhopal City situated in Madhya Pradesh state of India. The subsoil characteristics of each zone are studied in detail. The study region mainly comprises of black cotton soil and at some places, red soil and yellow soil is also available. Characteristics of artificial soil (bentonite) in different proportion with black cotton soil have also been studied. Artificial soil has been included in the analysis to have a large variety in the data set of plasticity characteristics of soil, so that the reliability of correlation proposed can be justified.The distribution of number of samples tested is given in table 2.

**Table 2:** Distribution of Soil Samples Tested

| **S. No.** | **Type of Soil** | **No. of soil samples tested** |
|---|---|---|
| 1. | Black cotton soil | 9 |
| 2. | Red soil | 4 |
| 3. | Yellow soil | 3 |
| 4. | Bentonite | 2 |
| 5. | Black cotton soil with different proportion of bentonite | 5 |

A data set containing basic soil properties like Liquid Limit (LL), Plasticity Index (PI), Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and Differential Free Swell (DFS) are used to conduct a statistical study to determine suitable correlations for estimating Compression

Index ($C_C$). The range of these parameters is given in table 3. This analysis can provide information regarding trends, relationshipsand statistical properties, a mechanism whereby test results can be checked and which can provide geotechnical information for preliminary design purposes. The basic soil characteristics of each zone are studied up to a depth of 4 m. Generally, foundation ofbuildings is located at 3 to 4 m depth in the study region.

**Table 3:** Overall Ranges of Soil Parameters

| Soil Parameter | Range |
|---|---|
| LL, % | 41.28 – 141.56 |
| PL, % | 21.67 – 45.88 |
| PI, % | 18.38 - 98.27 |
| OMC, % | 13.22 – 28.16 |
| MDD, g/cc | 1.54 – 1.85 |
| DFS, % | 22 – 203.41 |
| $C_c$ | 0.17 – 0.893 |
| Classification | CL, CI, CH |

## Methodology

In the present study, an attempt has been made to estimate compression index as a function of basic soil properties, since their determination is comparatively easy [16]. Soil samples of different types are collected from different locations of Bhopal city situated in Madhya Pradesh state of India. 16 different samples are taken from different locations of Bhopal city and 7 samples of artificial soil (Bentonite) in different proportion with black cotton soil are prepared and tested. A total number of 23 soil samples having different classifications have been investigated for their geotechnical parameters namely liquid limits, plastic limits, optimum moisture content, maximum dry density, differential free swell and compression index. All the tests for determination of basic properties are done according to their relevant IS Codes. Consolidation testing is done using remolded soil sample with initial moisture content of about 1.5 times the optimum moisture content. The determination of Compression Index ($C_C$) is done in accordance with the "Void Ratio Method" [2, 17].Remaining procedure for consolidation is kept same as in the IS 2720 (Part XV) - 1986. Based on experimental results, correlation between the compression index and soil index properties are made using single linear and multiple linear excel data analysis tool (regression).

## Results and Discussion

The results of test are presented in Table 4.

