Consolidation Coefficient in Horizontal Direction (C_h) Determined from Field Settlement Data By Using Terzaghi, Asaoka, and Finite Element Methods

Case Study: Reclamation for Container Yard at Kuala Tanjung, Medan, North Sumatera

Yudhi Lastiasih[1], Noor Endah Mochtar[2], Farah Nasya[3]

[1]Lecturer of Civil Engineering, FTSP, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.
[2]Professor of Civil Engineering, FTSP, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.
[3] Undergraduate Student of Civil Engineering, FTSP, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

[*]*Corresponding author:* yudhi.lastiasih@gmail.com, noormochtar@gmail.com

Abstract - **In order to predict the consolidation period in the field, consolidation coefficient in vertical direction (C_v) parameter is needed. When vertical drains installed in the compressible layer in order to shortened the consolidation period, it needs consolidation coefficient in horizontal direction (C_h). This C_h parameter has to be determined from the field settlement that usually obtained from the trial embankment. However, it is very expensive to carry out the trial embankment; therefore, it is usually assumed to be 2 till 5xC_v. In this paper, the assumption of the C_h value will be proven by using field settlement data taken from the trial embankment at the reclamation area for container yard at Kuala Tanjung, Medan, By choosing the C_h value, the compression vs time curves were predicted by adopting the Terzaghi, Asaoka, and Finite Element methods. Afterwards, these predicted settlement curves were plotted with the field settlement curves; from this plotting, it could be figured out the predicted curves which has C_h value the same with the field C_h value. The results show that from three methods adopted in this study, only the Terzaghi and the Asaoka methods give satisfactory results in settlement prediction. Consequently, only the Terzaghi and Asaoka methods are adopted to determine the C_h value. The C_h value obtained is about the same, that is 3C_v until 5C_v. When that C_h value used back to predict the settlement, the Asaoka method gives better result than the Terzaghi method.**

Keywords—Asaoka method, consolidation coefficient C_h, finite element method, Terzaghi method, trial embankment

I. INTRODUCTION

Consolidation settlement is a common problem found when embankment is built on very soft to soft clay soil. It takes place in very long period of time due to permeability coefficient of the clay soil is very small. Therefore, method to accelerate the consolidation process has been developed. One of the common method is preloading combined with vertical drain. The common material used for vertical drain is prefabricated vertical drain (PVD). By installing the PVD, the excess pore water pressure will flow out in vertical and horizontal directions. For this purpose, it needs coefficient consolidation in vertical direction (C_v) and horizontal direction (C_h).

The value of C_h has to be determined from the field settlement that is usually obtained from the trial embankment. However, it is very expensive to carry out the trial embankment; therefore, it is usually assumed to be 2xC_v until 5xC_v. In this paper, the C_h value will be determined from settlement field data taken from the trial embankment at the reclamation area for container yard at Kuala Tanjung, Medan, North Sumatera. The methods adopted to determine the C_h value were Terzaghi [1], Asaoka [2], and Finite Element [3] methods. From this study, it will be known the exact value of C_h and the best method to determine it.

II. TERZAGHI, ASAOKA, AND FINITE ELEMENT METHODS

A. *Terzaghi Method*

Terzaghi formula to predict the consolidation settlement in the field has been popularly known since 1925. The existing formula has to be slightly modified if the embankment placed step by step. If load placed each step is Δp, the effective overburden stress is p_o', and the pre consolidation stress is p_c' (as shown in Figure 1) the consolidation formula [4] is

1. For $[p'_o + \Delta p_1] \le p_c'$

$$Sc = \frac{Cs}{1+e_0}\left[H \log\left(\frac{p'o + \Delta p_1}{p'o}\right)\right] \quad (1)$$

2. For $[p'_o + \Delta p_1 + \Delta p_2] > p_c'$ (see Figure 1)

$$Sc = \frac{Cs}{1+e_0} H \log \frac{p'_c}{p'_0 + \Delta p_1} + \frac{C_c}{1+e_0} H \log\left(\frac{p'_0 + \Delta p_1 + \Delta p_2}{p'_c}\right) \quad (2)$$

3. For $[p'_o + \Delta p_1 + \Delta p_2 + \Delta p_3] > p_c'$ (see Figure 1)

$$Sc = \frac{Cc}{1+e_0}\left[H \log\left(\frac{p'o+\Delta p_1+\Delta p_2+\Delta p_3}{p'o+\Delta p_1+\Delta p_2}\right)\right] \quad (3)$$

where:

C_c = compression index

C_s = swelling index

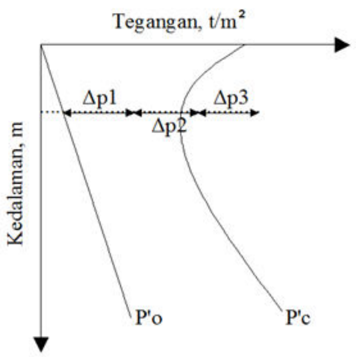

Figure1. Diagram of the overburden stress (p_o'), pre consolidation stress (p_c'), and step loading (Δp).

