Comparison Between Two Methods for Determination Parameters Consolidation

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ABSTRACT

Preconsolidation pressure is the maximum vertical effective stress under which a soil has been consolidated. This pressure is a very useful in geotechnical engineering for analysing and predicting settlement behaviour and for normalizing other engineering parameters for comparative purposes. Preconsolidation pressure is generally determining using consolidation test data. The main purpose of consolidation tests is to obtain soil data which is used in predicting the rate and amount of settlement of structuzseres founded on clay. Two methods are used in this study for determining the preconsolidation pressure and correcting for sample disturbance using Schmertmann's correction for 220 consolidation tests performed on the soil samples obtained from various transportation projects Benghazi city, and the results that used in this paper were obtained in soil lab in Benghazi University. These methods are Casagrande **(1936)** and Sällfors **(1975)**. The objective of this study is to comparing between these methods for different values of data. In addition, statistical analysis was studied for the two methods by using the Reliability Analysis software with collected data from laboratory tests. The results showed that the preconsolidation pressures for Sällfors method have smaller values than Casagrande for most of the data.

الملخص

يعتبر الضغط المسبق (**Preconsolidation pressure**) هو الحد الأقصى للإجهاد الفعال الرأسي الذي من خلاله يتم تصلب التربة. هذا الضغط مفيد جدًا في الهندسة الجيوتقنية لتحليل وتوقع الهبوط ولمعرفة الخصائص الهندسية الأخرى لأغراض المقارنة، يتم ايجاد الضغط المسبق باستخدام اختبار التصلب، الغرض الرئيسي من اختبارات التصلب هو الحصول على بيانات التربة التي يتم استخدامها للتنبؤ بمعدل ومقدار الهبوط للمباني القائمة على التربة الطينية. تم استخدام طريقتين في هذه الدراسة لتحديد الضغط المسبق وتصحيح اضطراب العينة باستخدام تصحيح **Schmertmann** لـ **220** اختبار تصلب تم إجراؤها على عينات التربة التي تم الحصول عليها من مختلف مشاريع النقل بمدينة بنغازي وتم اجراء هذه التجارب فى معامل جامعة بنغازى. هذه الطرق هي **Casagrande** (**1936**) و **Sällfors** (**1975**)، الهدف من هذه الدراسة هو المقارنة بين هذه الأساليب للقيم المختلفة للبيانات. بالإضافة إلى ذلك، تمت دراسة التحليل الإحصائي للطريقتين باستخدام برنامج تحليل الوثوقية مع البيانات التي تم جمعها من الاختبارات المعملية. أوضحت النتائج أن الضغط المسبق لطريقة **Sällfors** لها قيم أصغر من **Casagrande** لمعظم البيانات.

Keywords: Casagrande, Sällfors method, preconsolidation pressures.

INTRODUCTION

The preconsolidation pressure, **σ_p'**, is the maximum past effective overburden pressure to which the soil specimen has been subjected. Overconsolidation pressure ratio, **OCR,** is the ratio of the preconsolidation pressure to the existing vertical effective overburden pressure **(σ'_{v0})**. If the preconsolidation pressure equal the currently existing effective vertical overburden pressure, soils are normally consolidated and have an **OCR = 1**, a soil whose preconsolidation pressure is greater than the existing overburden pressure, then **OCR > 1** and this soil is overconsolidated. It is also possible to find a soil that has an **OCR < 1**, in which case the soil would be underconsolidated. Underconsolidation can occur, in soils that have only recently been deposited, either geologically or by human activity, and are still consolidating under their own weight **(Holtz et al. 2011)**.

There are a few graphical methods for determining the preconsolidation pressure based on laboratory oedometer data. No suitable criteria exists for appraising the relative merits of the various methods. These methods are usually based on the relationship of experimental void ratio **(e)** and effective consolidation pressure **(p)**. Several authors have proposed methods to estimate the pre-consolidation stress of a soil sample: Casagrande **(1936)**, Pacheco-Silva **(1970)**, Sällfors **(1975)**, Tavenas et al. **(1979)**, Gregory et al. **(2006)**, simple method **(Holtz et al.2011)**, among others. The earliest and the most widely method was the one proposed by Casagrande **(1936)**, and the simplest method is the method that used by some engineers, simple method **(Holtz et al. 2011**).

