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Consolidation characteristics of over consolidated clays in Jakarta

Caractéristiques de consolidation des argiles surconsolidées à Jakarta

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ABSTRACT: The determination of the coefficient of consolidation (Cv) which can be estimated using Casagrande's Logarithm of Time Fitting Method or Taylor's Square Root of Time Fitting Method. However, the methods are not appropriate for Over Consolidated Clays (OC Clays). This research is conducted on OC Clay based on the Oedometer Tests and settlement monitoring of high-rise building with raft foundation in Jakarta, Indonesia. The results of building settlements on OC Clay showed a significant 'early consolidation stage', where the consolidation settlement took place quickly at the early stage. Consolidation test results on OC Clays show that the 'early consolidation stage' reached 50%-70% of the final settlement. Investigation on monitoring of building settlements on some high-rise buildings in Jakarta after topping off shown 60%-70% from the final settlement. Therefore, the time rate of consolidation for OC Clays does not follow the time rate pattern recommended by Terzaghi. Burland et. al. (1977) had also indicated this phenomenon. This paper proposes a revised method to estimate the time rate of consolidation for OC Clay, by Tv Matching Curve Method. The determination of the Cv parameter using the Matching Curve Method is done by separating the 'early consolidation stage', and the Cv parameter obtained using trial-error of Cv value to the actual time vs settlement data after the 'early consolidation stage'. This method is promising for general practice in practicing the time rate of consolidation for OC Clays.

RÉSUMÉ : La détermination du coefficient de consolidation (Cv) qui peut être estimé à l'aide de la méthode d'ajustement du logarithme du temps de Casagrande ou de la méthode d'ajustement de la racine carrée du temps de Taylor. Cependant, les méthodes ne sont pas appropriées pour les argiles surconsolidées (argiles OC). Cette recherche est menée sur OC Clay sur la base des tests œdométriques et de la surveillance du tassement d'un immeuble de grande hauteur avec fondation en radier à Jakarta, en Indonésie. Les résultats de la construction de colonies sur OC Clay ont montré une 'étape de consolidation précoce' importante, où la colonisation de la consolidation a eu lieu rapidement au début. Les résultats des tests de consolidation sur OC Clays montrent que la 'phase de consolidation initiale' a atteint 50 % à 70 % du tassement final. Enquête sur la surveillance des implantations de bâtiments sur certains immeubles de grande hauteur à Jakarta après avoir complété 60 à 70 % par rapport au règlement final. Par conséquent, le taux temporel de consolidation pour OC Clays ne suit pas le modèle de taux temporel recommandé par Terzaghi. Burland et. Al. (1977) avaient également signalé ce phénomène. Cet article propose une méthode révisée pour estimer le taux temporel de consolidation pour OC Clay, par Tv Matching Curve Method. La détermination du paramètre Cv à l'aide de la méthode de la courbe d'appariement se fait en séparant la 'étape de consolidation précoce' et le paramètre Cv obtenu en utilisant l'erreur d'essai de la valeur Cv par rapport au temps réel par rapport aux données de règlement après la 'étape de consolidation précoce'. Cette méthode est prometteuse pour la pratique générale dans la pratique du taux de consolidation pour les OC Clays.

KEYWORDS: Over Consolidated Clay (OC Clay), Coefficient of Consolidation (Cv), Time Rate of Settlement

1 INTRODUCTION

Two main issues that are considered in the analysis of settlement of a high-rise building are the settlement value and time rate of the settlement that will occur. The estimation of the settlement value is relatively easier to determine based on the results of field test data or consolidation tests for NC Clay and OC Clay. However, the methods available for determining the time rate of consolidation settlement are limited to timing for NC Clay.

This paper discusses the time rate of consolidation on OC Clay soils based on laboratory test results and actual settlement measurement data in some high-rise buildings in Jakarta. This paper also proposes a method that can be used to estimate the coefficient of consolidation parameter in OC Clay.