If PVD is installed to accelerate the consolidation period, the formula to calculate the degree of consolidation caused by excess pore water flows into the PVD (U_h) [5] is:

$$U_h = 1 - \left[\frac{1}{e^{\left[\frac{1x8x0,2654}{157,5^2 x2x2,122}\right]}}\right] \quad (4)$$

B. *Asaoka Method*

For Asaoka Method, settlement data from the trial embankment are plotted as shown in Figure 2. By taking the same time interval, Δt, the settlement ρ_1, ρ_2, ρ_3, ..., ρ_n can be determined. The values of ρ_n and ρ_{n-1}, then plotted in Y-axis and X-axis, respectively, as shown Figure 3. From the data plotted, it is constructed a straight line that intersect the Y-axis at β_0. This straight line is also intersect the line which make angle of 45° ($\rho_n = \rho_{n-1}$) at ρ_f; where ρ_f is the final settlement. From the values of ρ_f and β_0, the angle of the constructed straight line β1 can be determined:

$$\beta 1 = \frac{\rho f - \beta 0}{\rho f} \quad (5)$$

By adopting the Hausmann theory [6], the value of C_h can be determined as follows:

$$\frac{-\ln \beta 1}{\Delta t} = \frac{8Ch}{d^2 F(n)} + \frac{\pi^2 Cv}{4H^2} \quad (6)$$

where:

C_v : consolidation coefficient in vertical direction;

H : the compressible soil layer thickness

β_1 : slope of the straight line (Equation [5])

Δt : time interval

C_h : consolidation coefficient in horizontal direction

d_e : diameter of area influence by one PVD

F(n) : restriction factor due to spacing of PVD

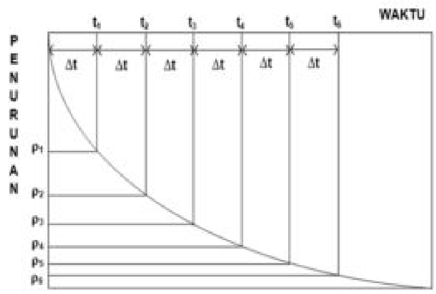

Figure 2. Plotting of field settlement data and example to determine the values of ρ_1, ρ_2, ρ_3, ..., ρ_n for the same time interval Δt.

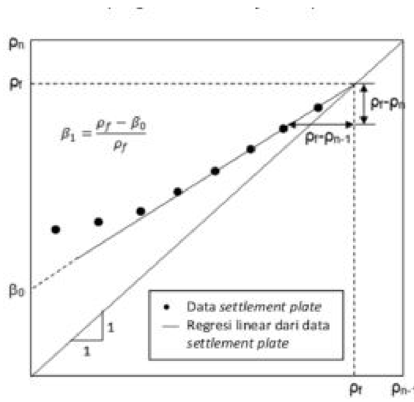

Figure 3. Prediction of final consolidation settlement using Asaoka method

C. *Finite Element Method*

In this method, the settlement is predicted by using the Finite Element Method (FEM). Soil parameters adopted in FEM model: Young modulus (E) and Poisson's Ratio (μ) were taken from Bowles [7] based on the soil type; the other soil data were determined in soil laboratory. In order to predict the consolidation magnitude using FEM, soil model is constructed as the real condition in the field and the soil displacement determined is as shown in Figure 4.

III. LABORATORY AND FIELD DATA

Case study presented in this paper is the reclamation area for container yard at Kuala Tanjung, Medan. The soil data were determined from laboratory and collected from trial embankment taken from the field. The Standard Penetration Test (SPT) data and soil samples were taken from bore holes BH-1 and BH-2. The SPT data as shown

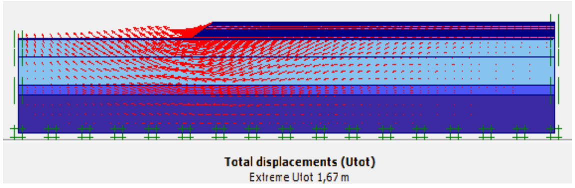

Figure 4. Soil displacement at SP-01 determined using the Finite Element Method (FEM)

in Figure 5 and other soil data are tabulated in Table 1. Soil data of embankment materials are given in Table 2.

From Figure 5, it is seen that thickness of soft soil layer ($N_{SPT} < 10$) is about 15 meters. The data from Table 1 where the samples taken until 15.0 meters depth confirmed that the soil is soft cohesive soil. Soil for the trial embankment is c-φ soil, as shown in Table 2. For the trial embankment, soil was placed layer by layer; thickness of each layer was 50.0 cm. Settlement data taken for this study were from SP-01 and SP-05. The embankment height was 5.0 meters at SP-01 and 4.8 meters at SP-05. The loading schedule and settlement data plotting from SP-01 and SP-05 are shown in Figures 6 and 7, respectively. From those figures, it can be figured out that the final height of embankment reached at 20 weeks and the settlement becomes constant when the preloading is already applied about 39 weeks. At t= 336 days (48 weeks) the total settlement at SP-01 was 1.770 meters and 1.493 meters at SP-05.

