# Geotechnical Properties Correlations of High Compressible Soil

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## Abstract

Compressibility properties of soils are one of the most important properties in geotechnical engineering because of the needs for a safe and economic design for structures foundations. Compressibility parameters are used in the settlement calculations. Direct determination of compression index (Cc) and recompression index (Cr) are costly, cumbersome and consuming time. These indices require undisturbed soil samples depending on a lot of experiences in the field works. Due to those factors, useful correlations were developed previously to predict compressibility properties. In the current study, the correlations conducted by using consistency properties, which are easy measurable variables.

In this study, single (linear equation) and multiple empirical equations were proposed to predict compressibility indices (Cc) as a function of index properties (LL, PL, PI and $e_0$) and recompressibility indices (Cr) as a function of index properties (LL, PL, PI and $e_0$) The equations were predicted using data of 40 undisturbed fine-grained soil samples, and these data collected from 10 earlier research. Coefficient of determination (R2) was used as an evaluation criterion in order to check the calculated empirical correlations equations. The statistical analysis showed that there is a direct and positive correlation among the selected parameters. In addition, accurate correlations were obtained in comparison to the existing relationships.

# Chapter 1

## 1. Introduction

Most of the foundations of structures are placed on soils. Soil is one of the most important materials used in construction that civil engineers have to study the geotechnical properties of it. Performing subsurface investigation must be undertaken to obtain sufficient number of undisturbed soil samples and then tested in the laboratory to obtain the necessary soil properties such as consolidation parameters.

Compressibility characteristics of soils forms one of the most important parameters required in the design of foundations. The oedometer test is used to determine the compressibility characteristics of fine-grained soils and the slope of the straight-line portion of the void ratio (e) versus logarithm of effective pressure (log p) curve, defined as compression index (Cc) is widely used world over to estimate the consolidation settlement of foundations on clays. But, estimation of compression index from laboratory oedometer test requires considerable time and effort. In view of the above and also due to the cost involved in obtaining undisturbed samples, it is highly desirable, at least for a preliminary assessment of settlement of structures, that an empirical correlation for compression index is developed. Shear strength, compressibility and permeability are considered to be the three most important properties of a soil mass applicable in areas such as in the design and analysis of dams, retaining walls, soil foundation systems and in other applications pertaining to geotechnical engineering practice. Among these three, compressibility is the most significant parameter while evaluating the settlement of soil under the load of an infrastructure constructed on that soil mass (Tiwari and Ajmera, 2012). Compressibility of a soil mass is its susceptibility to decrease in volume under pressure and is indicated by soil characteristics like coefficient of compressibility, compression index and coefficient of consolidation. Although coefficient of volume compressibility is the most suitable, and most popular, of the compressibility coefficients for the direct calculation of settlement of structures, its variability with confining pressure makes it less useful when quoting typical compressibility's or when correlating compressibility with some other property.

For this reason, the compression index of soils is generally preferred as its value does not change with the change in confining pressure for normally consolidated clays (Carter and Bentley, 1991). Hence several attempts have been made in the past to correlate the value of compression index of soils with index properties of soil which are relatively easier to determine and take lesser time.

Thus, numerous attempts have been made by several researchers to correlate the compression index of soil specifically dependent upon some simple index properties that mostly include, liquid limit, plastic limit, plasticity index, initial void ratio, etc.

In comparison with the consolidation test, obtaining the soil index properties has the advantages of being relatively inexpensive testing that does not require much time or any complex systems. Therefore, it could be very useful in practice to use the existing empirical correlations of compression index for estimation of settlement. However, due to their developments based on the site-specific data and/or widely sourced data, the available correlations of compression index in the literature could not be always assumed to have a general validity for other regions of local sites Alternatively, the best way is to develop the correlations of compression index with the data of local site of the interested region, provided that data is available. In this way, it is the most possible to obtain the realistic results for settlement estimation by means of correlations.

# Chapter 2

## 2. Correlation of Soil Type with Compressibility

In fully saturated natural soils, it is well known that certain index properties may be used to indicate compressibility characteristics of cohesive materials. For example, the relationship between the liquid limit of a low to medium sensitivity material can be used to estimate the compression index of that material. For compacted cohesive materials, the problem becomes more difficult because not only are the properties of the materials involved but also the effect of the compaction process which is used to compact the soil. Regardless of the compaction procedure, however, certain conclusions can be drawn concerning the relationship between material properties and the compressibility of the material. Investigations by (Gould, 1954) on rolled fill material indicate that the compressibility is significantly influenced by the plasticity of the fines in the soil.