The Oedometer Test is used to obtain the relationship between time and decrease in various pressures, assuming that all excess pore pressure is dissipated at each test load. The empirical procedure for determining the value of the coefficient of consolidation parameter (Cv) was developed by Casagrande (Logarithm of Time Fitting Method) and Taylor (Square Root of Time Fitting Method).

Both methods use the Tv (time factor) parameter by Terzaghi to determine the Cv parameter. The Tv parameter represents the time rate of settlement. Unfortunately, the Tv parameter is only suitable for NC Clay soil. This Tv parameter becomes unsuitable if it is used for OC Clay soil. The author(s) suspects that the Tv parameter is not suitable for OC Clay because there are differences in the excess pore pressure generated for NC Clay and OC Clay for the equal applied load.

2 PUBLICATIONS RELATED CONSOLIDATION CHARACTERISTICS OF OC CLAY

In 1957, Skempton and Bjerrum proposed μ value for clay soils which the μ value is the proportion of the consolidation settlement to the total settlement. The results of these studies indicate that OC Clay soils such as London Clay, Weald, Kimmeridge Oxford, and Lias Clays give μ values of 0.5 - 0.7. On heavy OC clays, the μ value is 0.2 - 0.5. The test results indicate that the immediate settlement that occurs is 30% -70% of the total settlement. Skempton and Bjerrum recommend that the immediate settlement must be calculated separately and then subtracted from the result of the total settlement calculation for stiff clays. Another study conducted by Burland, Broms, and de

Mello (1977) concluded that for deep layers of OC Clays, the immediate settlement is about 50% - 60% of the total settlement.

3 CONSOLIDATION CHARACTERISTICS OF OVER CONSOLIDATED CLAY IN JAKARTA

In general, soils in Jakarta consist of soft sedimentary soil on the top layer, medium-stiff clay below. Beneath the medium-stiff clay layer is a very dense sand lens. The layer under the dense sand is diluvium stiff clay with a depth range of 30m to more than 150m. The layer was formed in the tertiary period and it is over consolidated (OC Clays).

Most of the high-rise buildings in Jakarta use pile foundations and some of them use raft foundations. If the building base (with the basement) is in stiff clays or dense sands, raft foundation and raft-pile foundation are also used. The building settlement that occurs in Jakarta is dominated by compression of OC stiff clays under the dense sands. Hence, an understanding of the time rate of settlement behavior of the OC clays is needed.

This research is conducted at three (3) projects in Jakarta, namely the Jakarta International Stadium (JIS) in North Jakarta (Site A), BUMN Tower in Central Jakarta (Site B), and District 8 Tower in South Jakarta (Site C). The location of the projects can be seen in Figure 1.

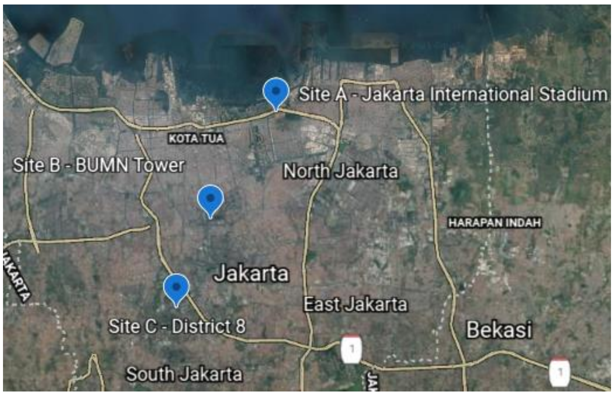
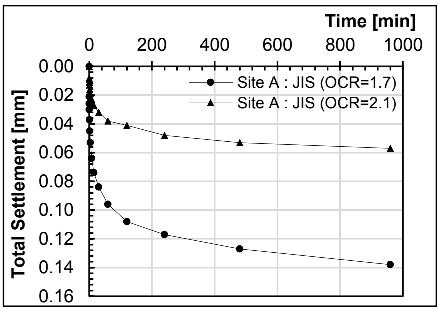
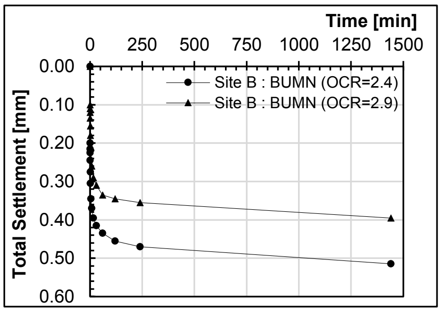