Table 1. Soil Parameters from BH-1 and BH-2

Soil Parameters	Unit	Values 0.0 to -6.0 Depth	-6.0 to -15.0 Depth
Specific gravity		2.607	2.607
Moist unit weight	ton/m^3	1.482	1.482
Saturated unit weight	ton/m^3	1.548	1.548
Liquid limit	%	58.650	56.902
Plasticity index	%	24.840	12.982
Water content	%	58.340	43.840
Void ratio		1.79	1.53
Compression index		0.96	0.77
Consolidation coefficient	cm^2/s	0.0980	0.0010
Young modulus	ton/m^2	500	1000
Poisson ratio		0.2	0.2
Permeability coefficient in x-direct	m/s	3.80E-04	2.00E-04
Permeability coefficient in y-direct	m/s	3.80E-04	2.00E-04
Cohesion	ton/m^2	1.9	13
ϕ	^{0}	0	0
ψ	^{0}	0	0

Table 2. Data of Embankment Soil

Soil Parameters	Unit	Value
γ_t	ton/m^3	1.850
γ_{sat}	ton/m^3	1.850
E	ton/m^2	25000
ν		0.4
c	ton/m^2	1
ϕ	^{0}	30
ψ	^{0}	0

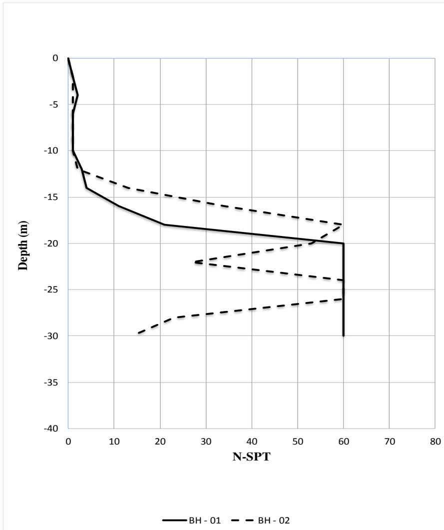

Figure 5. SPT data of soil from BH-1 and BH-2

IV. PREDICTION OF THE CONSOLIDATION MAGNITUDE BY USING TERZAGHI, ASAOKA, AND FINITE ELEMEN METHODS

As mention previously that the settlement data of trial embankment studied were from SP-01 and SP-05. Therefore, the settlement prediction was carried out for SP-01 and SP-05 by adopting the soil data from Table 1 and Table 2. By using the Terzaghi, Asaoka, and Finite Element methods, the prediction consolidation settlement magnitudes for t=48 weeks are presented in Table 3.

Table 3. Field Settlement Data and Settlement Prediction at SP-01 and SP-05 for t = 336 days (48 weeks)

Methods to Predict	Settlement Prediction (meter) for C_h= $4C_v$. SP-01	SP-05
Terzaghi	1.687	1.626
Asaoka	1.776	1.518
Finite Element	1.576	1.415
	Field Settlement Data (meter)	
	SP-01	SP-05
Settlement Plate	1.770	1.493

