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Reliability of the Method for Determination of Coefficient of Consolidation (c_v)

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ABSTRACT: Many curve-fitting procedures based on the Terzaghi uncoupled consolidation theory have been proposed for determination of the laboratory coefficient of primary consolidation (c_v). Six available methods are used in this study to evaluate the coefficient of consolidation for an expansive clay soil in Yogyakarta, Indonesia. This paper presents c_v values obtaining from Casagrande's logarithm of time, Taylor's root of time, the early stage of log-t, the inflection point, the $\sqrt{t_{60}}$ and the $\sqrt{t_{45}}$ root of time method. A correlation between the value of c_v and pressure shows that the larger variability of c_v was found if the applied pressure was lower than 5 kPa. Beyond this pressure, the variability of c_v was quite small and very close together. In general, the early stage of log-t method gives higher values than other methods and lower, whereas, the inflection point method have a lowest c_v values among others. At higher applied pressure, four methods; Taylor's $\sqrt{t_{90}}$ method, Feng and Lee $\sqrt{t_{60}}$, Robinson and Allam's $\sqrt{t_{45}}$, and Mesri et. al inflection point method; give quite consistent c_v value that close to the best fit line. Regardless of this fact, the data and conclusions presented address important findings for uses of the c_v method for practical range of interest.

Keywords : primary consolidation, coefficient of consolidation, expansive clay.

1 INTRODUCTION

In the analyses of the settlement behavior over time of a structure founded on a consolidating soil layer commonly adopts the Terzaghi uncoupled consolidation theory. The primary parameter that controls the settlement rate is the coefficient of consolidation (c_v). This parameter, which is evaluated on the basis of in situ measurements or laboratory test data, must be determined correctly to predict the true time rate of the settlement. Many methods have been developed to obtain c_v value such as log-time and its variant, square root of time and its variant, inflection point, hyperbolic, and least square methods (Casagrande and Fadum, 1940; Taylor, 1948; Mesri et al., 1999; Sridharan and Prakash, 1985; Chan, 2003). Most of the methods of obtaining c_v from the laboratory time-settlement data are determined graphically and are based on Terzaghi's consolidation theory. The very existence of so many procedures itself is an indication that all methods may not be applicable under all circumstances. As the values of c_v obtained by different methods vary widely, it is difficult to decide which value of c_v is a reasonable estimate for the soil; at least in the laboratory testing conditions, though not the field behavior.

In practice, an engineer uses laboratory test data to estimate the rate of settlement of a soil and has to decide which of the methods needed to be used. So the main objective is to study the variation of the coefficient of consolidation values using different methods in order to draw a conclusion on which of those methods is more realistic and reasonable to predict the time rate of consolidation settlement. In this study six available methods are studied for determining the coefficient of consolidation that are Casagrande's logarithm of time method, Taylor's root of time method, the early stage of log-t method, the inflection point method, the $\sqrt{t_{60}}$ and the $\sqrt{t_{45}}$ root of time method. The values of the coefficient of consolidation using these methods are determined and compared.

2 THEORY

According to the Terzaghi theory of one-dimensional consolidation, the relationship between average degree of consolidation, U, and time factor, T, in an incremental loading consolidation test is

$$U = 1 - \sum_{m=0}^{\infty} \frac{2}{M^2} \exp\left(-M^2 T\right) \qquad (1)$$

where, $T = \dfrac{c_v t}{H^2}$ (2)

c_v = coefficient of consolidation; H = maximum drainage distance; t = time elapsed from application of pressure increment; and M = $\pi(2m + 1)/2$. When values of t, T, and H are known, the coefficient of consolidation can be determined from eq. (2).