Figure 1. Project Locations

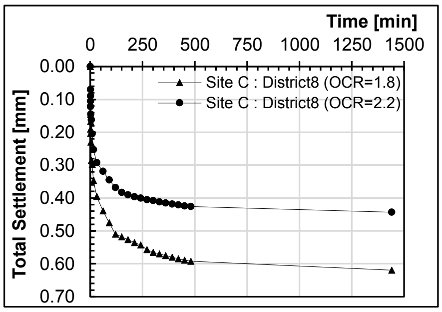
This research is conducted at three (3) projects in Jakarta, namely the Jakarta International Stadium (JIS) in North Jakarta (Site A), BUMN Tower in Central Jakarta (Site B), and District 8 Tower in South Jakarta (Site C). The location of the projects can be seen in Figure 1.



(a) Site A : JIS – North Jakarta



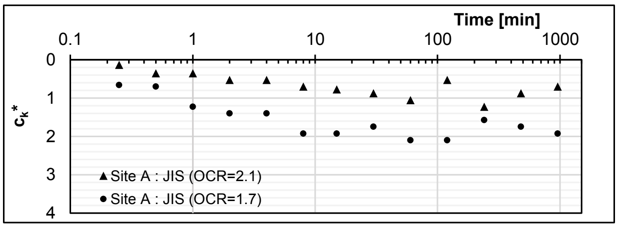
(b) Site B : BUMN Tower – Central Jakarta



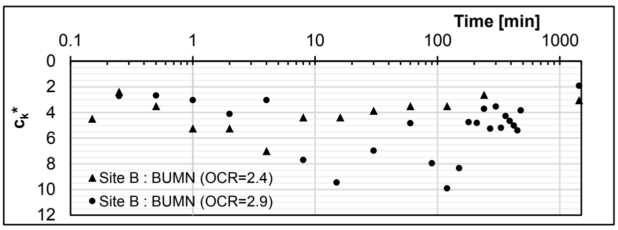
(c) Site C : District 8 Tower - South Jakarta

Figure 2. Oedometer test results

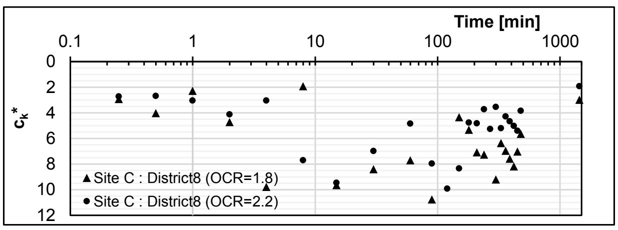
In general, many people develop one value of time rate of settlement for a certain applied load. The time rate of settlement varies for an applied load. This study proposes to take the gradient of the strain vs time (log scale) curve, with a parameter called c_k*. The c_k* represents the time rate of settlement, where this parameter varies with time for the same applied load.



(a) Site A : JIS – North Jakarta



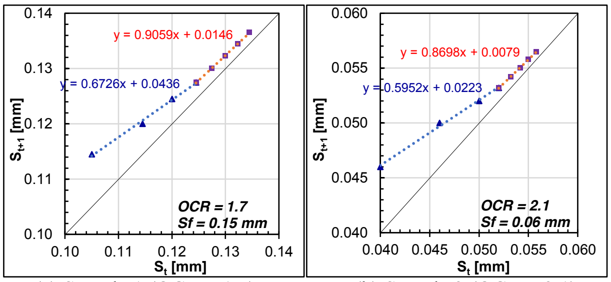
(b) Site B : BUMN Tower – Central Jakarta