**Table 4:** Engineering / Index Properties of Soil Samples Tested

| S.N. | LL | PL | PI | OMC | MDD | DFS | Cc | SOIL TYPE & CLASSIFICATION |
|---|---|---|---|---|---|---|---|---|
| 1. | 48.77 | 22.36 | 26.415 | 14.32 | 1.69 | 32 | 0.24 | Black Cotton (CI) |
| 2. | 50.16 | 23.22 | 26.945 | 14.12 | 1.63 | 29 | 0.25 | Black Cotton (CH) |
| 3. | 48.35 | 22.14 | 26.21 | 13.29 | 1.54 | 41 | 0.28 | Black Cotton (CI) |
| 4. | 50.32 | 23.67 | 26.652 | 15.20 | 1.65 | 32 | 0.33 | Black Cotton (CH) |
| 5. | 51.1 | 24.15 | 26.95 | 14.66 | 1.71 | 40 | 0.36 | Black Cotton (CH) |
| 6. | 50.64 | 23.90 | 26.748 | 15.54 | 1.77 | 31 | 0.27 | Black Cotton (CH) |
| 7. | 41.28 | 22.90 | 18.38 | 14.00 | 1.62 | 32 | 0.17 | Black Cotton (CI) |
| 8. | 42.35 | 21.67 | 20.68 | 13.44 | 1.55 | 36 | 0.24 | Black Cotton (CI) |
| 9. | 42.11 | 22.64 | 19.47 | 13.76 | 1.54 | 27 | 0.21 | Black Cotton (CI) |
| 10. | 51.83 | 24.18 | 27.65 | 13.24 | 1.78 | 22 | 0.38 | Red Soil (CH) |
| 11. | 50.49 | 24.59 | 25.9 | 14.87 | 1.71 | 24 | 0.26 | Red Soil (CH) |
| 12. | 48.77 | 23.66 | 25.11 | 14.52 | 1.64 | 27 | 0.26 | Red Soil (CI) |
| 13. | 53.28 | 24.55 | 28.73 | 14.18 | 1.75 | 25 | 0.29 | Red Soil (CH) |
| 14. | 48.18 | 26.11 | 22.07 | 13.67 | 1.81 | 28 | 0.25 | Yellow Soil (CI) |
| 15. | 47.65 | 25.54 | 22.11 | 13.22 | 1.73 | 26 | 0.27 | Yellow Soil (CI) |
| 16. | 50.16 | 26.41 | 23.75 | 14.86 | 1.65 | 32 | 0.32 | Yellow Soil (CH) |
| 17. | 51.46 | 26.54 | 24.92 | 16.48 | 1.63 | 48.25 | 0.33 | B.C. + 10% Bentonite (CH) |
| 18. | 57.23 | 30.21 | 27.02 | 17.92 | 1.59 | 67.14 | 0.37 | B.C. + 20% Bentonite (CH) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 19. | 62.59 | 31.69 | 30.9 | 19.56 | 1.54 | 95.56 | 0.43 | B.C. + 30% Bentonite (CH) |
| 20. | 70.55 | 34.58 | 35.97 | 20.80 | 1.50 | 134.59 | 0.49 | B.C. + 40% Bentonite (CH) |
| 21. | 81.24 | 38.87 | 42.37 | 22.42 | 1.46 | 167.88 | 0.58 | B.C. + 50% Bentonite (CH) |
| 22. | 140.56 | 42.29 | 98.27 | 26.32 | 1.85 | 200.11 | 0.893 | Bentonite (CH) |
| 23. | 135.38 | 45.88 | 89.50 | 28.16 | 1.83 | 203.41 | 0.813 | Bentonite (CH) |

Using above data, the correlations are obtained using single and multiple linear regression analysis, which are given in table 5:

**Table 5:** Correlation developed and their Coefficient of determination ($R^2$)

| **S. No.** | **Parameters Taken** | **Correlation Developed** | **$R^2$** |
|---|---|---|---|
| 1. | LL | $C_C = 0.0067(LL) – 0.0364$ | 0.94 |
| 2. | DFS | $C_C = 0.0029(DFS) + 0.1837$ | 0.88 |
| 3. | OMC | $C_C = 0.0404(OMC) - 0.3024$ | 0.89 |
| 4. | LL and PI | $C_C = 0.0128 (LL) – 0.008 (PI) – 0.1423$ | 0.92 |
| 5. | DFS and OMC | $C_C = 0.0244 (OMC) + 0.0012 (DFS) – 0.1123$ | 0.89 |
| 6. | LL, PI, OMC and MDD | $C_C = 0.0149(LL)–0.0092(PI)–0.00671(OMC)–0.10692(MDD)+0.0554$ | 0.95 |
| 7. | LL, PI, OMC, MDD and DFS | $C_C = 0.0122 (LL) – 0.0069 (PI + OMC) – 0.061 (MDD) +0.0004 (DFS) +0.0451$ | 0.94 |

