HWYL Method for Predicting Settlement of Soft Soil

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ABSTRACT: The HWYL method is one of the analytical methods for predicting the amplitude and time of settlement that occurs, based on the field observations using a settlement plate or extensometer. The data used for the analysis was the result of observations from a settlement monitoring instrument of some road embankment and reclamation projects on soft soil in Indonesia. The data was analyzed using a statistical approach to determine the behavior and correlation of settlement amplitude versus time curve shape. This method obtains an equation formula to predict the consolidation amplitude and when the final settlement of last embankment occurred
Keywords: Consolidation settlement, settlement instrument monitoring, soft soil.

1. INTRODUCTION

In the implementation of embankment work, especially on a layer of soft soil, for either embankment roads or coastal reclamation, problems frequently arise with landslides (puncture, sliding) and the immediate and consolidation settlements (Si + Sc). The total settlement can be predicted from Terzaghi equation. However, the question related with the amplitude of the actual final settlement and time of settlement often arises. The amplitude of the final settlement can be determined in the field using a soil-monitoring instrument during construction, such as a settlement plate or extensometer. Observations of the actual result of filling are presented in the form of the settlement magnitude as a function of time, according to the stages of implementation elevation.
Before the final settlement is completed, there are several methods for predicting its amplitude and the actual time remaining until settlement. These utilize the results of settlement versus time curves, such as the Asaoka graphic method (Asaoka, 1979), hyperbolic method (Tan,1992), the Chunlin method (Li, 2014) and others. Geotechnical engineers in the field often use the Asaoka method and find the results of the analysis to be quite valid. Against Asaoka's method that settlement should have already finished , in fact in some cases it is still goes on, although relatively small.

In this study, an attempt is made to obtain a new non-graphic method, as an alternative and enriched method of settlement monitoring. The purpose is to simplify the calculation process and generate more accurate results. The proposed HWYL (Herman Wahyudi Yudhi Lastiasih) method is valid only for layers of soft soil conditions.

2. RECENT METHOD FOR PREDICTING OF FINAL SETTLEMENT

2.1 ASAOKA METHOD

For Asaoka Method, settlement data from the trial embankment is plotted as shown in Figure 1. By taking the same time interval, Δt, the settlement S_1, S_2, S_3, ..., S_i can be determined. The values of S_i and S_{i+1}, then plotted in X-axis and Y-axis, respectively, as it is shown in Figure 1. 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 creates angle of 45° ($S_i = S_{i+1}$) at S_f, where S_f is the final settlement. The settlement at time (t) can be calcukated with Eq.1.

$$S(t) = \frac{\beta_0}{1-\beta_1} - \left(\frac{\beta_0}{1-\beta_1} - S_0\right)\beta_1^{\,t} \tag{1}$$

Where, So is settlement at initial time, and β_1 can be calcultaed with Eq.2

$$\beta_1 = \frac{S_f - \beta_0}{S_f} \tag{2}$$

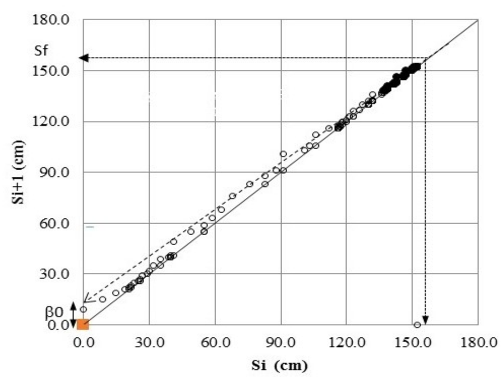

Figure 1 Prediction of final consolidation settlement at the reclamation project using Asaoka method (TGU, 2016)

2.2. CHUN LIN METHOD

Chunlin method is a combination of Terzaghi's 1D method and Asaoka method. Based on the loading stage in the field, the settlement can be calculated by using the Terzaghi's 1D equation. The Chunlin method (Li, 2014) uses Eq.3 to calculate the settlement occurring at certain time.

$$S_t = S_\infty\left(1 - \frac{8}{\pi^2}e^{bt}\right) \tag{3}$$

Where S_∞ is the final settlement from Terzaghi 1D consolidation equation, S_t is the settlement at time t and b is a coeeficient. Parameter b can be determined from the slope of straight line from relationship between $\ln\left[S_p\pi^2 \big/ (8S_\infty)\right]$ and t.

