EVALUATION OF COMPRESSION INDEX OF ADDIS ABABA RED CLAY SOILS FROM LIQUID LIMIT

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ABSTRACT*: It is a common practice to use empirical equations in computing engineering properties of soils in geotechnical engineering and we usually use such empirical formulae that are developed in other countries, particularly those countries found in the temperate zone. However, it is noticeable and apparent that these empirical formulae are site specific and give a better result for soils from which they are formulated and hence it may be erroneous to use them as they are for our soils which have, in most cases, dissimilar properties. Most of the existing correlation relationships which are used for the estimation of compression index of clay soil in terms its index properties are of linear in form. In this study, with the objective of predicting the compression index value from index properties of Addis Ababa red clay soil, laboratory tests on remolded samples have been carried out and few data were collected from previous study and the subject study has been carried out on data points or sample size of 30.*

A software package named SPSS has been utilized to undertake the regression analysis. In analyzing the regression, the independent variable considered is Liquid Limit (LL) and the variable to be predicted (dependent variable) is Cc. A relatively strong correlation was established between Cc and LL with coefficient of determination of 0.664 for a total sample size of 30.

Key words: Clay soils, consolidation, compression index, remolding, correlations, empirical formula, regression, liquid limit

1. INTRODUCTION

Consolidation characteristics of clay soils form an important aspect in the design of foundations and other earth retaining structures and embankments. The determination of consolidation, through the usual consolidation tests, properties or characteristics namely the compression index, the coefficient of consolidation and the coefficient of secondary compression is time consuming and costly. In addition to the test itself, getting undisturbed samples for the consolidation test also requires great precaution during sampling and transportation, which both costly and time consuming.

In order to curb such problems, researchers have resorted to correlating the compressibility behavior of soils with simple index properties. In relation to this, it appears that it is a common practice in our country to use the empirical equations developed by different authors for estimating the compression index from liquid limit for the calculation of settlements of foundations resting on clay soils. However, it is noticeable and apparent that these empirical formulae are site specific and give a better result for soils from which they are formulated and hence it may be erroneous to use them as they are.

In view of the above points, it would be an imperative task to make an assessment on the applicability of the different empirical formulae that are being used to determine the compression index parameter (Cc) for our soils – Addis Ababa red clays. Thus, the evaluation will be undertaken on selected samples of the red clay of Addis Ababa. Therefore, the intention of this paper is to undertake an evaluation on the correctness of applying the various correlation formulae provided by different authors such as Terzaghi and Peck, which is given by $Cc = 0.007(LL-10)$, to the Addis Ababa's red clay soil.

Disturbed samples of red clay soils have been collected from Addisu Gebeya and Kolfe areas, which are identified locations of red clay soils of Addis Ababa as per the papers by Samuel, T. and Hailemeariam, A. Consolidation and index property tests have been conducted on these samples and the results used for the development of the intended empirical formulae.

2. SOIL REMOLDING

There are, generally, two types of soil samples collected from project sites: undisturbed samples and disturbed samples. In this view, engineering soils when used either as construction materials or foundation for structures could be in their natural condition, which is simulated by undisturbed samples or remolded state, which is expressed as disturbed sample, depending on the specific requirement and degree of accuracy envisaged. For most clay soils reconstituting will destroy the natural make up and it will in turn will significantly increases the compressibility of clays, particularly at lower stress levels.

For the purpose of this research disturbed samples of Addis Ababa red clay soil were collected and remolded in the laboratory in accordance with the provisions and procedures outlined by BS 1377 – 1:1990. Thus, using specimens produced by the remolding, the consolidation test is undertaken pursuant to the procedures set forth by ASTM D 2435 - 90.

3. EXISTING CORRELATIONS

3.1 General

Over the past fifty years, numerous efforts have been exerted by different researchers in order to develop empirical equations that relate compression index to soil index properties. To this effect, currently, there are a number of correlation methods that exist to estimate the compression index of a soil, based on soil classification, other index test values, and/or physical property measurements of the soil.