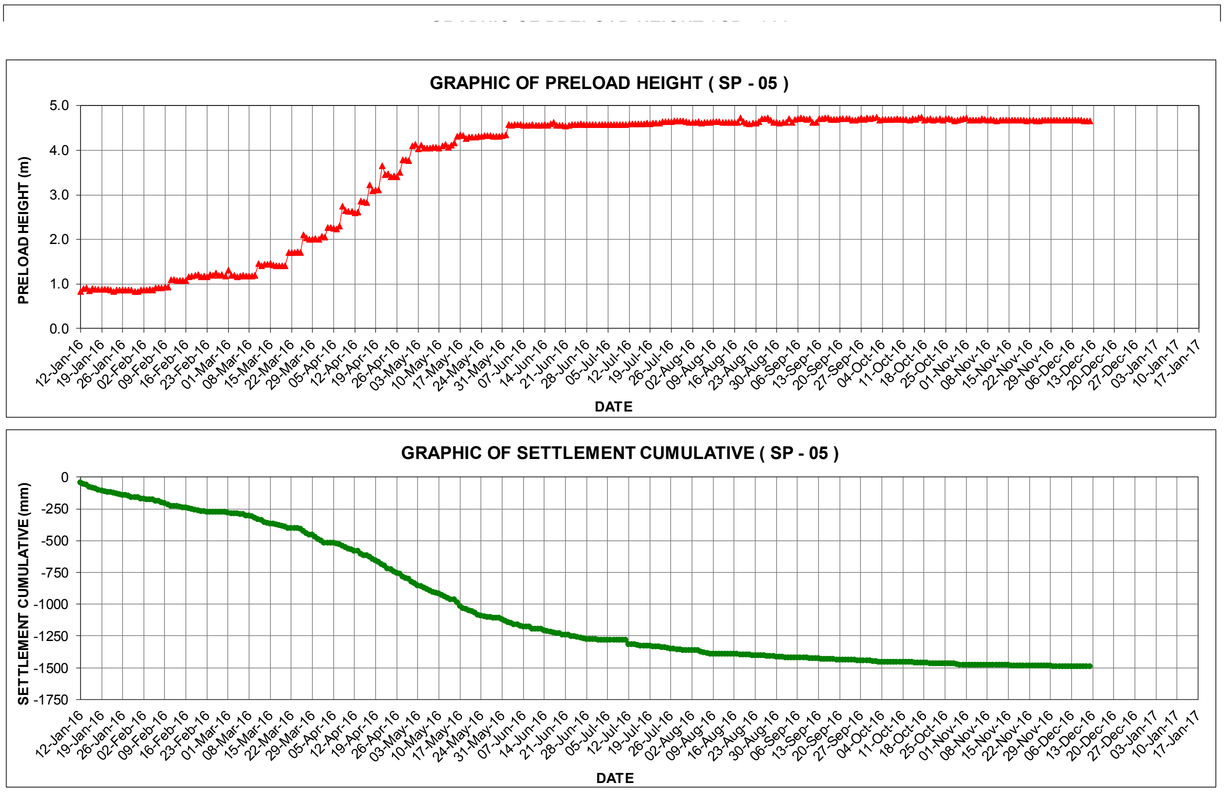

Figure 7. Step loading and settlement data from settlement plate SP-5 (for t = 48 weeks)

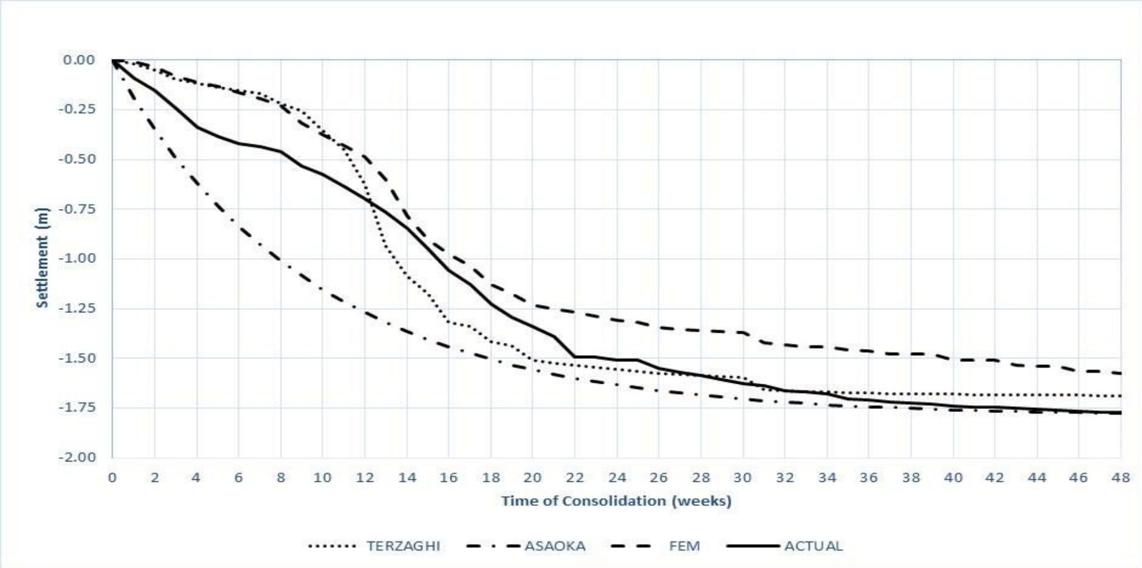

Figure 8. Soil settlement predicted using the Terzaghi, Asoka, and Finite Element methods with $C_h = 4xC_v$ and field settlement data taken from SP-01