Where S_p is potential settlement that obtained from the settlement plate result.

3. HWYL NEW METHOD

The HWYL method proposed in this study is based on a statistical approach to settlement versus time curves. The curves are taken from observations of settlement plates in several reclamation projects and road embankments on soft soil layers. These include: reclamation of the Semarang Pelindo III container terminal (PT.PP, 2003-2004), reclamation of the Lamong Bay container terminal Pelindo III (PT.PP dkk,2013), Embankment KIE Bontang (TGU,2016), Embankment Road Porong (TGU,2013) and Embankment Kuala Tanjung (TGU, 2016). Based on the data of settlement versus time curves which has been collected, analyzed and concluded, gradient shape curves in Figure 2 tend to occur. Furthermore, a regression was conducted in order to obtain an equation with settlement and time variables. From this equation, constants were obtained that indicate the amplitude and the time of final settlement.

There are certain limitations to the use of the HWYL equation method:

- It is only valid for embankments on layers of very soft and soft clay soil foundations
- It does not consider the elevation and density of the embankment.
- It is only valid for the final stage of embankment elevation.
- It is only valid for the form of settlement versus time curve that tends to have reached the final stage of the settlement process,

The HWYL formulation (Figure 2) is as follows:

$$y = a(1 - \exp(-b(x - c))) \qquad (4)$$

where:
y = settlement
a = final settlement final (unit: length)
b = rate of settlement (unit: length/day)
c = initial time (day)
x = time (day)

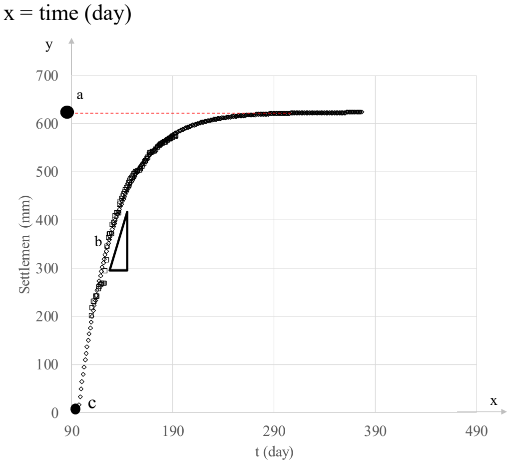

Figure 2 Prediction of settlement based on several reclamation & road embankment projects using HWYL method

The formula consists of the parameters a, b and c which must be determined. These parameters can be found using curve fitting with Excel or Matlab to obtain the value of R^2 close to 1. Generally, curve fit algorithms determine the best-fit parameters by minimizing a chosen merit function. In order to optimize the merit function, it is necessary to select a set of initial parameter estimates and then iteratively refine the merit parameters until the merit function does not change significantly between iterations. The goodness of fit is shown as an R2-value. A value of R2=1.0 indicates a perfect fit, whereas R2=0.0 indicates that the regression model might be unsuitable for this type of data. The stages to determine the parameters a, b, and c using Matlab are as follows:

1. Create a table for x and y in Array Editor Matlab where the x-axis is the observation time and the y-axis is the magnitude of settlement. The settlement data and time included in this table are from the settlement plate test results
2. Use Matlab's curve fitting tool, "cftool." To do this enter "cftool" at the Matlab prompt.
3. Let's start by importing the data. Hit the "Data" button, and then choose "time" as the "X data", and "settlement " as the "Y data." Then hit the "Create data set" button
4. Now choose "Fitting." Set "Fit Name" to "Fit1" and "Type of fit" to "Custom Equation" and then create custom equation like as equation 1.
5. When doing non-linear curve fitting, it is helpful to give the program as much information as possible. It is apparent from looking at the data that "a" , "b" and "c". So open the "Fit options" and enter these initial guesses.
6. Close the fit options, and start the fit, by hitting "Apply." The final fit looks good if parameter a, b and c are appropriate and R^2 closer to 1. If it is not fit and R^2 has not yet closer to 1, change "a" , "b" and "c" manually .
7. For the initial number of iterations, the following guidelines can be used:
   - The initial parameter a is the settlement value of the last observation
   - The initial parameter b is the average value of differential settlement divided by the days of observation in the interval as included in Matlab
   - The initial parameter c is the value of the initial observation time.