It was observed that fine sand and silt with little or no plasticity, when placed dry of optimum, have low compressibility, whereas clays of low to medium plasticity compacted dry of optimum exhibit higher compressibility. It was found that, in general, the compressibility increases in the following order:

(a) gravel and sands with silty fines.

(b} silts of low plasticity.

(c) gravel and sands with slightly plastic fines.

(d) sands with clayey fines.

(e) mixtures of gravel sands and silts with clay.

(f) clays of low to medium plasticity.

Gould concluded that this trend emphasized the importance of the plasticity of the fine fraction on the compressibility compared to gradation or grain size characteristics. Recent laboratory investigations by (Matyas, 1960). provide additional evidence of the fact that compressibility is significantly inferenced by the type and amount of fines and also by the molding water content. It may be concluded that soil type is undoubtedly one of the basic factors influencing the compressibility characteristics of a compacted cohesive material, but additional factors such as the method of compaction, molding water content, and degree of saturation will also have significant effects upon the compressibility characteristics.

# Chapter 3

## 3. Materials and Methods

### 3.1 Collection data of soil samples

In this report, (40) data of soil samples were collected from different Research and report of different location. Undisturbed soil samples were collected from shallow depths from the natural ground level. Undisturbed soil samples were collected for one dimensional consolidation tests, while disturbed soil samples were collected for determination of the Atterberg limits (liquid limit and plastic limit). The collected soil samples were conducted according to ASTM standards.

### 3.2 Atterberg limits (ASTM D 4318-10):

Soils intended to support structures, pavements, or other loads must be evaluated by geotechnical engineers to predict their behavior under applied forces and variable moisture conditions. Soil mechanics tests in geotechnical laboratories measure particle size distribution, shear strength, moisture content, and the potential for expansion or shrinkage of cohesive soils. Atterberg limits tests establish the moisture contents at which fine-grained clay and silt soils transition between solid, semi-solid, plastic, and liquid states.

In 1911, Swedish chemist and agricultural scientist Albert Atterberg was the first person to define the limits of soil consistency for the classification of fine-grained soils. He found that plasticity is a unique property of cohesive (clay and silt) soils and suggested classifying soils with a particle size of 2µm (0.002mm) or less as clays.

Karl Terzaghi and Arthur Casagrande recognized the value of characterizing soil plasticity for use in geotechnical engineering applications in the early 1930s. Casagrande refined and standardized the tests, and his methods still determine the liquid limit, plastic limit, and shrinkage limit of soils. Atterberg limits tests (liquid limit, plastic limit) were done on the soils, which were passed sieve No. 40. The liquid limit was measured through the Casagrande liquid limit equipment. For all Atterberg limits, the testing procedures were confirmed accordingly the ASTM D 4318-10. The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

The plastic limit, liquid limit, of soils are all test results obtained by direct measurements of the water content following the standard test methods.

- **Liquid Limit (LL)** is the water content at which soil changes from a plastic to a liquid state when the soil specimen is just fluid enough for a groove to close when jarred in a specified manner.
- **Plastic Limit (PL)** is the water content at the change from a plastic to a semi-solid state. This test involves repeatedly rolling a soil sample into a thread until it reaches a point where it crumbles.

### 3.3 Some available equations for compression index

It would be useful to review available equations of compression index and recompression index in literature to understand the independent parameters of compression index as well as their mathematical form. The equations could also be beneficial to compare the developed correlations in this study. In the review of the equations, it is observed that, in most of cases, the compression index (Cc and Cr) is expressed by establishment with the single index property, primarily including liquid limit (LL) and plastic limit (PL) and Plastic Index (PI) and initial void ratio ($e_0$).

Thus, this study will mainly be focused on the derivation of the correlations for the compression index with single parameter using these basic index soil properties (i.e., $LL = f\,(Cc)$, $PL = f\,(Cc)$, $PI = f\,(Cc)$, $e0 = f\,(Cc)$, $LL = f\,(Cr)$, $PL = f\,(Cr)$, $PI = f\,(Cr)$, $e0 = f\,(Cr)$).

# Chapter 4

## 4. Results and Discussions

### 4.1 Results:

#### 4.1.1 Correlations between compressibility and consistency properties

Linear simple regression analysis of the compression index against the consistency properties are presented in Figures 1 to 8. Also, multiple regression analysis was used to correlate the indices with Atterberg limits. The graphs show the predicted relationship among the variables with the coefficient of determination (R2).