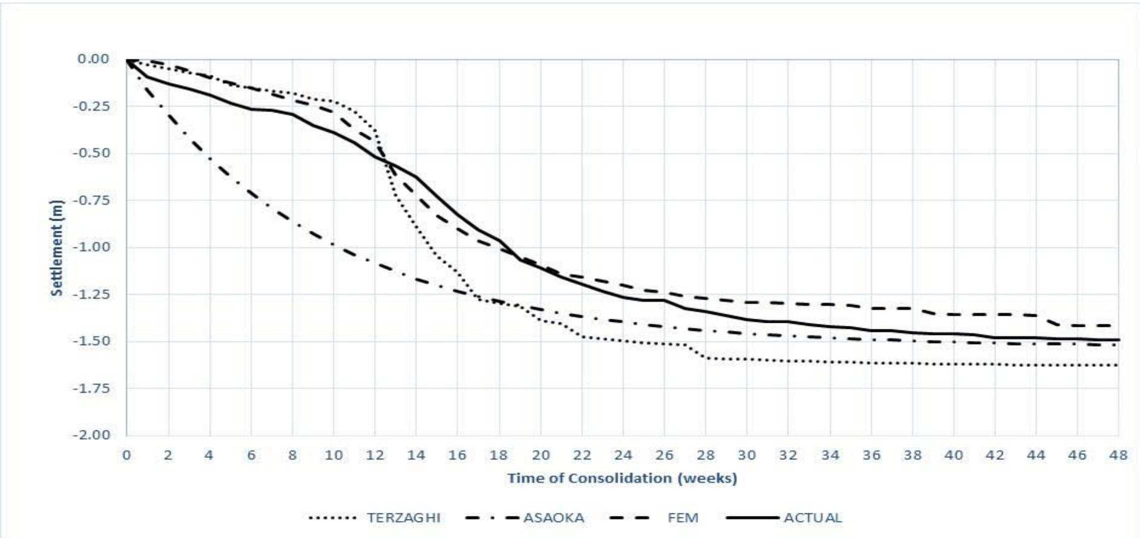

Figure 9. Soil settlement predicted using the Terzaghi, Asoka, and Finite Element methods with $C_h = 4xC_v$ and field settlement data taken from SP-05

From the settlement data shown in Table 3, the settlement at t=48 weeks of SP-01 is bigger than that of SP-05 although thickness of the compressible layer and the soil data at SP-01 and SP-05 are the same. This condition could be due to the embankment height of SP-05 is 20cm lower than that of SP-01 and could be there are incompressible lenses in SP-05.

In order to see which of Terzaghi, Asaoka, and Finite Element methods that give better result in settlement prediction, the settlement is predicted by assuming that $C_h = 4xC_v$ and then plotted as shown in Figures 8 and 9. The settlement curves show that the curves predicted using Asaoka method gives better prediction compared to the other two methods. At the beginning of the loading period, however, it gives much bigger prediction settlement than the others; it is because the settlement prediction is determined by using the field data where the load is already constant or the final load. The Terzaghi method gives smaller settlement prediction in SP-01 but it gives bigger prediction in SP-05. It is due to the settlement prediction is based on the assumption that the compressible layer is 15 meters by neglecting the existing of incompressible lenses. The finite element method, however, does not give any good prediction results in SP-01 and SP-05. It could be because the soil parameters, Young Modulus (E) and Poisson's Ratio (μ), are based on the assumption. Because of that the accuracy of settlement prediction using the finite element method is really depending on the soil parameter assumed.

V. DETERMINATION OF C_h VALUE BY USING TERZAGHI, ASAOKA, AND FINITE ELEMEN METHODS

In order to determine the value of consolidation coefficient in horizontal direction (C_h) using the three methods, Terzaghi, Asaoka, and Finite Element methods, the settlements are predicted using different C_h values ($C_h = 2C_v$; $C_h=3C_v$; $C_h = 3.5C_v$; $C_h = 4C_v$; and $C_h = 5C_v$). Those settlement curves are then plotted as shown in Figures 10 (SP-01) and Figure 11 (SP-05) for Terzaghi method; Figure 12 (SP-01) and Figure 13 (SP-05) for Asaoka method; and Figure 14 (SP-01) and Figure 15 (SP-05) for Finite Element method.

prediction for SP-05 is not used to determine the C_h value.

From this settlement prediction curves (Figure 10), it can be concluded that by using the Terzaghi method, the C_h value that gives a good result in settlement prediction is equal to $3C_v$ until $5C_v$.

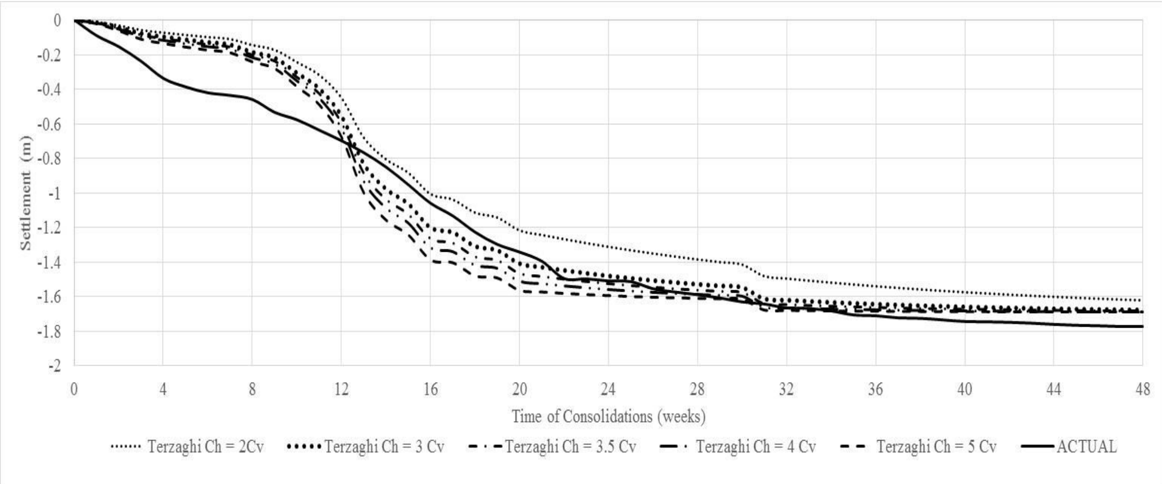

Figure 10. Plotting of settlement predicted using the Terzaghi method with different C_h values and field settlement taken from SP-01