(c) Site C : District 8 Tower - South Jakarta

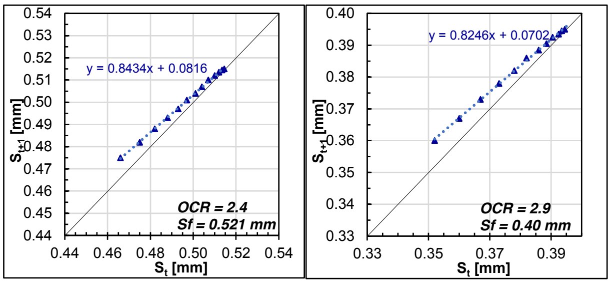
Figure 3. The c_k* parameter from $\Delta\varepsilon$ vs Δt

From each test result, the final settlement for each sample was interpreted using the Asaoka Method. This method is carried out by plotting the magnitude of St and St+Δt where Δt is a certain time range. The final settlement is obtained when the regression data intersect with the line at an angle of 45^0 or the value of St equal to St+Δt. Figure 4, Figure 5, and Figure 6 are the interpretation of the final settlement for each site.



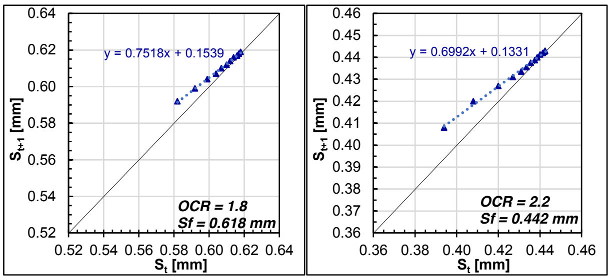
(a) Sample 1 (OCR = 1.7) (b) Sample 2 (OCR = 2.1)

Figure 4. Final settlement estimation from Oedometer Test for Site A : JIS – North Jakarta



(a) Sample 1 (OCR = 2.4) (b) Sample 2 (OCR = 2.9)

Figure 5. Final settlement estimation from Oedometer Test for Site B : BUMN Tower – Central Jakarta



(a) Sample 1 (OCR = 1.8) (b) Sample 2 (OCR = 2.2)

Figure 6. Final settlement estimation from Oedometer Test for Site C : District 8 Tower - South Jakarta

An interesting thing that is found that there are two data trend lines for Site A in North Jakarta. Edil, et. al. (1991) stated there is creep when the second trendline is stepper. Hence, the trendline is separated, where the first line (blue line) is the primary consolidation, and the second line (red line) is the secondary consolidation (creep). The creep is started before the primary consolidation ended.

Based on the test results above, it can be seen that there was a large settlement at the beginning of the test. One interesting thing is that the trend in OC Clays does not follow any of the Cv values for NC Clays, meanings that the Tv values used for NC Clays cannot be used for OC Clays. Figure 7 is an example of the matching curve for any Cv value on the results of the OC Clay soil consolidation test.

Based on the previous discussion, no Cv value produces a curved shape similar to the results of the Oedometer Test. Therefore, Terzaghi's assumption that the initial excess pressure is equal to the applied increment of stress (Δσ), does not appropriate for OC Clays.

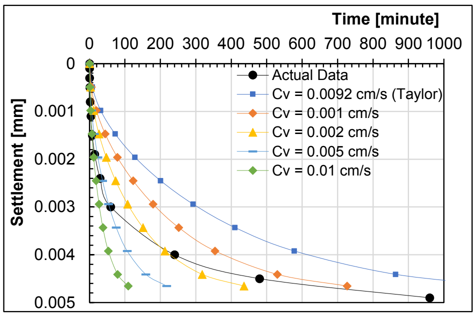


Figure 7. Settlement vs time for various Cv for Site A (OCR = 1.7)

4 PREDICTION OF LOADING MECHANISM ON OC CLAYS

The assumption in the one-dimensional consolidation theory by Terzaghi is that at the beginning of the load applied to saturated soil, the initial excess pressure is equal to the applied increment of stress (Δσ), where the entire load is carried by the water pressures at the beginning of the loading. However, the theory does not appropriate for OC Clays. In OC Clays, there is a proportion of the load carried by the contacts between the soil grains at the beginning of the loading and some proportion of load carried by the water pressures.