The majority of available empirical formulas relate linearly compression index to liquid limit, natural water content, plasticity index, shrinkage limit and initial void ratio. Several authors have listed a number of such empirical equations in terms of soil index properties as shown in Table 3.1.

Table 3.1 Various correlation equations between index properties and compression index

No	Equation	Applicability	Reference
1	Cc = 0.007(LL-10)	Remolded clays	Skempton, 1944
2	Cc = 0.009(LL-10)	Normally consolidated clays	Terzaghi and Peck, 1948
3	Cc = (LL-13)/109	All clays	Mayne, 1980
4	Cc = 0.0046(LL-9)	Brazilian clays	Bowles, 1984
5	Cc = 1.15(eo - 0.35)	All clays	Nishida, 1956
6	Cc = 0.0093wn	All clays	Koppula, 1981
7	Cc = 0.37(eo + 0.003LL – 0.34)	Not Specified	Azzouz et al., 1976
8	Cc = 0.046+0.0104PI	Not Specified	Nakase et al., 1988
9	Cc = 0.40(eo + 0.001 wn -0.25)	Not Specified	Azzouz et al., 1976
10	Cc = 0.15(eo + 0.007)	Not Specified	Azzouz et al., 1976
11	Cc = 0.54(eo-0.35)	Not Specified	Arora, 2004
12	Cc = 0.0054(2.6wn-35)	Not Specified	Arora, 2004
13	Cc = 0.008(LL – 10)	Italian Soft Clays	Burglignoli and Scapelli, 1985
14	Cc = 0.40(eo – 0.25)	Not Specified	Azzouz et al., 1976
15	Cc = 0.00234LLGs	Not Specified	Nagaraj and Murthy, 1986
16	Cc = 0.01(w – 5)	Not Specified	Azzouz et al., 1976

Skempton conducted consolidation and Atterberg limit tests on remolded specimens of many different types of clay soils where the initial moisture content of the materials were at the liquid limit. The resulting relationship between compression index and liquid limit pursuant to his study is given as equation (1) in Table 3.1. Terzaghi and Peck suggested that Skempton's equation can be modified to reflect compression index of normally consolidated clays by simply multiplying it by a factor of approximately 1.3, which resulted in equation (2) of the same table. The bases for the empirical expressions given in Table 3.1 are many and varied with one commonality; they all are based on regression analysis performed on laboratory test data.

3.2 Compression Index and Atterbeg Limits

According Gopal Ranjan and A.S.R Rao (2000) the natural structure of a clay soil has a marked influence on its engineering properties. However, except for shrinkage limit, which can be determined for both undisturbed and remolded soil conditions, the consistency limits are determined on thoroughly remolded soils. And yet the Atterberg Limits are found to correlate well with the engineering properties of soils because both the Atterberg Limits and the engineering properties are found to be influenced by the same set of factors such as the clay minerals, the ions in pore water, the stress history of the soil deposit, etc.

Generally, the effect of liquid limit and plasticity index on the engineering properties of clay soils is indicated in Table 3.2.

Table 3.2 General relationship between Atterberg Limits and engineering properties

Characteristics	*Comparing soil properties at equal LL with PI increasing*	*Comparing soil properties at equal PI with LL increasing*
Strength	*Increases*	*Decreases*
Toughness near plastic limit	*Increases*	*Decreases*
Compressibility	*About the same*	*Increases*
Permeability	*Decreases*	*Increases*
Rate of volume change	*Decreases*	*Increases*

Some researchers reported that though there are a number of empirical formulas developed to correlate the compression index with index properties, the compressibility behavior has not been considered together in any single study to examine which of the index property of the soils correlate better with the compressibility behavior, especially with the same set of test results. Despite this fact, it has been shown by different authors that correlating the compression index with the liquid limit has received a higher preference and many empirical formulas derived so far tried to make use of the same.