A. The Terzaghi Method

Figures 10 and 11 show that curves of the settlement prediction using the Terzaghi method are close to each other except for $C_h = 2C_v$. At loading period reaches 28 weeks, all of the settlement predictions for SP-01 are slightly smaller than the field settlement. On the other hand, the settlement prediction for SP-05 (Figure 11) is always bigger than the field settlement. It could be due to (as mention previously) the incompressible lenses occurred in the SP-05. Because of that, the settlement

B. The Asaoka Method

The settlement prediction using the Asaoka method (Figures 12 and 13) shows better results than that using the Terzaghi method although the settlement prediction at SP-01 is still slightly better than that at SP-05, as the Terzaghi method. The settlement prediction gives a good result for all C_h values except for $C_h=2C_v$.

From this settlement prediction curves (Figure 12), it can be concluded that by using the Asaoka method, the C_h value that gives a good result in settlement prediction is equal to $3C_v$ until $5C_v$.

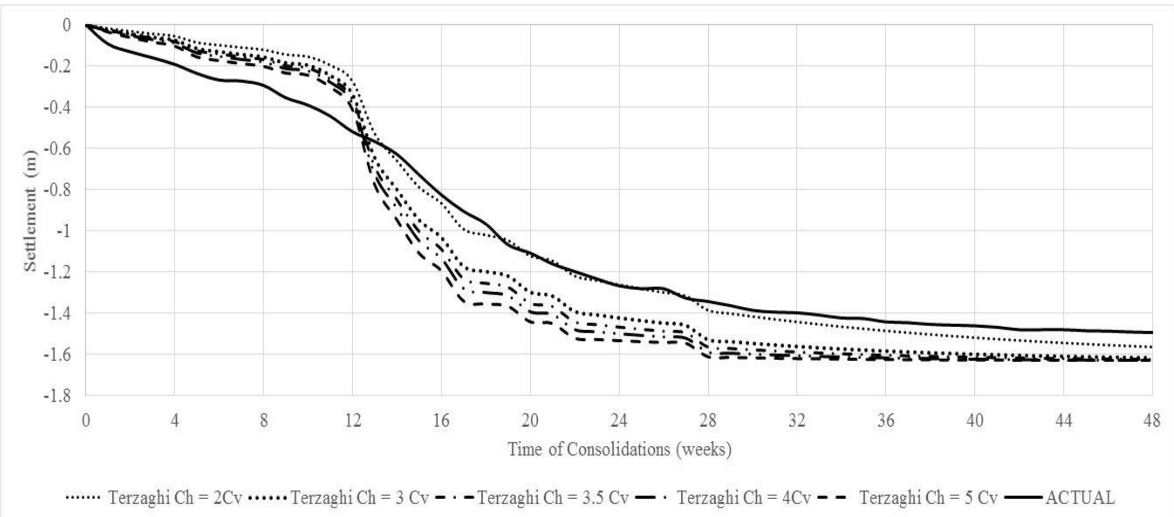

Figure 11. Plotting of settlement predicted using the Terzaghi method with different C_h values and field settlement taken from SP-05

C. The Finite Element Method (FEM)

In this study, the FEM does not give a good results in predicting the settlement, as shown in Figures 14 and 15. All of the settlement prediction curves plotted above the field settlement curve. As mention previously that the accuracy of settlement prediction using the finite element method is really depending on the soil parameter assumed. Because of that the FEM is not used to determine the C_h value in this study; otherwise the soil parameters have to be changed.