The initial effective stress from the soil grains causes the settlement to be very quick at the beginning of the loading. The large settlement at the beginning will be called as "early consolidation stage". The proportion of the load carried by the water pressure and the soil effective stress can be obtained from the Triaxial Test at the consolidation stage.

5 PROPOSED METHOD TO OBTAIN TIME RATE OF SETTLEMENT ON OC CLAYS FROM OEDOMETER TEST

In this study, a revised method is proposed which can be an alternative to obtain the time rate of settlement for OC Clay, named “Tv Matching Method”. The proposed method is explained by the following steps.

5.1 *Step 1 : Develop the Cv parameter from the Asaoka Method*

From the Asaoka Method, the β value can be obtained from the gradient of the trendline data. The β value represents the rate of settlement. The Cv parameter can be developed from the equation from Edil et. al. (1991) using Equation (1) and Equation (2).

$$\ln(\beta) = \frac{-6\, c_v\, \Delta t}{H^2} \quad \text{(for double drainage)} \tag{1}$$

$$\ln(\beta) = \frac{-2\, c_v\, \Delta t}{H^2} \quad \text{(for single drainage)} \tag{2}$$

For example, in Sample 1 for Site C, the equation using Asaoka Method is y = 0.7518 x + 0.1539. The β value (the line gradient) for this equation is 0.7518. Using Eq. (1), the Cv obtained is 2.86×10^{-5} cm²/s. The Cv value for each site can be seen in Table 1.

Table 1. The Cv parameter from Asaoka Method

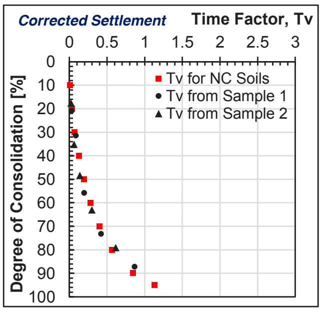
Site	Sample	β	*Cv [cm²/s]*
A	1	0.6726	3.98×10^{-5}
	2	0.5952	5.2×10^{-5}
B	1	0.8434	1.71×10^{-5}
	2	0.8246	1.93×10^{-5}
C	1	0.7518	2.86×10^{-5}
	2	0.6992	3.43×10^{-5}

5.2 *Step 2 : Back analysis of the Tv value, then plot the relationship of Tv to the degree of consolidation*

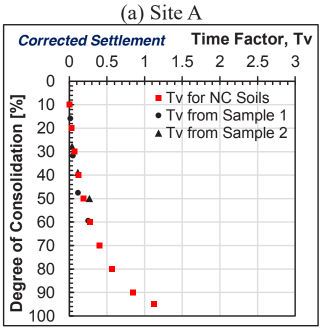
After the final settlement estimated (The Asaoka Method can be used), the degree of consolidation can be obtained. The time factor (Tv) can be calculated from the Cv value. Plot the Tv value and the degree of consolidation, then compare the curve with the trend for NC Clays.

However, the trend of Tv value to the degree of consolidation is not matched. Hence, correction data is needed to separate the "early consolidation stage" part by correcting the Tv vs %U relationship curve until the curve for NC Clays approach. Correction data is conducted by removing some initial settlement data until the Tv vs %U obtained near similar to Tv vs %U for NC Clay.

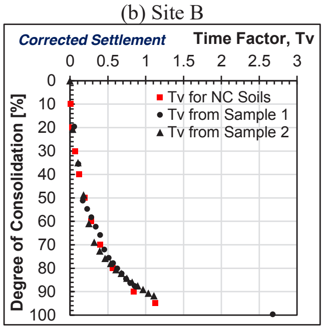
From the tests for each location, some initial data reading is removed until the Tv vs %U calculated "match" to Tv for NC soils, as can be seen in Figure 8.