In this study only two different methods are used to determine the consolidation parameters with collected data from laboratory tests and field studies, and to compare among these values that calculated from different methods. For the same data of a test, these methods may estimate different values of preconsolidation pressures. Statistical analysis was also considered and performed by using Reliability Analysis software to present the data by statistical distribution for two methods that indicated above with laboratory tests. In the statistical process descriptive statistics **(example, mean, standard deviation, and variances)** were compared by **t-Test**: Two-sample assuming unequal variances and **ANOVA** analyses- single factor.

TEST DATA TO STUDY

Preconsolidation parameters, including preconsolidation pressure, compression index **(Cc)**, overconsolidation ratio, and recompression index **(C_r)** were investigated based on the relationship of experimental void ratio and effective consolidation pressure for **220** soil samples taken from previous transportation projects throughout Benghazi city. In some tests, it is difficult to use one or more of the two methods that applied in this paper.

DETERMINATION OF PRECONSOLIDATION PRESSURE BY DIFFERENT METHODS

Preconsolidation parameters were obtained graphically using different methods from laboratory oedometer data: Casagrande **(1936)** and Sällfors **(1975)**.

Casagrande (1936) Method

Casagrande developed the most commonly used method and it is shown in figure **1**. The Casagrande method of obtaining the preconsolidation pressure from consolidation test is based on the point of greatest curvature **(Solanki, and Desai 2008)**. The following steps describe this construction for Casagrande **(1936)** method as described in Holtz **(2011)**.

1. Choose by eye the point of minimum radius **(or maximum curvature)** on the consolidation curve **(point A in Fig. 1)**
2. Draw a horizontal line from point **A**;
3. Draw a line tangent to the curve at point **A**;
4. Bisect the angle made by steps **2** and **3**;
5. Extend the straight-line portion of the virgin compression curve up to where it meets the bisector line obtained in step **4**. The point of intersection of these two lines is the preconsolidation stress **(point B of Fig.1)**.

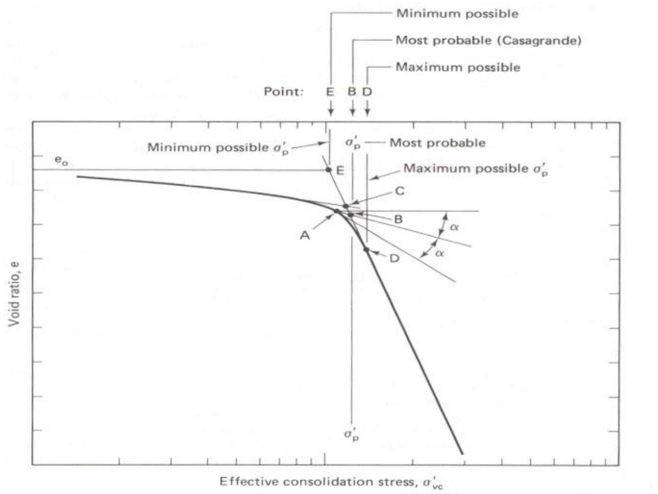

Fig. 1 Casagrande's Method for Determining Preconsolidation Pressure (Holtz et al. 2011)

Sällfors (1975) Method

Sällfors developed an alternative method to calculate the preconsolidation. It is graphical like Casagrande's method. He showed from field loading tests on sensitive Swedish clays that the method predicts the in-situ preconsolidation pressure very well **(Holtz 1991)**. Using fig.**2** to follow these steps as found in Holtz **(2011)**.

1. Extend the straight-line portions of the **e-log σ'_{vc}** curve at the break in the curve (**around the preconsolidation pressure)**, as lines **1** and **2**;

2. Place a line tangent to the data curve and adjust it until you make an isosceles triangle with its two sides of length **x**;

3. Extend the left side of the tangent line until it intersects with the top data line, line **1**. The preconsolidation pressure is equal to the pressure at this intersection point.