On the other hand, Amir Al-Khafaji (2005) has made a thorough investigation on the available empirical correlations in the light of comprehending the applicability of the existing formulae. In accordance with the paper presented by Amir Al-Khafaji, almost all empirical equations, developed so far, do not seem to have theoretical basis to justify their development. Furthermore the author reported that the developers of these empirical equations do not explicitly specify whether their equations are for undisturbed samples or remolded samples except their mentioning that the equations are for all clay soils. In this respect the author is of the view that there is a need for the development of objective and rational procedures which could provide a meaningful measure of validity and applicability of regression equations. It is to be noted here that this study covers exclusively the correlation between liquid limit and compression index for remolded clay soils.

4. ANALYSIS AND DISCUSSIONS

4.1 General

A statistical analysis technique termed as regression analysis is usually employed to develop relationships between engineering properties of materials. The method of regression analysis is a statistical technique used for modeling and investigating the relationship between two or more variables. Regression analysis may take the form linear, parabolic, logarithmic etc depending on the trend that may exist between the variables under consideration.

Usually, a linear regression model is employed in problems of geotechnical engineering. Such type of regression analysis can be further divided into either simple regression or multiple regression analysis pertinent to the number of variables involved in the system. A regression model that contains more than one regressor variable is called multiple regression model. On the other hand, a regression model containing one independent variable or regressor is termed as simple regression model. Where the terms described in the preceding sentences are defined as follows. A variable whose value is to be predicted is called dependent variable or response. A variable(s) used to predict the value of dependent variable is termed independent or regressor variable (s).

According to Douglas C. M. George C. Runger (2003), the development and subsequent fitting of regression model entails several statistical assumptions. Estimation of the model parameters requires the assumption that, the residuals (actual values less estimated values or the response values) corresponding to different observations

are uncorrelated random variables with zero mean and constant variance, σ2. Tests of hypotheses and interval estimation require that the errors, commonly denoted by ε, be normally distributed. In addition, we assume that the order of the model is correct; that is, if we fit a simple linear regression model, we are assuming that the phenomenon actually behaves in a linear or first order manner. This is indeed fundamental assumption of any tests of hypothesis and interval estimation.

4.2 Scatter Plot

In this work, the Compression Index value is considered as the dependent variable where as Liquid Limit is the independent variables for the subject clay soil. In carrying out the whole statistical analysis, a statistical software program called SPSS software (which can be accessed through the URL http://www.wessa.net/ website and readily available software) was used.

Using twenty six laboratory test results conducted by the researcher and making use of four test data taken from previous research work, relationships between Compression Index and liquid limit was studied. In order to study the relationship existing between the two variables, first a diagram called scatter diagram is applied. Precisely, it can be defined as a visual method used to display the relationship between two variables. The scatter plot of the dependent variable Cc (yi) with the regressor variables (xi), using the test data described herein above is shown below in Figure 4.1.

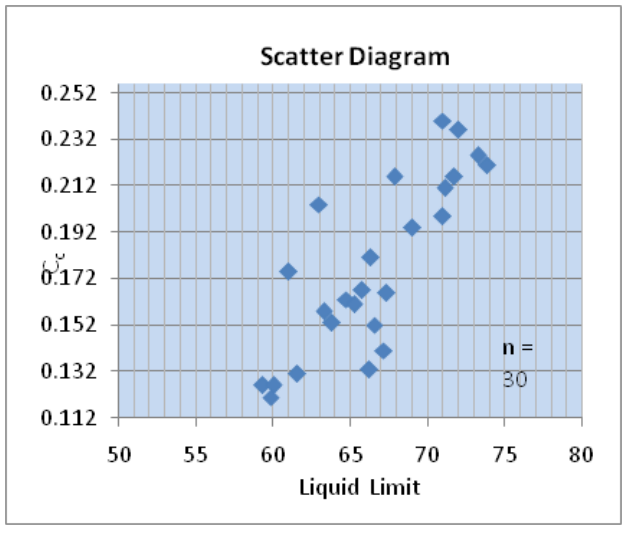


Figure 4.1 Scatter Diagram of Cc versus Liquid Limit

The scatter diagram is just a graph on which each (xi, yi) pair is represented as a point plotted in a two-dimensional coordinate system. The above scatter diagram was produced by making use of the excel spreadsheet, by selecting an option that shows dot diagrams of the x and y variables making it easy to see the distributions of the individual variables. Inspection of the above scatter diagram indicates that, although no simple curve will pass exactly through all the points, there is a reasonable indication that the points lie scattered randomly around a straight line.