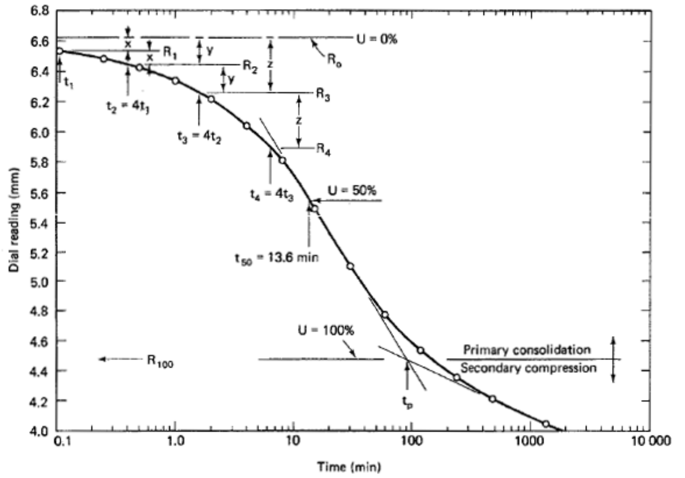

Fig.1 Logarithmic of time method for determining coefficient of consolidation (Casagrande and Fadum, 1940).

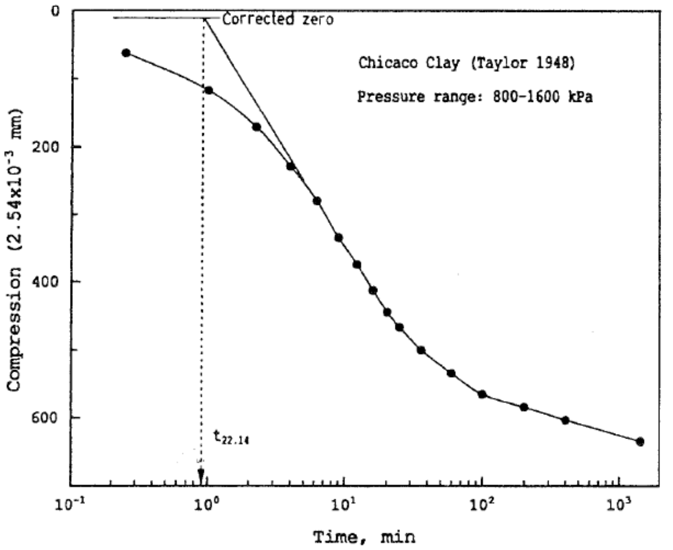

Fig. 2 Early stage log-t method for determining coefficient of consolidation (Robinson and Allam, 1996).

The log t method by Casagrande and Fadum (1940) involves finding 0% consolidation from the early segment of the log *t* consolidation curve and 100% consolidation from the secondary compression segment and the tangent line passing through the inflection point. The coefficient of consolidation is determined using eq. (2) with T_{50} = 0.197 and the consolidation time t_{50} corresponding to 50% consolidation. This method has probably been used most frequently (Fig. 1). The early log t method by Robinson and Allam (1996) involves using both the early segment and the inflection point of the log t plot to find the time of 22.14% consolidation. The coefficient of consolidation is determined using eq. (2) with $T_{22.14}$ = 0.038 and the consolidation time $t_{22.14}$ corresponding to 22.14% consolidation (Fig. 2). The initial compression may affect the early segment of the consolidation curve and lead to an inaccurate estimation of 0% consolidation (Mesri et al. 1999). The inflection-point method by Mesri et al. (1999) involves using only the inflection point of the log t plot to find the time of 70% consolidation. Then the coefficient of consolidation is determined using eq. (2) with T_{70} = 0.403 and consolidation time t_{70} corresponding to 70% consolidation. It should be noted that this method only uses information from 70% consolidation that may only be little affected by the secondary compression. The above three methods all require an inflection point appearing on the consolidation curve.