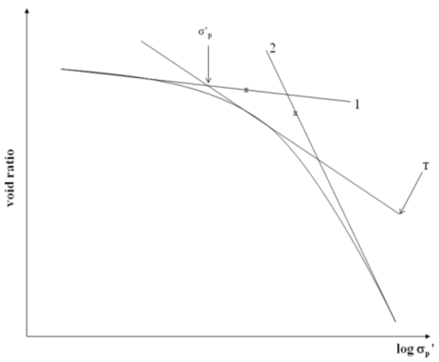

Fig. 2 Sällfors' Method for Determining Preconsolidation Pressure (Holtz et al. 2011)

Determination of Cc and Cr

From a plot of compressibility versus the log of the applied stress, other consolidation parameters may be estimated **(e.g., compression index, Cc and recompression index, Cr)**
Cc and **Cr** indices obtained from the oedometer test are necessary in settlement calculation for clayey soil layers. The compression index is the slope of what's termed the "virgin compression curve" because it represents a state at which the soil has never existed before **(the applied stress is greater than the preconsolidation pressure)**. The recompression index may also be taken as the slope of the unload-reload portion of the curve as shown in **fig.3**.

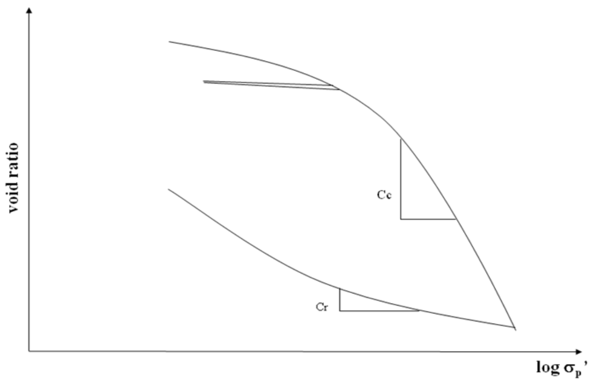

Fig. 3 Consolidation curve

Reconstruction of Field Compressibility Curves

Even a perfect soil sample has some degree of disturbance. Therefore, the in-situ compression line is likely to have a slightly higher slope than that obtained from an oedometer test **(laboratory data)**. The most common procedure to obtain the field compressibility curve from the one observed in the laboratory is Schmertmann **(1953)**, he provides an empirical method for recovering the curve field compressibility from the laboratory data. Schmertmann found out that the oedometer compression line meets the in-situ compression line at a void ratio of approximately **0.42** times the initial in-situ void ratio $\mathbf{e_0}$**,** because the intersection of the field initial virgin slope with the initial virgin slopes of laboratory consolidation tests ranges from about **40** to **46** percent of the sample's initial void ratio, $\mathbf{e_0}$, so Schmertmann recommended that an initial virgin-slope intersection point at **42** percent of e_0 be used as a reasonable estimate for most clays **(Bartlett and Alcorn 2004)**. Once the preconsolidation pressure is obtained using one of the methods discussed above, points **E** and **F** are shown in **fig.4** on in-situ compression line can easily be fixed, and the line between them is the estimated field compression curve.

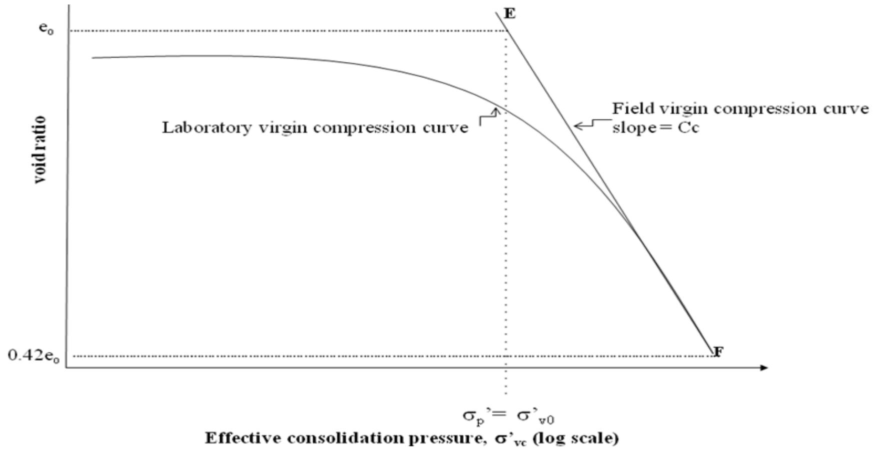

Fig.4 In-situ e-log (σ'_p) curve

SUMMARY OF RESULTS

Preconsolidation pressure for different methods

The preconsolidation pressures were calculated using Casagrande and Sällfors method are shown in **fig. 5 .** Casagrande method resulted in higher values compared to Sällfors method.