(a) Site A



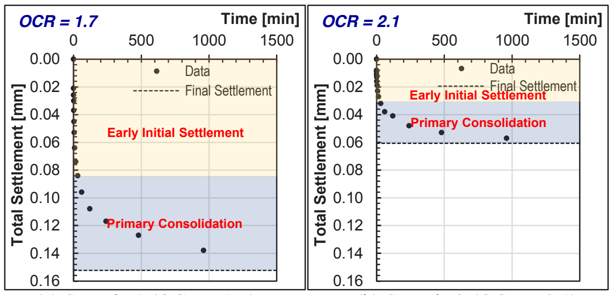
(b) Site B



(c) Site C

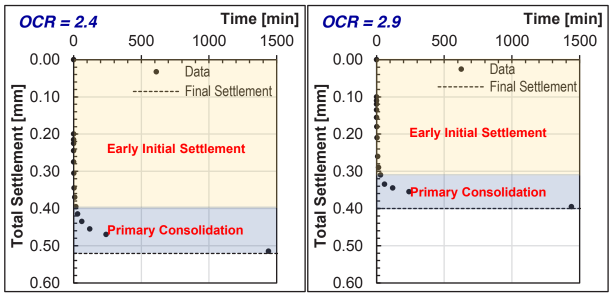
Figure 8. Relationship of Time Factor and The Degree of Consolidation for Corrected Settlement

After that, the removed data represent the "early initial settlement". The settlement after the "early initial settlement" is the primary consolidation settlement. The "early initial settlement" stage and the primary consolidation settlement stage can be seen in Figure 9, Figure 10, and Figure 11.



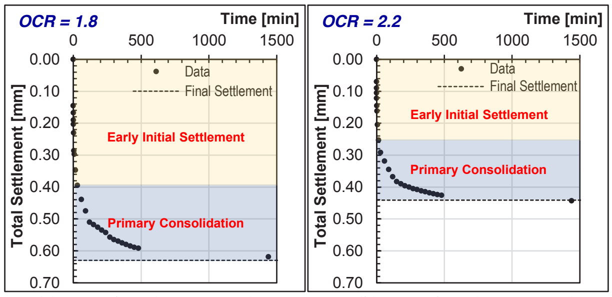
(a) Sample 1 (OCR = 1.7) (b) Sample 2 (OCR = 2.1)

Figure 9. The early initial settlement and the primary consolidation for Site A : JIS – North Jakarta



(a) Sample 1 (OCR = 2.4) (b) Sample 2 (OCR = 2.9)

Figure 10. The early initial settlement and the primary consolidation for Site B : BUMN Tower – Central Jakarta



(a) Sample 1 (OCR = 1.8) (b) Sample 2 (OCR = 2.2)

Figure 11. The early initial settlement and the primary consolidation for Site C : District 8 Tower - South Jakarta

Figure 12 shows the relationship between the OCR and the proportion of the early settlement to the final settlement from the samples. It is obtained that the early initial settlement varies from 57%-77% for OC Clays.

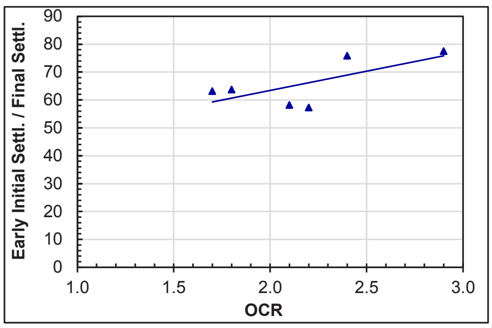


Figure 12. The proportion of early consolidation stage to final settlement

6 CASE STUDY : TIME RATE OF SETTLEMENT OF OC CLAYS ON HIGH-RISE BUILDING WITH RAFT FOUNDATION IN JAKARTA

District 8 Office Tower (Site C) is located in Senopati area, Central Jakarta as shown in Figure 13. This building consists of 55 floors and 4 basement floors. The foundation system is designed using a raft foundation with the thickness of the raft used is 4 m. The building is the highest building with a raft foundation in Indonesia until 2021.