**Comparison of Predicted Correlation with Available Correlations –**

The values predicted from the correlation obtained having highest value of coefficient of determination ($R^2$) i.e. equation 6 in the present study are compared with the values given by proposed correlations of various researchers and the values of Compression Index ($C_c$) obtained from laboratory testing programme. On comparing, it can be seen that the $C_c$ values obtained for the study region differ from those given by most of the researchers. The Graphical presentation of comparison is as given in fig 1 to 4.

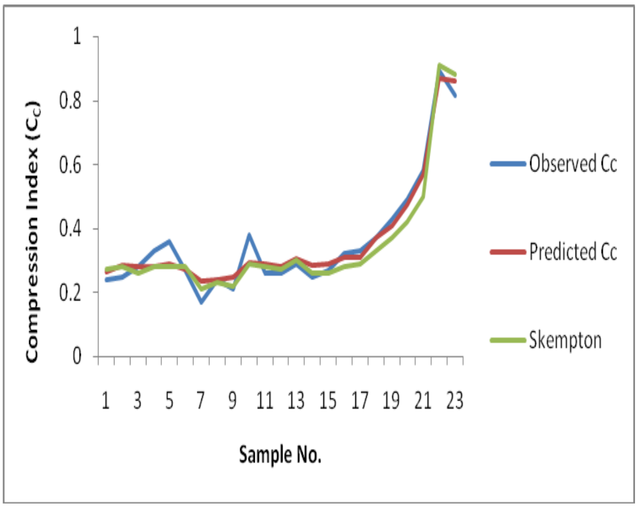


**Figure 1:** Comparison of Predicted $C_C$ with $C_C$ Proposed by Skempton (1944)

From the comparison graph in fig 1, it can be seen that the predicted values of compression index (Cc) are much closer to the observed values than the values obtained from the correlation given by Skempton. Moreover, values predicted by Skempton are much closer to the observed values among correlations given by other researchers.

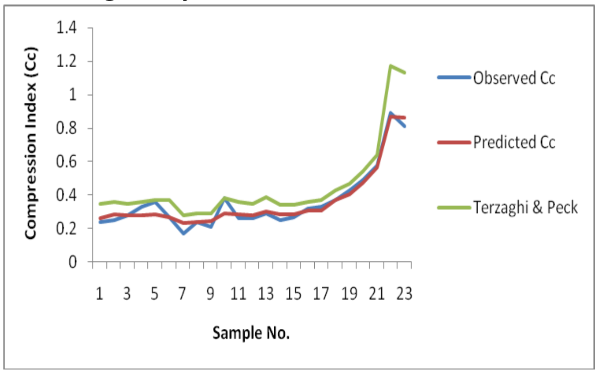


**Figure 2:** Comparison of Predicted $C_C$ with $C_C$ Proposed by Terzaghi and Peck (1967)

From Fig 2, it can be seen that the values obtained from correlation given by Terzaghi & Peck are overestimating the $C_C$ value for the study region.