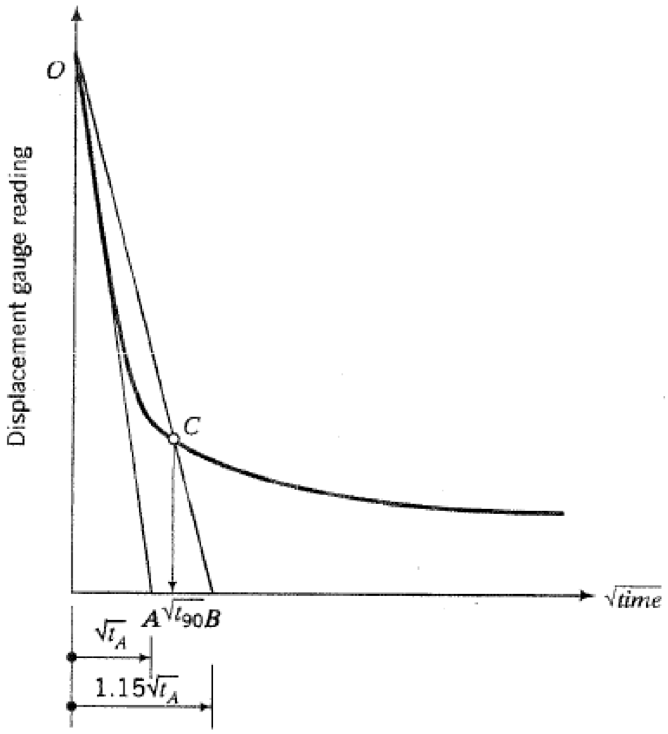

Fig. 3 Square root of time method for determining coefficient of consolidation (Taylor, 1948).

Taylor (1948) developed the square root of time ($\sqrt{t}$) method based on the assumption that the hydrodynamic process dominates up to 90% consolidation. This method involves first drawing a straight line from the linear segment of the oedometer $\sqrt{t}$ consolidation curve and then using it to plot the second straight line that intersects the $\sqrt{t}$ consolidation curve at 90% consolidation (Fig. 3). General concern about this method is that the consolidation curve near 90% consolidation may be significantly affected by secondary compression (Robinson and Allam 1996). In fact, the shape of the $\sqrt{t}$ consolidation curve could also be affected by the secondary compression. Feng and Lee (2001) proposed simplified Taylor $\sqrt{t}$ method by drawing a straight line passing through the linear portion of the measured $\sqrt{t}$ consolidation curve. The point at which the consolidation curve deviates from this straight line gives the time of 60% consolidation. The coefficient of consolidation can then be computed by substituting the time of 60% consolidation into eq. (2) with T_{60} = 0.286 and consolidation time t_{60} corresponding to 60% consolidation (Fig. 4). The Feng and Lee method was revised by Robinson and Allam (2002). The linear segment of the oedometer $\sqrt{t}$ consolidation curve and then using it to plot the second straight line that intersects the $\sqrt{t}$ consolidation curve at 45% consolidation instead of 60% consolidation. The coefficient of consolidation can then be computed by substituting the time of 45% consolidation into eq. (2) with T_{45} = 0.145.

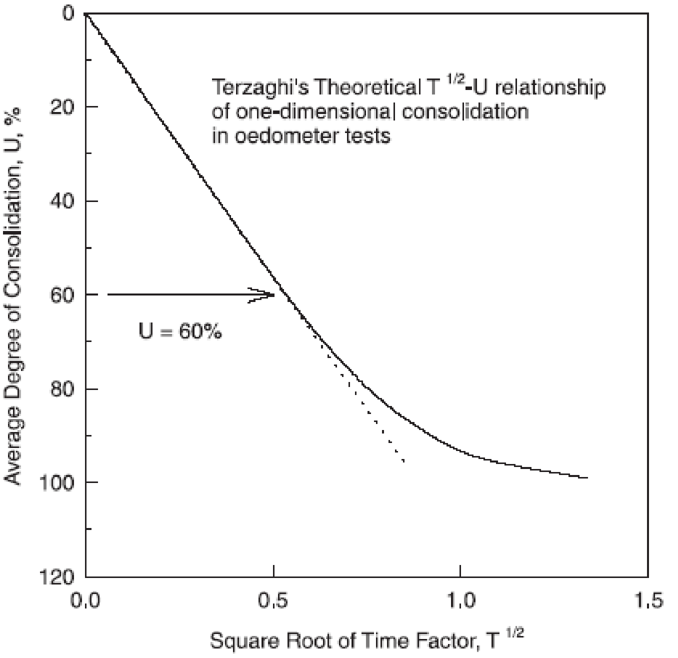

Fig. 4 Variant of square root of time method for determining coefficient of consolidation (Feng and Lee, 2001).