Figure 13. District 8 Office Tower, South Jakarta (Site C)

6.1 *Soil Condition*

Soil investigations carried out at this location consist of drilling, Standard Penetration Test (SPT), Pressuremeter Test (PMT), and laboratory tests. The PMT has the advantage that it can be carried out quickly and is more representative than laboratory tests due to the disturbance of the sample and the difficulty of modeling the actual stresses. The PMT test was carried out at a depth of 10.5 m, 12.5 m, 18 m, and 29 m.

OCR values shown in Figure 14 from Oedometer and Pressuremeter testing show that the stiff clay layers are over-consolidated clay with the OCR value higher than 1.5. Some of the Oedometer Test data used are shown in Figure 2.(c). Based on the geological condition, the stiff clays under the sand layer are formed at the tertiary period.

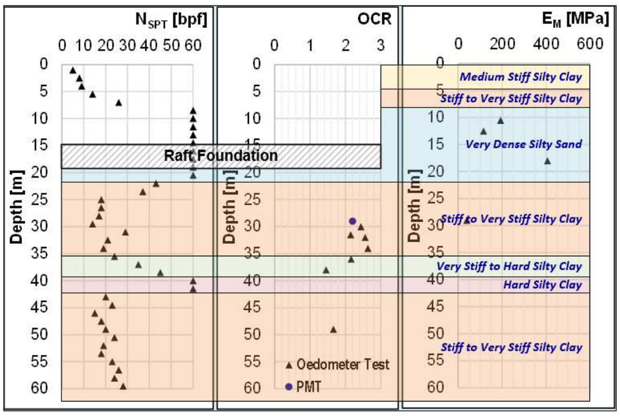


Figure 14. Soil Condition

6.2 *Actual Settlement Monitoring Data*

Settlement monitoring was conducted during construction. Figure 15 shows the actual building settlement monitoring data during construction until 7 months after topping-off.

The final settlement has been conducted using The Asaoka Method and the predicted final settlement is about 168 mm (refer Figure 16). The settlement when end-of construction is 102 mm. Hence, the degree of the early consolidation settlement is about 60.7%.

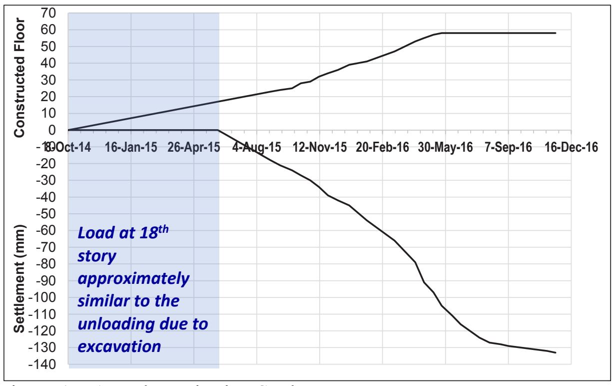


Figure 15. Actual Monitoring Settlement Data

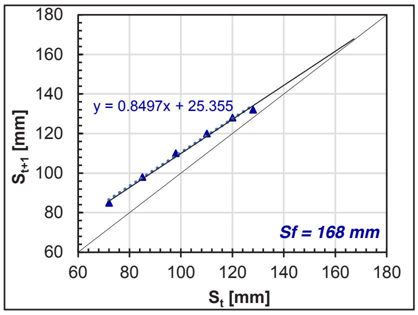


Figure 16. Prediction of Final Settlement

6.3 *Settlement Analysis using Finite Element Method*

Settlement analysis has been conducted using the 3D Finite Element Method. Soil layers are modeled using the Hardening Soil Model. The analysis is conducted by the following steps.