The parameters a, b and c can also be iterated by using Excel Solver. The stages are as follows:

1. Create a spreadsheet wherein column A is the observation time, column B is the settlement observations, column C is the prediction of the settlement depending on the parameters a, b and c. The settlement data and time included in this table are from the settlement plate test results
2. Formula in column C use equation 4. This formula is copied to the entire column C.
3. Column D is (C-B) ^{2} / C. This formula is copied throughout column D.
4. Column E is the total of column D, and this is the $\chi 2$ (chi square) value. If the prediction curve is very close to the field curve observations, $\chi 2$ (chi square) will be small.
5. In menu "Data" select "Solver", which will appear The Solver dialogue box. It has the following 4 parameters that need to be set:
   1) The Objective Cell. This is the target cell that we are either trying to maximize, minimize, or achieve a certain value.
   2) Minimize or Maximize the Target, or attempt to achieve a certain value in the Objective cell.
   3) Decision Variables – A set of variables that will be changed by the Excel Solver in order to optimize the target cell.
   4) Constraints – These are the limitations that the problem subjects the Solver to during its calculations
6. In "set objective" select colum E; under the box there is the option to set the value to be max, min or zero; it is set as min.
7. Then in "By changing the variable cells", insert column where parameters a, b and c are typed. These steps are taken to make the solver iterate parameters a, b and c in order to obtain the smallest χ^2 value.
8. To ascertain the parameters a, b, and c obtained from the "Solver", they are plotted against the observations (Figure 3).
9. Once parameters a, b and c are known, the following can be obtained:

- Final settlement = parameter a
- Final time = 5% x (parameter a - the last observation settlement) / parameter b

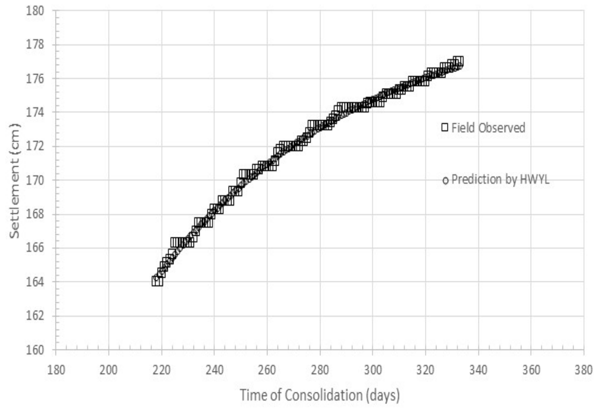

Figure 3 Fitting curve result between field observations versus HWYL prediction in settlement – time curves

There is no difference between the results obtained in these two methods. Therefore, Parameters a, b and c derived from Excel and MATLAB are the same.

4. VERIFICATION

The verification of Eq. (1), in addition to plotting the observations and the predicted results, is compared to other methods such as the Asaoka method. Table 1, Figures 4 & 5 show the comparison between the Asaoka and HWYL methods for some individual projects.

Table 1 Comparison of final settlement and time by Asaoka and HWYL Method

No of Data	Final Settlement (S-cm)		Final Time (days)	
	Asaoka Methode	HWYL Methode	Asaoka Methode	HWYL Methode
1	581.8	605.4	40	47
2	137.78	138.7	28	36
3	750	752.5	21	32
4	789	789.3	40	46
5	153.79	156	4	8

Table 1, Figures 4 & 5 show that the HWYL method predictions give a final settlement amplitude that is slightly larger than the Asaoka method, as well as a longer final settlement time. HWYL Method produce final settlement that is larger 0.03% to 4% than Asaoka method, while the time required to complete the settlement for HWYL is greater 10% to5 0% than Asaoka This shows the same trend as is actually found in the field, where often the settlement occurring is larger and longer than predicted using the Asaoka method.

Further verification is conducted by plotting the settlement vs time curve for actual conditions, Asaoka, Chunlin and HWYL methods. The result of the settlement plate used for verification takes case study of Kuala Tanjung results (GTU, 2016) as in Figure 6. As shown in Figure 6 that the observations on the settlement have tended to be asymptotic. It indicates that the settlement is completed. Therefore, this data will be used to verify the accuracy of the proposed equation.