### 4.2 Discussions

Depending on the obtained results presented in the previous section, the discussions have been developed in the following sections.

#### 4.2.1 Relationship between compression index and liquid limit

In the current study, the compression index significantly correlated with the liquid limit as a single variable. This is noticed from the achieved value of $R^2$ which was (0.5651). As shown in Figure 1

**LL=156.52Cc+13.082** $R^2$=0.5651

#### 4.2.2 Relationship between compression index and plastic limit

From Figure 2, according to the achievement of the good values of $R^2$, it was found that the compression index is significantly correlated with the plastic limit as a single variable in which is ($R^2$ equal to 0.6879)

**PL=33.061Cc+17.717** $R^2$=0.6879

#### 4.2.3 Relationship between compression index and plasticity index

In the current study, the plasticity index has a sufficiently reliable correlation with the compression index as a single variable equation. This was noticed from the achieved value of $R^2$ which was (0.7268), As shown in Figure 3.

**PI=89.111Cc+3.1608** $R^2$=0.7268

### 4.2.4 Relationship between compression index and initial void ratio

According to the achievement of the good values of $R^2$, it was found that the compression index is significantly correlated with the Initial void ratio as a single variable in which is ($R^2$ equal to 0.8978), As shown in Figure 4.

**$e^o$=1.6322Cc+0.6147** $R^2$=0.8978

### 4.2.5 Relationship between recompression index and liquid limit

The liquid limit has a sufficiently reliable correlation with the recompression index as a single variable equation. This was noticed from the achieved value of $R^2$ which was (0.6347), As shown in Figure 5.

**LL=208.28Cr+26.672** $R^2$=0.6347

### 4.2.6 Relationship between recompression index and plastic limit

According to the achievement of the good values of $R^2$, it was found that the compression index is significantly correlated with the plastic limit as a single variable in which is ($R^2$ equal to 0.5857), As shown in Figure 6.

**PL=483.02Cr+16.405** $R^2$=0.5857

### 4.2.7 Relationship between recompression index and plasticity index

In the current study, the plasticity index has a sufficiently reliable correlation with the recompression index as a single variable equation. This was noticed from the achieved value of $R^2$ which was (0.6045), As shown in Figure 7.

**PI=101.13Cr+20.44** $R^2$=0.6045

### 4.2.8 Relationship between recompression index and initial void ratio

From Figure 8, according to the achievement of the good values of $R^2$, it was found that the recompression index is significantly correlated with the initial void ratio as a single variable in which is ($R^2$ equal to 0.6879)

**$e^o$=4.6803Cr+0.4736** $R^2$=0.6035

## 4.3 METHODOLOGY OF THE PRESENT STUDY

As per earlier research work, some of the researchers correlated the compression index with liquid limit only while some researchers correlated the compression index with plasticity index only and also same for the recompression index. So, to overcome the shortcoming of earlier models, in the present study the compression index and recompression index is related to all basic and index properties of soil. In the present study, an attempt has been made to estimate compression index as a function of soil index properties., and compression index as a function of soil index properties. Soil samples were collected from different Place. The values of liquid limits of the samples varied from 27 to 78 and The Values of Plastic limits of samples varied from 20.3 to 35.7, and 11 to 39.4 for Plastic Index, Values of Initial Void ratio of the samples varied from 0.47 to 5.8, Clays having low compressibility and recompressibility to Clays with high compressibility and recompressibility. The collected samples were subjected to laboratory investigations for the determination of geotechnical parameters namely liquid limits, plastic limits, plastic index, initial void ratio, compression indices and recompression index. Based on experimental results, correlation between the compression index and recompression index with soil index properties was attempted.