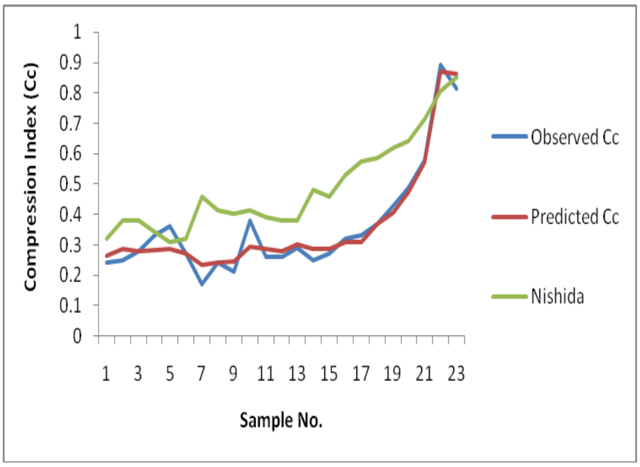


**Figure 3:** Comparison of Predicted $C_c$ with $C_c$ Proposed by Nishida (1956)

From Fig 3 it can be seen that the predicted correlation is closer to the observed values of $C_C$ for the study region whereas, values obtained by using correlation given by Nishida using the final void ratio of soils are highly overestimating. Only the predicted $C_C$ best fits with the observed values of Compression Index ($C_C$).

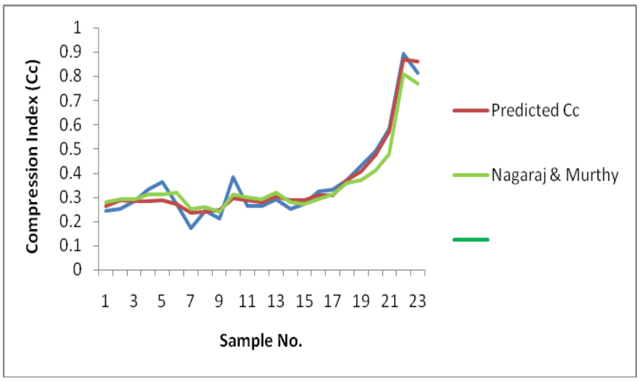


**Figure 4:** Comparison of Predicted $C_C$ with $C_C$ Proposed by Nagaraj and Murthy (1985)

Fig 4 shows a close variation between predicted $C_C$ and $C_C$ proposed by Nagaraj and Murthy. In this comparison also, the correlation coefficient of the predicted correction is much better and same can be used to obtain the Compression Index ($C_C$) values.

**Table 6** Validation of Equation Developed for Prediction of $C_C$

| **Soil Classification** | **LL** | **PI** | **OMC (%)** | **MDD (gm/cm$^3$)** | **$C_C$ Reported** | **$C_C$ Predicted** | **% Error** |
|---|---|---|---|---|---|---|---|
| CH | 51 | 25 | 16 | 1.73 | 0.25 | 0.29 | -16.00 |
| CH | 54 | 28 | 16 | 1.88 | 0.27 | 0.29 | -7.40 |
| CI | 48 | 22 | 15 | 1.9 | 0.23 | 0.26 | -13.04 |
| CI | 48 | 25 | 16 | 1.86 | 0.27 | 0.23 | 14.81 |
| CI | 49 | 27 | 12.8 | 1.77 | 0.29 | 0.26 | 10.34 |
| CI | 38 | 16 | 11.2 | 1.78 | 0.17 | 0.21 | -23.52 |
| CH | 47 | 23 | 14.9 | 1.77 | 0.21 | 0.25 | -19.04 |
| CH | 50 | 27 | 14.9 | 1.81 | 0.27 | 0.26 | 3.70 |
| CH | 48 | 24 | 12.9 | 1.92 | 0.23 | 0.26 | -13.04 |
| CH | 47 | 24 | 13.2 | 1.82 | 0.22 | 0.25 | -13.64 |

**Conclusion**

The paper presents the method to predict the compression index (Cc) for fined grained remolded soils with basic soil properties (LL, PI, OMC, MDD and DFS).Single and Multiple Linear Regression analysis were carried out to develop the correlation for estimation of compression index (Cc). In the results we can see that the compression index (Cc) correlated well with these basic soil properties.The equation 7 takes into account the effect of all soil parameters but Coefficient of determination (R2) for the equation 6 is greatest. Hence equation 6 is considered best amongst the others. However, other equations can also be used conveniently, in accordance with the requirement, as they also have a correlation coefficient greater than 0.85. The proposed equation is validated by 10 independent self-tested data which were not included in the regression and is found to give reasonably close results to the test values (Table 6).
Out of ten samples the observed and predicted values, the average variationis found to be -13.67% and +9.62%. Thus developed correlation equation 6 can be used confidently along with engineering judgment and experience.