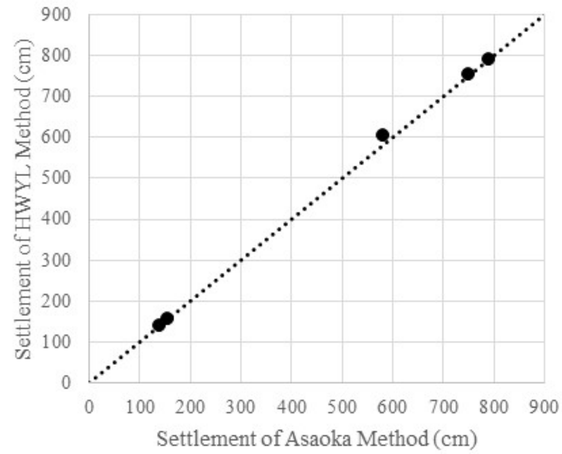

Figure 4 Comparison of settlement amplitude by HWYL and Asaoka methods

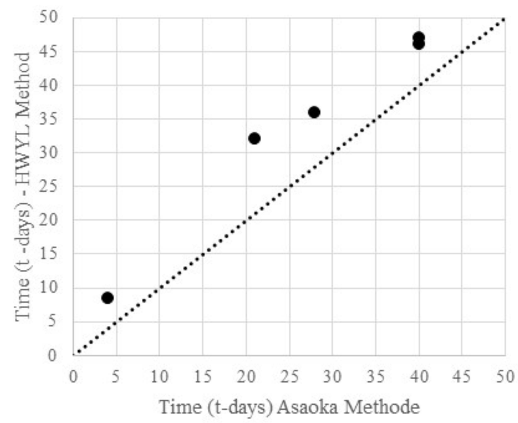

Figure 5 Comparison of settlement time by HWYL and Asaoka methods

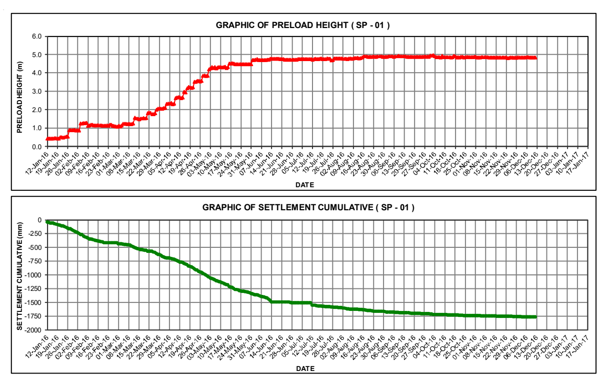

Figure 6 Stages of preload and settlement plate result of Kuala Tanjung Embankment (TGU, 2016)

After the plotting for this case study it is shown in Figure 7 that the HWYL method is closest to field observation than other methods.

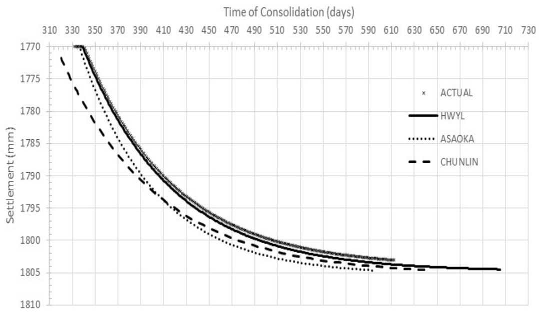

Figure 7 Comparison of settlement vs time by HWYL and Other methods

5. CONCLUSION

Based on the analysis that has been done, the following conclusions can be drawn:

1. The HWYL method with the equation $y = a(1 - \exp(-b(x - c)))$ has the same tendency as in the field.
2. Compared with the Asaoka graphical method, the HWYL method presents slightly larger values of amplitude and a longer time of settlement.
3. The HWYL method applies only to embankments on soft soil layers, while the form of the settlement versus time curve tends to have reached the final stage of the settlement process.
4. Settlement result of HWYL is closer to actual settlement.
5. HWYL is numerical method that applicable to those who apply it. It will produce the same settlement. It is fast method generating amplitude settlement sought.

6. ACKNOWLEDGEMENT

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