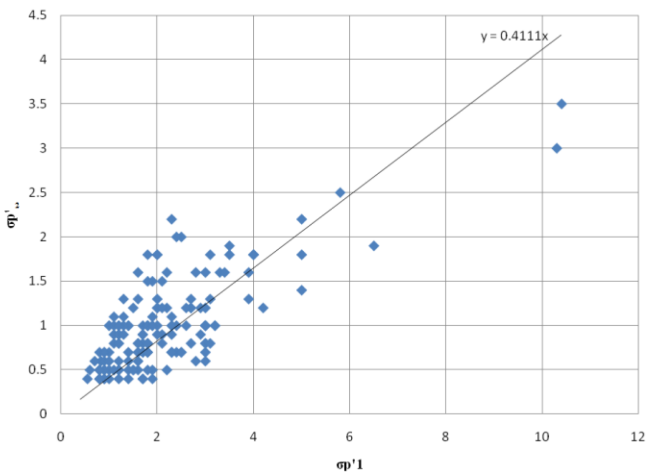

Fig.5 Casagrande (σ_p'1) vs. Sällfors method (σ_p'2)

Compression index for different methods

In **fig. 6**, compression indices were calculated using Casagrande and Sällfors method. In this figure, there is no big different between the compression indices that calculated by Casagrande and Sällfors method.

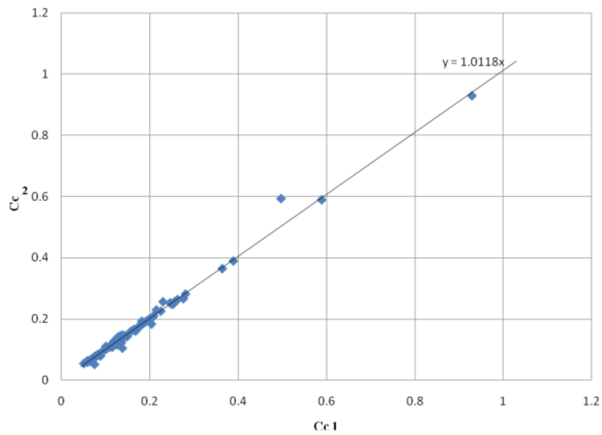

Fig.6 Cc1 (Casagrande method) vs. Cc2 (Sällfors method) for field

Field and laboratory compressibility for different methods

fig.7 and **fig.8** show the results of calculation of field consolidation curves from laboratory data. These corrections allow for a more direct comparison between compressibility measured in the laboratory oedometer test with that measured in the field. It found there is no big different between field and laboratory compressibility that calculated by the two different methods.

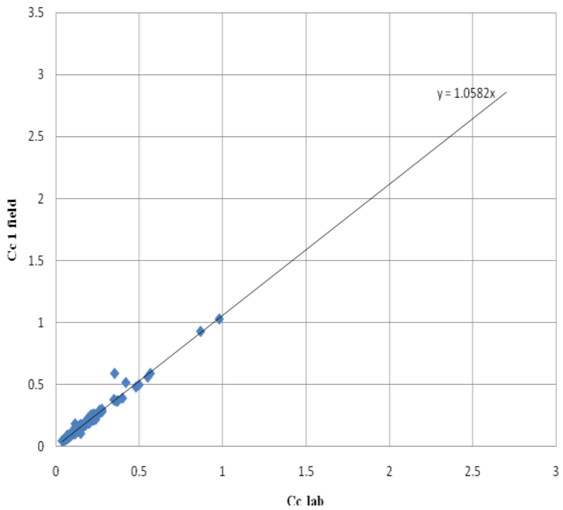

Fig.7 Cc (lab) vs. Cc1 (Casagrande method-field)