Furthermore, it can be seen in the figures 1 to 4 that the correlations proposed by Skempton (1944) and Nagaraj and Murthy (1985) are quite close to the observed results, whereas Nishida (1956) and Terzaghi and Peck (1967) are overestimating the results and that may lead to conservative design of footing which may not be economical.

## References

[1] Carter, M. and Bentley, S. P. (1991). “Correlations of Soil Properties.” Pentech Press, London.

[2] Ranjan, G. &Rao, A. S. R., “Basic and Applied Soil Mechanics (2nd Edition)”, New Age international publishers.

[3] Nagaraj, T.S., Shrinivasa Murthy B.R. and Vatsala, A. (1991). “Prediction of Soil Behaviors–Part–II Saturated Uncemented Soil”, Canadian Geotechnical Journal,Vol. 21 (1), pp. 137–163.

[4] Burland JB (1990) On the compressibility and shear strength of natural clays 30th Rankine lecture. Geotechnique 40(3), pp. 329–378.

[5] Wroth, C. P. and Wood, D. M. (1978).”The correlation of Index Properties with Some Basic Engineering Properties of Soils.” Canadian Geotechnical Journal, 15, pp. 137-145.

[6] Sharma, B. & Bora, P. K. (2014). “A Study on Correlation Between Liquid Limit, Plastic Limit and Consolidation Properties of Soils”, Indian Geotechnical Society.

[7] Wroth CP (1979) Correlations of some engineering properties of soils. 2nd International Conference on BOSS, Imperial College, London, pp 121–132.

[8] Solanki, C. H. (2009). “Empirical Model For Settlement Of Shallow Foundations of Alluvial Deposits”, Indian Geotechnical Conference (IGC), pp. 656-660.

[9] Tiwari, B. T. and Ajmera, B. (2012). “New Correlation Equations for Compression Index of Remolded Clays.” J. Geotech. Geoenviron. Eng., 138(6), pp. 757-762.

[10] Akayuli, C.F.A., Ofosu, Bernard (2013), “Empirical Model for Estimating Compression Index from Physical Properties of Weathered Birimian Phyllites”, Electronic Journal of Geotechnical Engineering, vol.18, pp. 6134-6144.

[11] Singh, Amardeep& Noor, Shahid (2012). “Soil Compression Index Prediction Model for Fine Grained Soils”, International Journal of Innovations in Engineering and Technology (IJIET) vol. 1 issue 4, pp. 34-37.

[12] Abbasi, N., Javadi, A. A., and Bahramloo, R. (2012). “Prediction of Compression Behavior of Normally Consolidated Fine-Grained Soils”, World Applied Science Journal 18 (1), pp. 6-14.

[13] Kalantary, F., Kordnaei, A. (2012). “Prediction of compression index using artificial neural network”, Scientific Research and Essays Vol. 7(31), pp. 2835-2848.

[14] Yoon, G.L. Kim, B.T. and Jeon, S.S. (2004). “Empirical Correlations of Compression Index for Marine Clay from Regression Analysis”, Canadian Geotechnical Journal, 41, pp. 1213–1221.

[15] B. C. Punmia, K. J. Ashok and K. J. Arun, “Soil Mechanics and Foundations”, 16th Edition. Laxmi Publications Ltd. New Delhi.

[16] Mustapha, A. M., andAlhassan, M. (2013) “Compression Index Correlation that Best Fits Clay Deposits in Nigeria”, IOSR Journal of Engineering (IOSRJEN)Vol. 3, Issue 11, pp. 41-45.

[17] Nagaraj, T. S., Srinivasa Murthy BR, and Vatsala A (1994). Analysis and prediction of soil behaviour. Wiley Eastern Limited, India.