3 METHOD OF EXPERIMENT

In this study, the methodology is based on the experimental works that have to be clearly identified to accomplish the objectives. Soil samples were collected from Kasihan, Yogyakarta. The soils samples were classified experimentally by carrying out some fundamental tests such as the grain size analysis test, hydrometer test, specific gravity test; Atterberg and limits tests. The consolidation tests were carried out for five undisturbed soil samples using the odometer apparatus. The consolidation tests were carried out according to ASTM D2435. The sequence of loading was increased incrementally from 0.8 kPa to 25 kPa. Duration of each load increment throughout the tests was 24 hours. For each pressure increment, the readings of the deformation and time were recorded. The coefficients of consolidation were determined at different applied pressures by different methods, namely:

1 The logarithm of time method (t_{50}),
2 The square root of time method ($\sqrt{t_{90}}$),
3 The early stage log-t method ($t_{22.14}$)
4 The linear segment of square root of time method ($\sqrt{t_{60}}$),
5 The linear segment of square root of time method ($\sqrt{t_{45}}$), and
6 The inflection point method (t_{70}).

The soil sample was comprised of 33% clay size, 51% silt size, and 16% sand fraction. The liquid limit and plasticity index were 59% and 29% respectively. Hence, the soil sample was classified into highly-plastic clay, and then be symbolized as CH. The clay mineral of the soil samples was identified as montmorillonite.