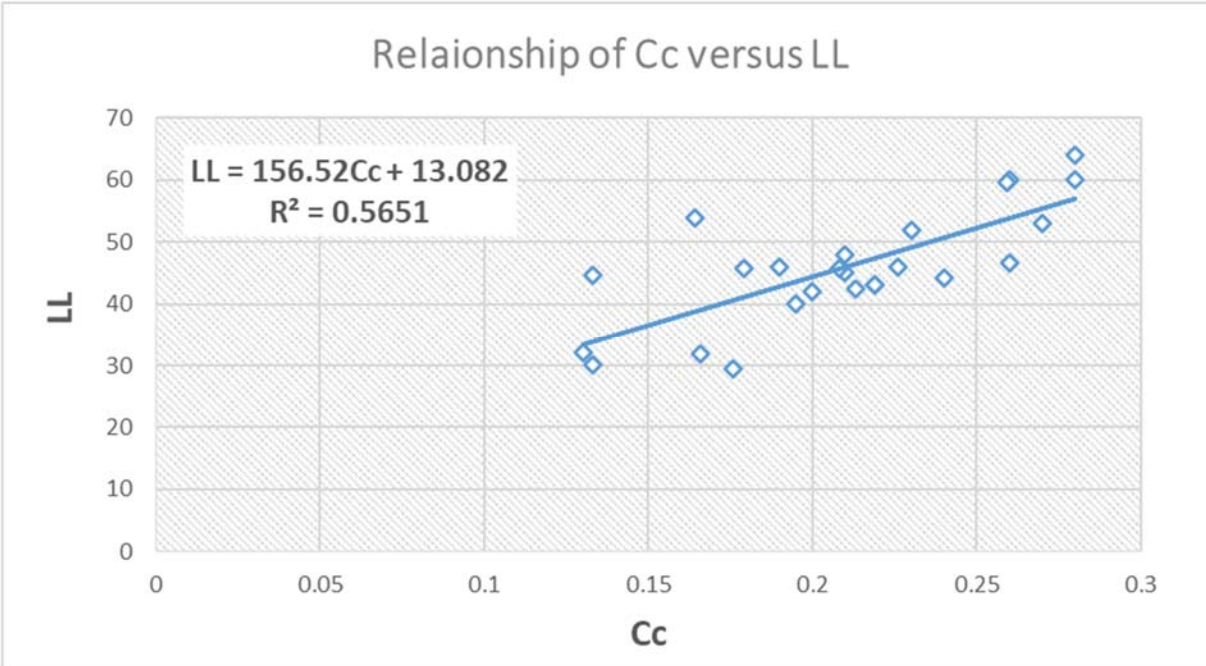


*Figure 1 relationship between LL & Cc*

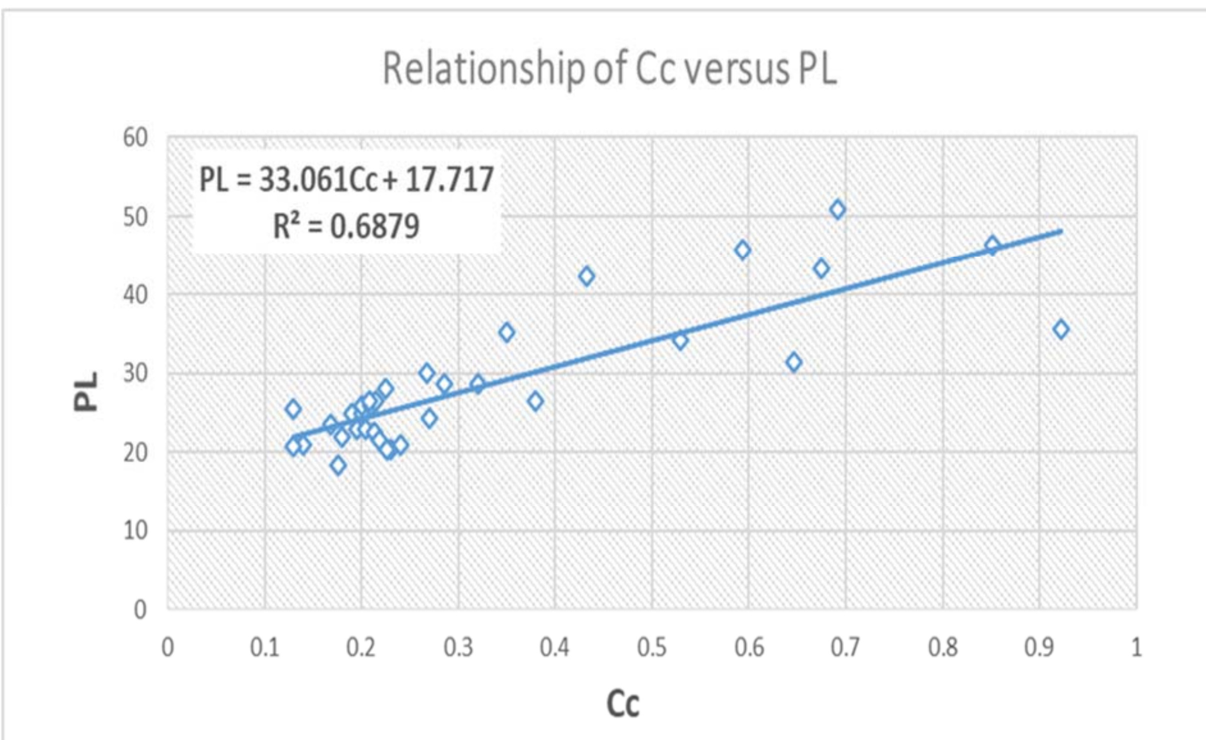


*Figure 2 relationship between PL & Cc*

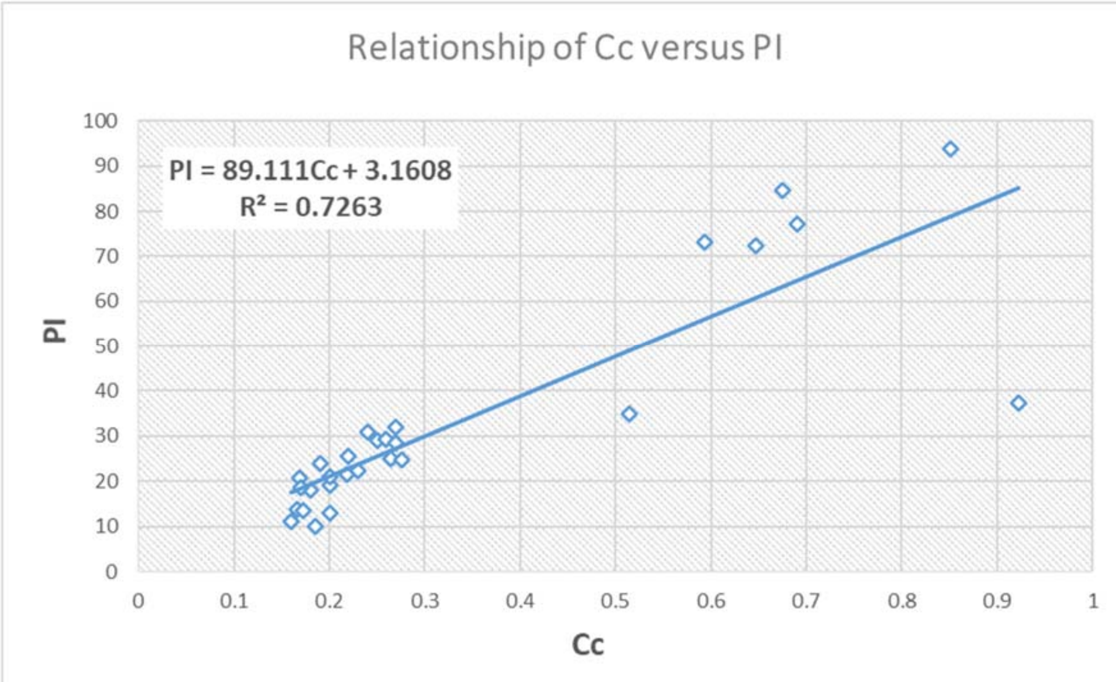


Figure 3 relationship between PI & Cc

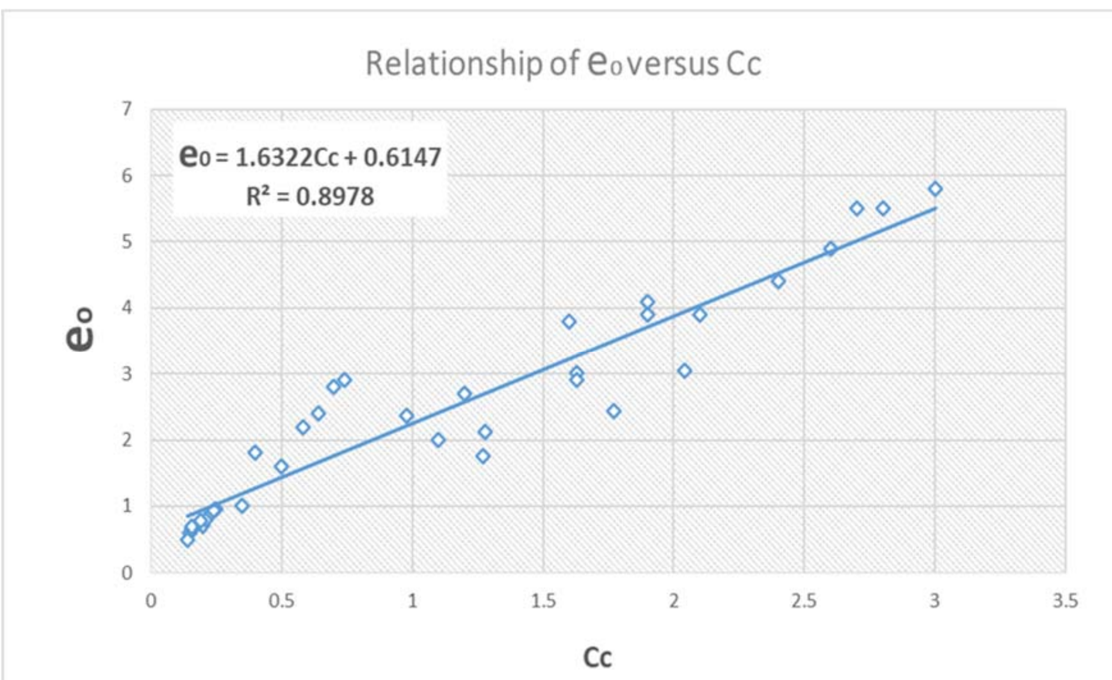


Figure 4 relationship between $e_0$ & Cc

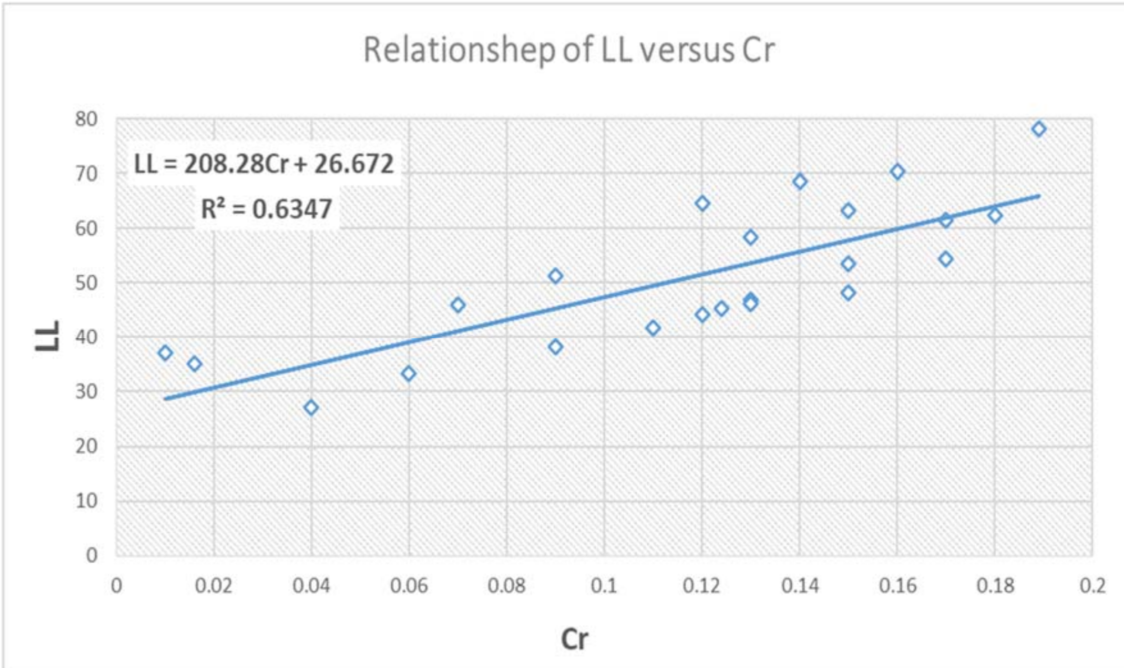


Figure 5 relationship between LL & Cr

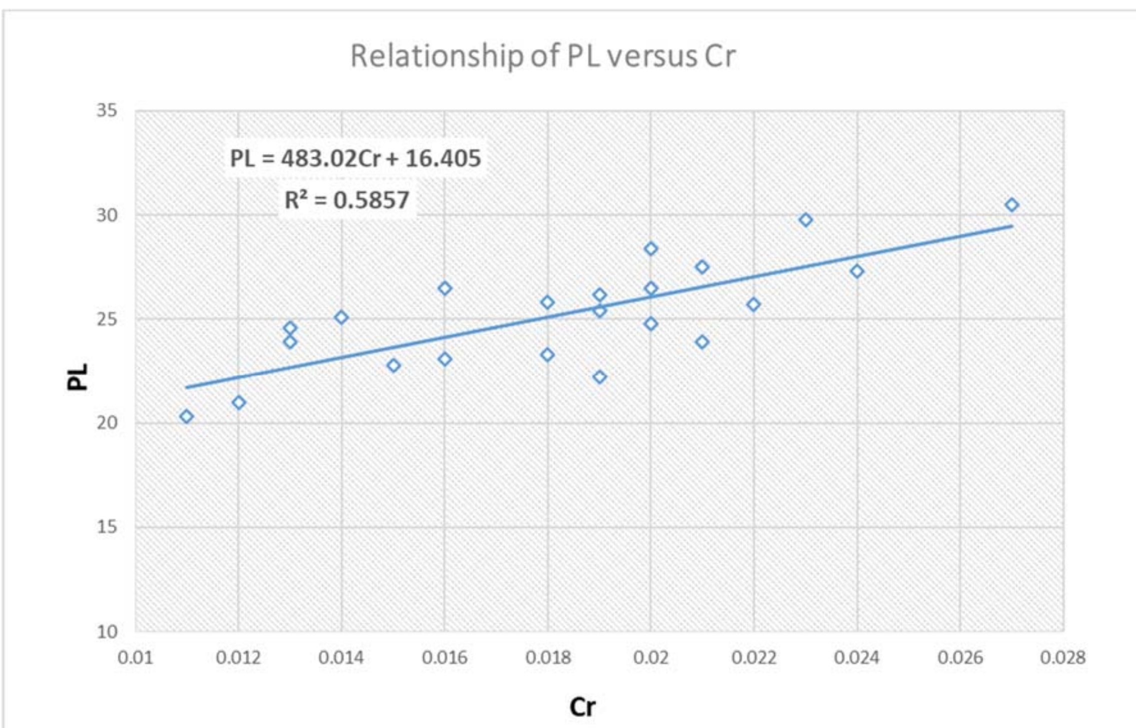


Figure 6 Relationship between PL & Cr

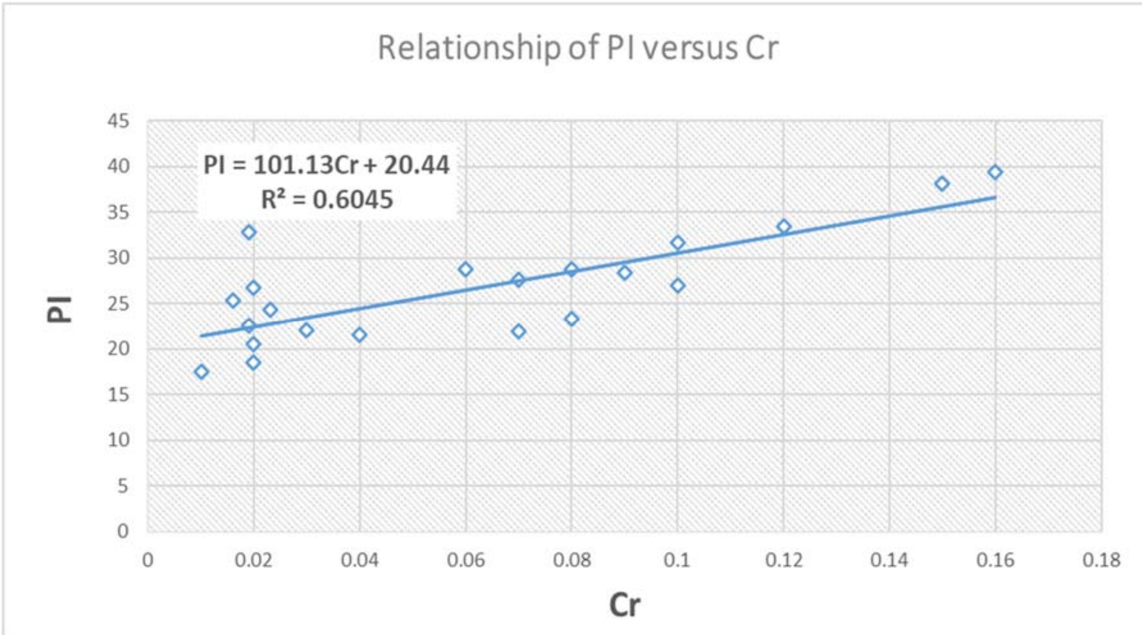


Figure 7 relationship between PI & Cr