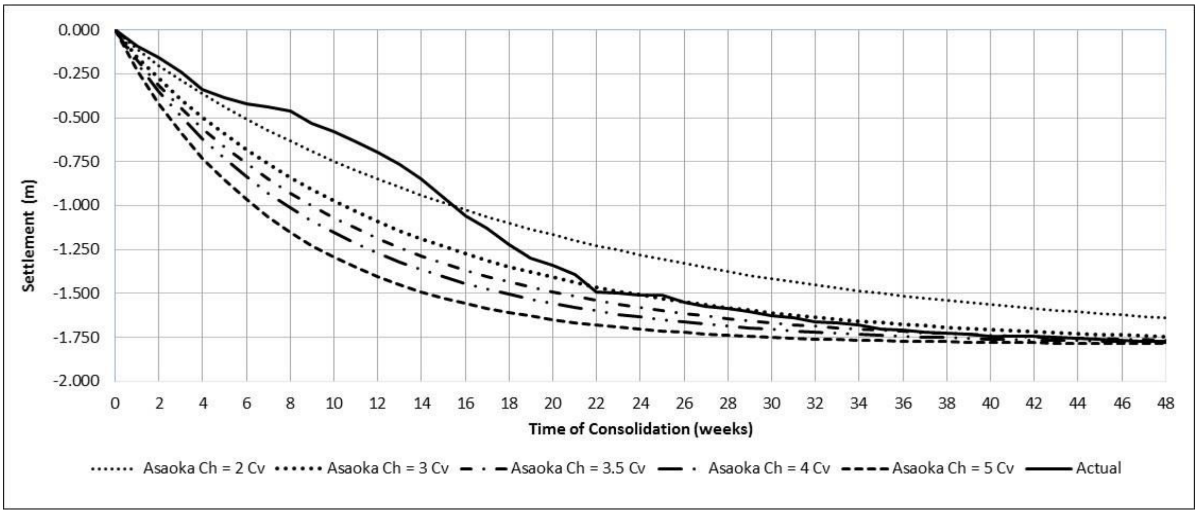

Figure 12. Plotting of settlement predicted using the Asaoka method with different C_h values and field settlement taken from SP-01

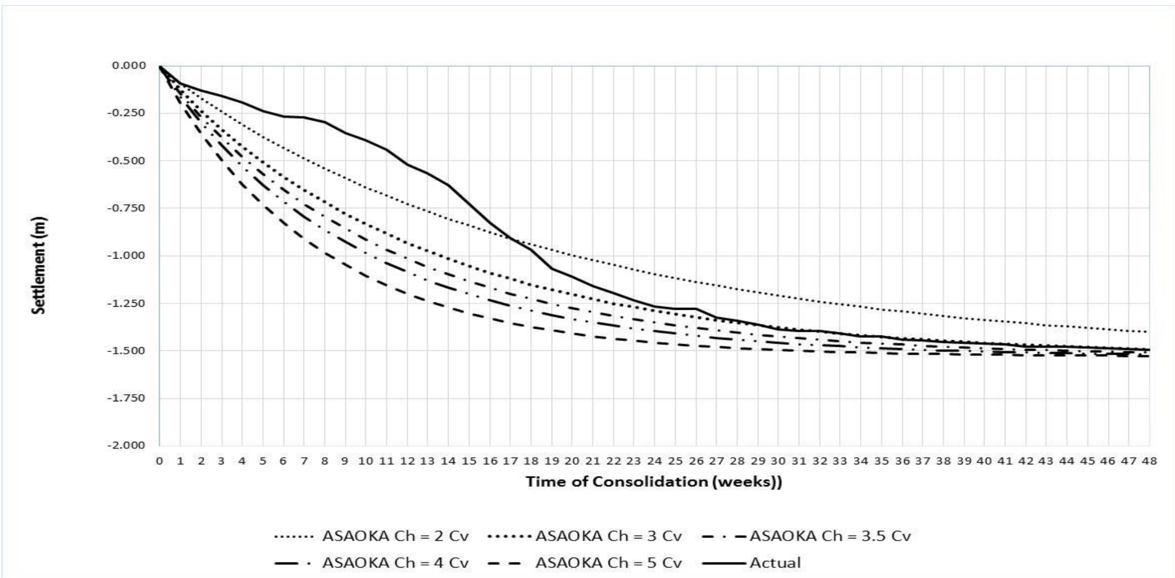

Figure 13. Plotting of settlement predicted using the Asaoka method with different C_h values and field settlement taken from SP-05

VI. CONCLUSSIONS

From the data and analysis presented above, it can be concluded as follows:

1. Thickness of the soft soil layer (N_{SPT} < 10) in the study area, container yard at Kuala Tanjung, Medan, Indonesia, is about 15 meters; soil for the trial embankment is c-φ soil.
2. The embankment height was 5.0 meters at SP-01 and 4.8 meters at SP-05; the soil of embankment was placed layer by layer where thickness of each layer was 50 cm; the final height of embankment reached at 20 weeks.
3. The total settlement in 336 days (48 weeks) at SP-01 is 1.770 meters and 1.493 meters at SP-05; the settlement becomes constant when the preloading was applied about 39 weeks.
4. The Terzaghi and the Asaoka methods give a good results in predicting the soil settlement; the Finite Element method, however, does not give a good result in settlement prediction.
5. The C_h value obtained from the Terzaghi and the Asaoka methods is about the same, that is $3C_v$ until $5C_v$; the Finite Element method is not adopted to determine the Ch value.
6. Using the C_h value obtained, the Asaoka method gives better result in predicting the settlement compared to the Terzaghi method.