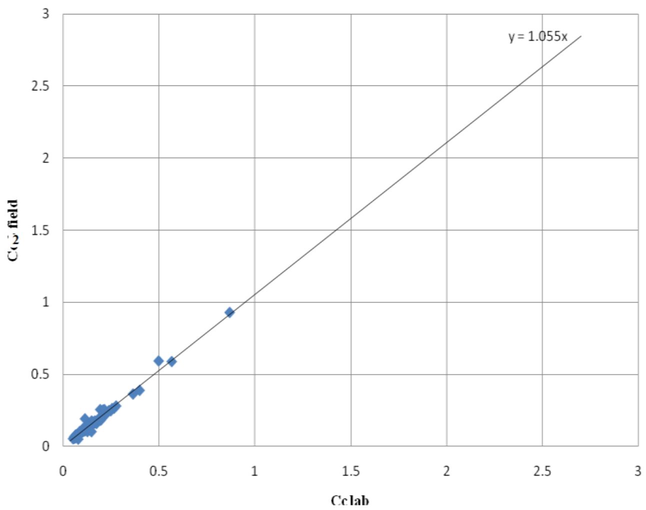

Fig.8 Cc (lab) vs. Cc2 (Sällfors method-field)

STATISTICAL ANALYSES

A statistical analysis of each data set was performed by using Reliability Analysis software and Excel Hypothesis Tools. Statistical analyses were performed to compare preconsolidation pressures for two different methods. Fig. 9 shows Statistical summary distribution for different methods, where f(t) is the probability density function, which describes the shape of the failure distribution (Ebeling 2010). This statistical distribution is done with the software of Reliability analysis. It shows Casagrande has lognormal distribution and Sällfors method has Normal distribution. Statistical summary of parameters such as mean, median, and standard deviation, coefficient of variance, skewness, kurtosis and range are shown in Table 1.

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Table 1 Summary of Descriptive Statistics

Casagrande Method		Sällfors Method	
Mean	2.180	Mean	1.008
Standard Error	0.111	Standard Error	0.041
Median	1.800	Median	0.900
Mode	1.800	Mode	1.000
Standard Deviation	1.385	Standard Deviation	0.515
Sample Variance	1.918	Sample Variance	0.265
Kurtosis	14.682	Kurtosis	3.972
Skewness	3.096	Skewness	1.616
Range	9.850	Range	3.100
Minimum	0.550	Minimum	0.400
Maximum	10.400	Maximum	3.500
Sum	342.280	Sum	158.300
Count	157.000	Count	157.000
Confidence Level (95.0%)	0.218	Confidence Level (95.0%)	0.081