The relationship between the variables then can be approximated by the following straight-line relationship. Here, it is probably reasonable to assume that the mean of the random variable Y is related to x.

$$Y(x) = bo + b1x + \ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

Where, the slope, b1, and intercept, bo, of the line are called regression coefficients and ε is the random error of the estimate. The above equation is a simple linear model as it has only one independent variable.

4.3 Regression Analysis

As stated earlier, statistical software called SPSS has been employed to study the relation between the regressor variables and the response to be predicted and the analysis is presented in this section. The basic assumption in this analysis is based on the least square method. The estimates of bo and b1 will have the property that the sum of the squared differences between the observed and predicted $(y-\bar{y})$ 2 is minimized using ordinary least squares (OLS). Thus the regression line represents the Best Linear and Unbiased Estimators of the intercept and slope. Least-squares line *(best fitting line)* – is a line where the errors sum of squares Sε2, is at a minimum and the technique that produces this line is the least squares method.

Linear regression models are widely used when the response is found to be linear. Linear relations are generally represented by equation (4.1).

Accordingly, the following result was observed with respect to the dependent and independent variables.

Correlation Between Compression Index (Cc) and Liquid Limit (LL)

The resulting equation from the regression analysis made between compression index and liquid limit is presented as follows

Cc = -0.229 + 0.006LL with R2 = 0.664 and sample size, n = 30

The above equation can also be re-written in a more convenient form as **Cc = 0.006(LL – 38)**

4.4 Comparisons Between the Existing and the Developed Equations

Comparison has been made by selecting one of the existing empirical equation and the newly developed equation. These equations are utilized to calculate the compression index in a view to analyze the significance of both formulae to the Addis Ababa red clay soils. To this effect, comparisons have been made between the actual values and the previously developed relationship.

The actual compression index as obtained from the Oedometer test is compared with the empirical relation developed by Skempton for remolded clay soils, which is given by Cc = 0.007(LL – 10) and the following newly developed correlation equation, Cc = 0.006(LL – 38).

Based on the comparison made between the above stated two equations, it is noted that the newly developed relation gives a better result when compared to the existing equations. The existing equations and the newly developed equations yield compression index values with a maximum variability of about 65% from the actual compression index values and a maximum variability of about 28% from the actual value respectively.

The above variations depict that the existing equation, which is developed for clay soils of other country, and the newly developed equation gave different values of compression index which in turn provides us the evidence that soil properties depend on the location of their formation. Furthermore, we can see that it is not appropriate to directly adopt such equations for our soils.

5. CONCLUSIONS

In accordance with the statistical computations made, the relationship that has been made between compression index and liquid limit is found to give a coefficient of determination (R2) value of 66.4% where the correlation equation for the same is given by:

Cc = 0.006(LL – 38 percent).

The equation developed by Skempton for remolded clays on the other hand is

Cc = 0.007(LL – 10 percent)

In accordance with comparisons made between the results of the newly developed equation and that of the existing one with the actual Cc value, the newly developed equation has produced a better result.

In view of the above points and the analysis carried out to relate compression index to the index property, the following conclusion are made.

1. The comparisons made between the newly developed equations and the existing equations reveal that the newly developed equations approximate compression index value of red clay soils of Addis Ababa in a better way.

2. Generally, the existing equations result in higher compression index values when compared with the actual for a given index property of the clay soil.

3. This study shows that the compression index increases as the Liquid Limit increases for the particular soil considered in the study.

4. In order to enforce the conclusions drawn herein above and determine the extent of applicability of the newly developed empirical equations, it is suggested that additional works are required to be executed. In addition, further works with greater number of data obtained from additional locations with similar soil nature are imperative to ensure the applicability of the newly developed equations as this research was limited to only 30 data points

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