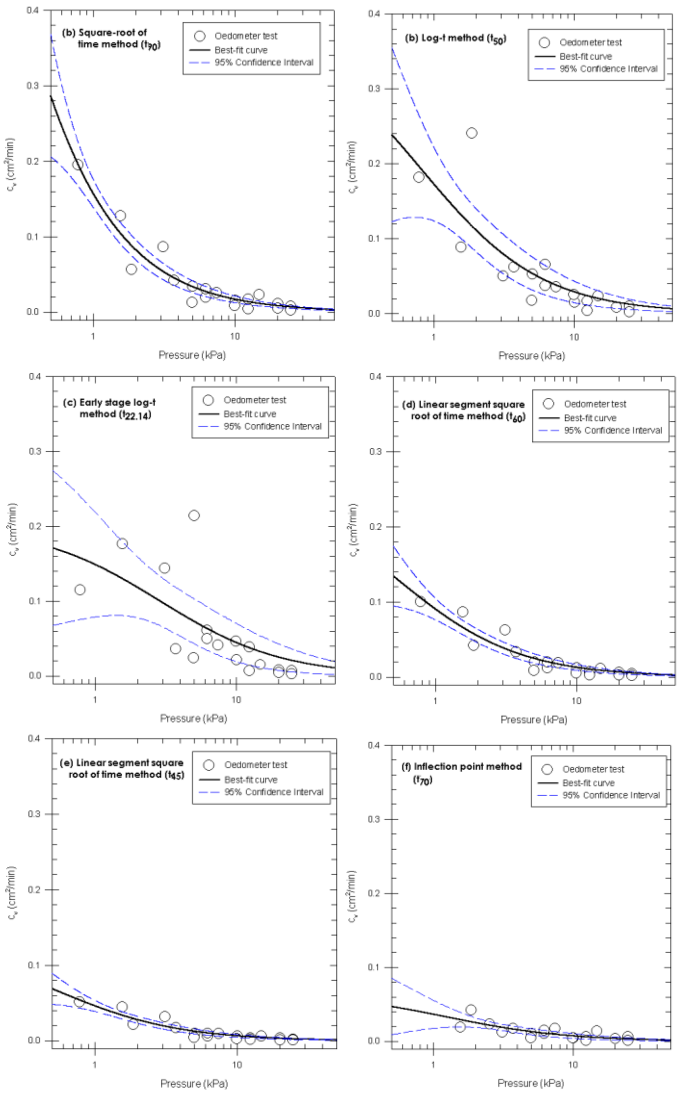

Fig. 5. Coefficient of consolidation values determined by Taylor $\sqrt{t_{90}}$ method (a), Casagrande log-t method (b), Early stage log-t method (c), Square-root of time $\sqrt{t_{60}}$ (d), Square-root of time $\sqrt{t_{45}}$ (e), and inflection point t_{70} method.

4 RESULTS AND DISCUSSIONS

The consolidation properties determined from the consolidation test are commonly used to estimate the magnitude and the rate of consolidation settlements of a structure or an earth fill. Determination of the c_v value is key importance in the design and the evaluation of settlement performance. The values of coefficient of consolidation determined by all methods at all levels of applied pressures are shown in Fig. 5. The values of the coefficient of consolidation determined by each method were fitted by the best curve fitting. This procedure gives the general behavior trend for each method.

Coefficient of consolidation values tend to decrease with increasing of applied pressure for all method (Fig. 5). This characteristic was also observed by Robinson and Allam (1996) for Brown soil and Black Cotton soil. For montmorillonite with water as pore fluid, the compression behavior is governed by physicochemical factor and c_v will decrease with increase in pressure (Robinson and Allam, 1998). It was observed in Fig. 5 that larger variability of c_v were found for log-t (Fig. 5b) and early stage log-t method (Fig. 5c). The variability may rise since the length of the measured secondary compression segment was not sufficient. The results show that log-t and early stage log-t method in some cases may not suitable to determines the c_v values when the recorded time-settlement data from consolidation test was insufficient to distinguish both primary and secondary compression (Feng, 2001).

It is of interest to compare the values of the coefficient of consolidation determined from the evaluated method. The best-fit curve of each method is plotted together in Fig. 6 to examine variability of c_v values with applied pressure. In general, the log-t and early stage of log-t method gives higher values than other methods and, whereas, the inflection point method have a lowest c_v values among others (Fig. 7). The Taylor's $\sqrt{t_{90}}$ method gives a modest c_v values among the evaluated methods. The characteristics were different from the study carried out by other researchers. Most researches concluded that log-t method yield a lowest c_v value (Robinson and Allam, 1996; Feng, 2001; Cortellazo, 2002). Sridharan and Prakash (1995) mentioned that log-t method is affected by secondary compression, with lower values of c_v expected. However, in this study, the method was always shown to be affected by initial compression and yield the increases in the value of c_v. In general speaking, therefore, the determined value of c_v depends on the relative weight of the effects initial compression and secondary compression. For $\sqrt{t_{60}}$ method, Feng (2001) recommended that the method was insufficient for a soft clay specimen having values of coefficient of consolidation around 0.6 cm^2/minutes or higher.