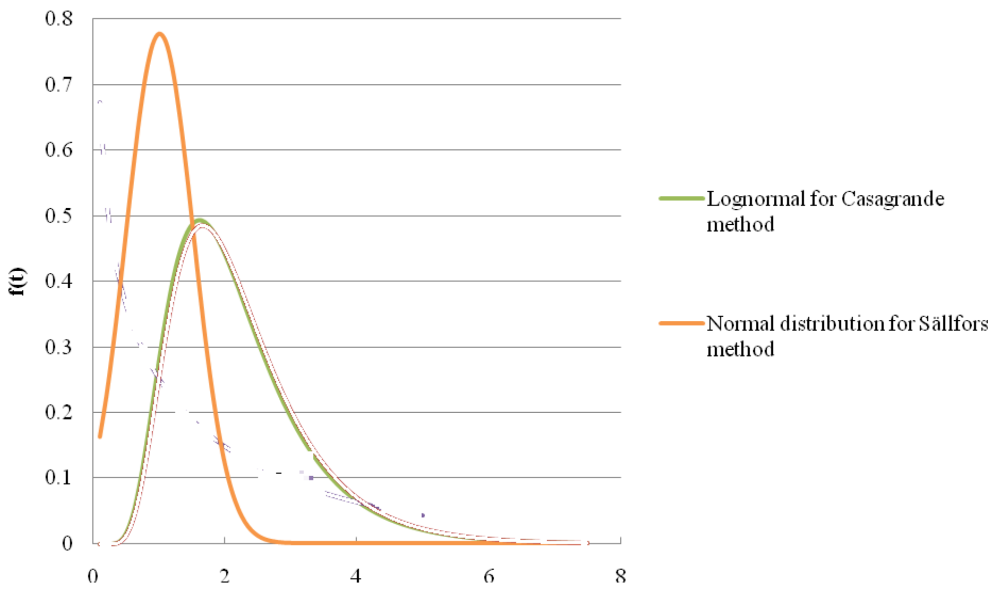

Fig.9 Statistical distribution for two different methods

Excel Hypothesis Tools

Researchers and scientists often use statistical tests called t-tests to assess whether two groups significantly differ from one another. **t-Tests** take into account the numbers on which the means are based to determine the amount of data overlap between two groups.

Excel offers several data analysis tools that are designed to be used for Hypothesis testing. They are

1- t-Test: Paired two sample for mean;

2- t-Test: Two-sample assuming equal variances;

3- t-Test: Two-sample assuming unequal variances **(Harmon 2011)**

t-Test: Two-sample assuming unequal variance was used in this paper because each method has different variance as shown in table **1**. As known, analysis of a negative **t-value** requires examination of its absolute value in comparison to the value on a table of **t-values**. Therefore, in table **2, t-Stat** studied as an absolute value then compared with **t- Critical** one-tail and two tail. It appears there is a different between Casagrande, Sällfors method**.**

Table 2 t-Test: Two-sample assuming unequal variances
Casagrande method vs. Sällfors method

Parameters	Variable 1 (Casagrande method)	Variable 2 (Sällfors Method)
Mean	2.180127389	1.008280255
Variance	1.918380753	0.265123306
Observations	157	157
Hypothesized Mean Difference	0	
df	198	
t Stat	9.9367368	
P(T<=t) one-tail	1.9567E-19	
t Critical one-tail	1.652585784	
P(T<=t) two-tail	3.9134E-19	
t Critical two-tail	1.972017432	

ANOVA analyses

Excel permits a number of **ANOVA** analyses- single factor, **two-factor** without replication, and **two-factor** with replication. In this study, single factor **ANOVA** as shown in **table 3** used to provide an extension of the **t-Tests** analysis to more than two samples means; thus, the **ANOVA** tests of hypothesis permit the testing of equality of three or more sample means, also the F-test is used to test for differences among samples variance **(Guerrero 2010)**.

Variance is a measure of the dispersion of a set of data points around their mean value, so table 3 shows the Sällfors Method has the smaller value of variance than Casagrande Method.

Table 3. Anova: Single Factor

Groups	Sum	Average	Variance
Casagrande Method	342.28	2.1801274	1.91838075
Sällfors Method	158.3	1.0082803	0.26512331

DISCUUSION AND CONCLUSION

In this study two different methods for the determination of preconsolidation parameters have been evaluated and the values compared. As shown in figures 5 to 9, the following conclusions could be drawn.

- The use of different methods lead into the different results of preconsolidation pressure values between the Casagrande (1936) method and Sällfors (1975) method, there are big different between these two methods, so preconsolidation pressures differed with different calculating methods studied.
- Casagrande graphing method is worldwide adopted to determine the preconsolidation pressure; but this empirical method has some drawbacks such as difficult to plot the curve and personal errors to determine the point with minimum radius of curvature when drawing scale is inappropriate
- In some cases, the preconsolidation pressure for the methods that used in this paper could not be obtained.
- In general, Sällfors method gives the lowest values of the preconsolidation pressure.
- Sällfors method is sometimes difficult in determining the compression index (Cc) value because overconsolidation ratio (ORC) is less than 1 (Underconsolidation).
- Each consolidation test was corrected for sample disturbance using Schmertmann's method for overconsolidation and normal consolidation.
- t-Test is a significance test to show if the different between two samples are big enough to be significant or no. As indicated, there is a big different between Casagrande method and Sällfors method for preconsolidation pressure..
- Form the graphical studies and statistical analysis; it concludes the Sällfors method has the most different values for preconsolidation pressures comparing with Casagrande method that studied in this paper.

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