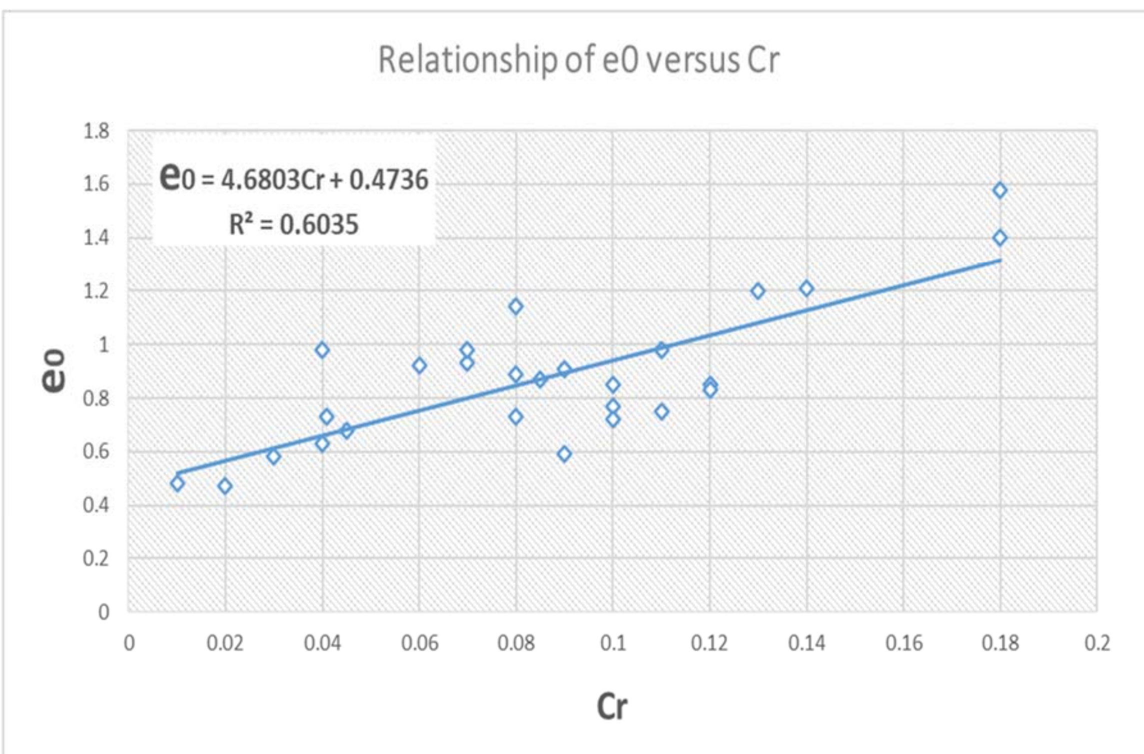


Figure 8 relationship between $e_0$ & Cr

# Chapter 5

## 5. Conclusions

From the results of this study, the following conclusions can be drawn:

1. Compression index can reasonably correlate with the basic soil properties as a single variable equation involving LL, PI, PL, $e^o$. Among them, better correlation between Cc and $e^o$ considered the greatest R2 factor, which is 0.8978. The lowest R2 factor obtained between Cc with LL, which is 0.5651. However, for all the graphs, increasing of index properties caused increasing of Cc.
2. Recompression index also can reasonably correlate with the basic soil properties as a single variable equation involving LL, PI, PL, $e^o$. Among them, better correlation between Cr and LL considered the greatest R2 factor, which is 0.6347. The lowest R2 factor obtained between Cr with PL, which is 0.5857. However, for all the graphs, increasing of index properties caused increasing of Cr.
3. The obtained correlation equation is considered simple, easy and more convenient for estimating compressibility index and re compressibility index, which may be helpful for the geotechnical engineers for quick determination of compressibility parameters and to predict the magnitude of settlement due to the structures loading.
4. The compressibility of a compacted soil influenced by the same factors that influence the shear strength. In general, the compressibility decreases with improved gradation and decreasing as-compacted void ratio. Unlike the effect on shear strength, increasing angularity will produce increasing compressibility.
5. Soil is found to have differences in shear strength that are caused by differences in soil structure. A flocculated soil structure is more rigid and produces smaller initial pore water pressures during shear than the same soil with a dispersed soil structure. This leads to increased strengths, particularly at low strains. The soil structure that is produced by compaction is governed by the soil type, the molding water content, and the compaction method.
6. Compressibility of compacted soil is influenced by soil type, molding water content, as-compacted dry density, initial degree of saturation and compaction method.

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