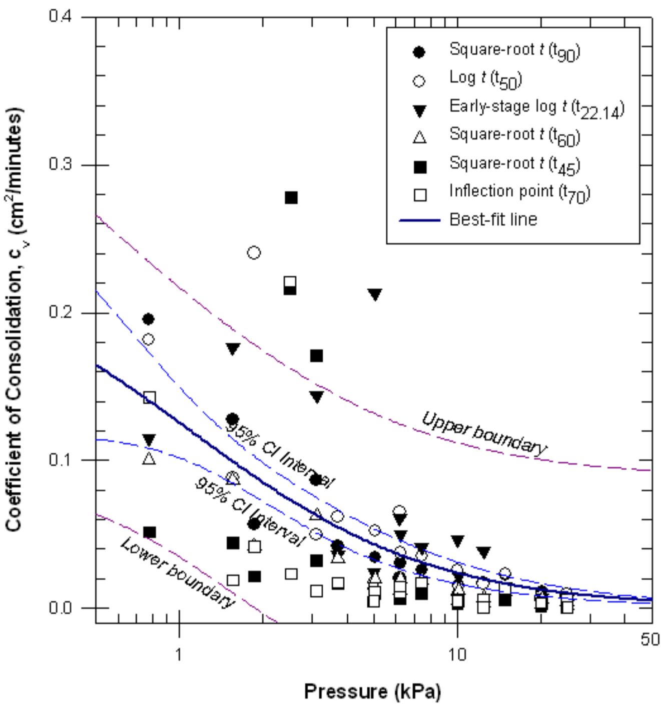

Fig. 6 Variability of the coefficient of consolidation with pressure for various methods.

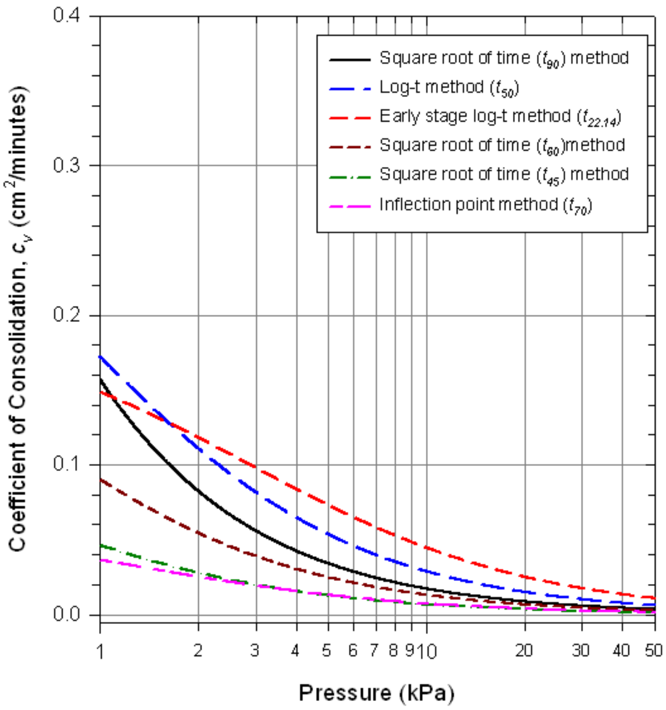

Fig 7. Comparison among the six methods for determination of the coefficient of consolidation with various pressures.

The rate of settlement in the field may be faster than that evaluated experimentally. This is because of the factors affecting the rate of settlement in the field that are not considered experimentally. Therefore, it is better to choose a method that gives the highest value of c_v. Since, this method is usually not affected either by the initial compression part of the consolidation curve or by the secondary compression part of the consolidation curve (Cortellazo, 2002).

5 CONCLUSIONS

The experimental works have been carried out successfully. Six methods for determination of coefficient of consolidation have been also evaluated. In the values of c_v determined from the laboratory test varies and depends on the methods used. Some noted, them, can be drawn from the results and discussions. A correlation between the value of c_v and pressure shows that the large variation of c_v was found if the applied pressure was lower than 5 kPa. Beyond this pressure, the variability of c_v was quite small and very close together. In general, the log-t and early stage of log-t method gives higher values than other methods and, whereas, the inflection point method have a lowest c_v values among others. The Taylor's $\sqrt{t_{90}}$ method gives a modest c_v values among the evaluated methods. At a pressure higher than 20 kPa, four methods; Taylor's $\sqrt{t_{90}}$, Feng and Lee's $\sqrt{t_{60}}$, Robinson and Allam's $\sqrt{t_{45}}$, and Mesri et. al inflection point method; give quite consistent c_v value that close to the best fit line. Regardless of this fact, the data and conclusions presented address important findings for uses of the c_v method for practical range of interest.

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