- Step 1 : Install the retaining wall and then excavate the soil layers until the bottom level of the raft foundation.
- Step 2 : Construct the raft foundation.
- Step 3 : Apply the load to follow the actual construction stage, then run the consolidation analysis until the excess pore pressure dissipated.

Figures 17 and 18 are the settlement value of the raft foundation at end-of-construction and the final settlement, respectively.

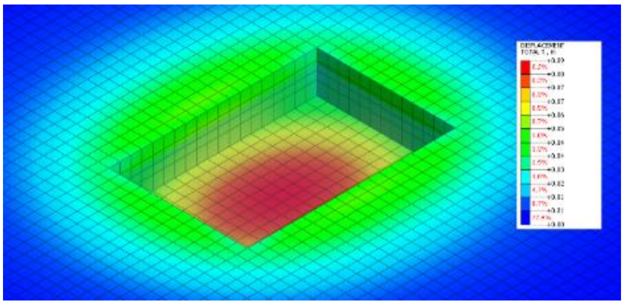


Figure 17. Settlement at end-of-construction from 3D Finite Element Method

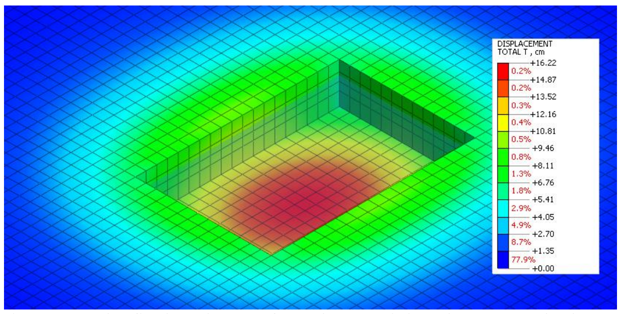


Figure 18. The final settlement from the 3D Finite Element Method

The maximum settlement at end-of construction from 3D FEM is about 94 mm and the final settlement is 162 mm. The degree of the early initial settlement is about 58%. The actual settlement at the final stage is 168 mm. Hence, it is clear that the early initial settlement is relatively high for OC Clay.

7 CONCLUSIONS

Determination of the time rate of settlement is the main problem in Over Consolidated Clays (OC Clays). Various consolidation test results in the laboratory with the Oedometer Test in Jakarta showed that saturated OC Clays has a large settlement at the beginning of the test (then referred to as "the early consolidation stage”), then the settlement is time-dependent. Determination of the Cv value with some conventional methods does not provide a trend curve that is close to the results of the consolidation test on OC Clays.

This study proposes a revised method to determine the time rate of settlement on saturated OC Clays. The method namely “Tv Matching Method”. First, determine the Cv parameter using the Asaoka Method for the last few data readings. Execute a back-analysis to obtain a plot of the relationship between Tv and %U. Correction the data by reducing some data at the beginning of the test until the Tv against %U curve obtained is close to the curve for NC Clays. Separate the initial settlement as “the early consolidation stage” which is the time-independent settlement.

The proposed method is carried out on some samples at 3 locations (North Jakarta, Central Jakarta, and South Jakarta) with various OCR and gave consistent results. The proportion of the early settlement to the final settlement from the samples and shows that the early initial settlement varies from 57%-77% for various OCR values.

In addition, a case study was conducted for a high-rise building (55 floors + 4 basement) with a raft foundation in South Jakarta. The raft foundation is seated on OC Clays which the OCR is obtained from The Oedometer Test and The Pressuremeter Test. The actual settlement monitoring data record shows that the degree of the early consolidation settlement is about 60.7% of the final settlement. Numerical modeling using the 3D Finite Element Method shows that the settlement at end-of-construction is 58% of the final settlement.

Therefore, the laboratory tests, the settlement monitoring data, and the numerical simulation show that there is “early initial settlement”, which resembles immediate settlement, are relatively high for OC Clay.

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