REFERENCE

[1] K. Terzaghi, *Theoretical Soil Mechanics*. New York: Wiley & Sons, 1943.
[2] A. Asaoka, “Observational Procedure of Settlement Prediction. Soil and Foundations.”
[3] H. Nawir, “Prediksi Penurunan Tanah Menggunakan

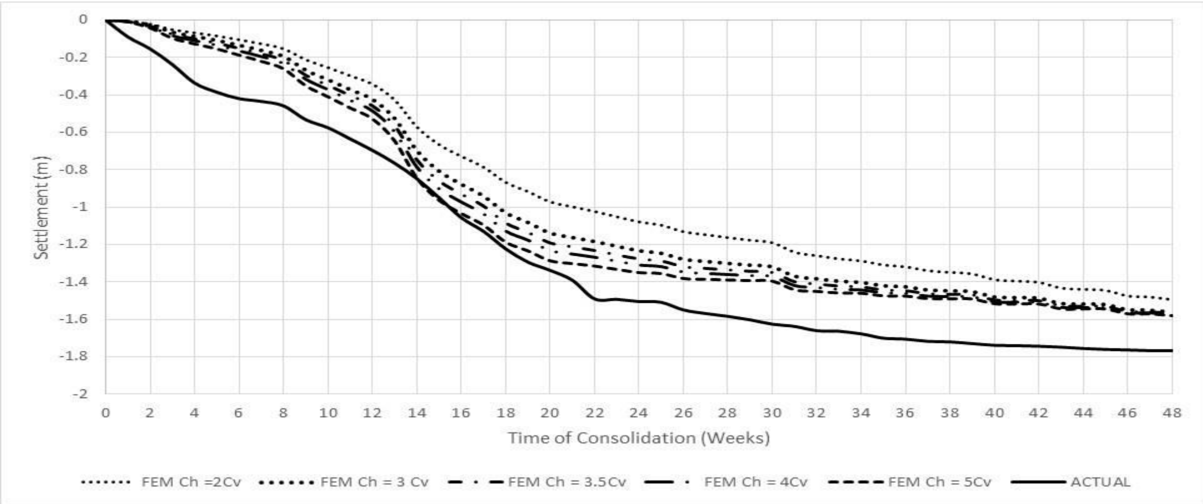

Figure 14. Plotting of settlement predicted using the Finite Element method with different C_h values and field settlement taken from SP-01

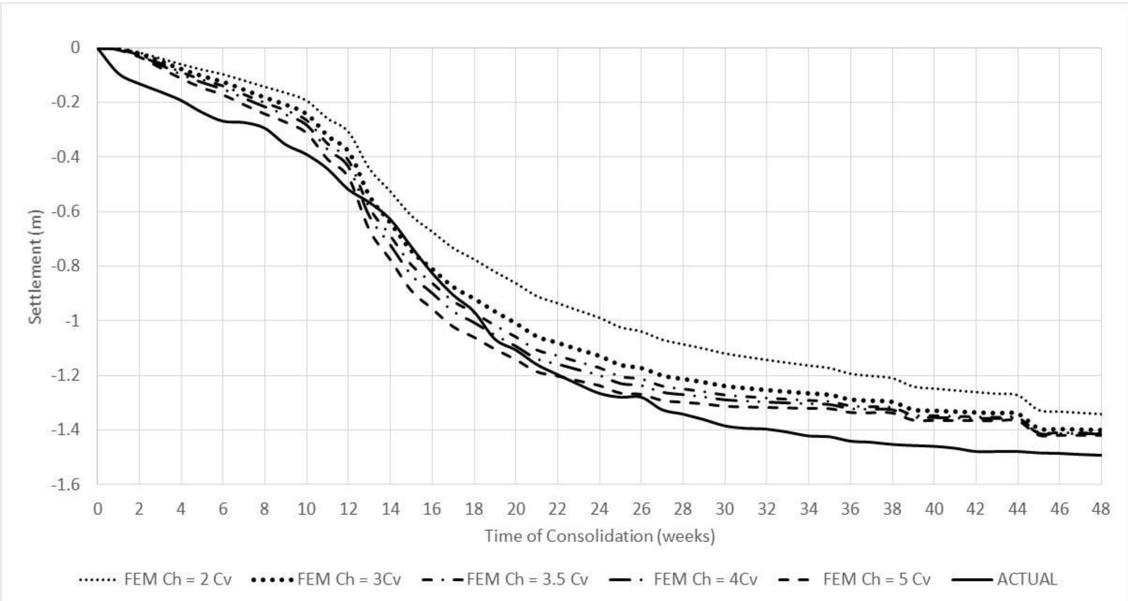

Figure 15. Plotting of settlement predicted using the Finite Element method with different C_h values and field settlement taken from SP-05

Prosedur Observasi Asaoka Studi Kasus: Timbunan di

Bontang, Kalimantan Timur," *J. Teor. dan Terap. Bid. Rekayasa Sipil*, 2012.

[4] N. E. Mochtar, "Modul Ajar Metode Perbaikan Tanah," *Jur. Tek. Sipil*, 2012.

[5] S. Hansbo, "Consolidation of Clay by Band Shaped Prefabricated Drains," *Gr. Eng.*, no. 5, pp. 16–25, 1979.

[6] M. . Hausmann, *Engineering Principles of Ground Modification*. McGraw-Hill, 1990.

[7] J. E. Bowles, *Foundation Analysis and Design*, 5th ed. 1977.