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PARAMETER IDENTIFICATION OF C_C IN SOFT SOIL THROUGH BACK ANALYSIS OF VACUUM PRELOADING

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ABSTRACT

The soft soil problem is one of the most common problems in the geotechnical field because the consolidation process in these soils takes a long time. One of the main problems that will be discussed in this research is the high compressibility of soft soil. The project reviewed in this research has clay soil characteristics with soft consistency so that the soil improvement method carried out in this project is vacuum preloading. In this research, a back analysis will be carried out based on the monitoring data available in this project where the modeling to be used is modeling with a finite element approach. The purpose of this back analysis is to obtain appropriate parameters based on monitoring data, the parameters adjusted in the back analysis are consolidation parameters in the form of C_c, C_s, e_0, k_x, and k_y. In this study, it only focuses on one of the consolidation parameters obtained from back analysis, namely the C_c parameter where the purpose of taking the C_c parameter in this study is to measure the high or low compressibility that occurs in soft soil in the project in this study. Based on the results of the back analysis obtained, the C_c value obtained from the 3 settlement plates ranges from 0.7 - 0.75 where the value indicates that the soft soil has high compressibility.

Keywords: Soft Soil; compression index; vacuum preloading

ABSTRAK

Permasalahan tanah lunak merupakan salah satu masalah yang sering terjadi pada bidang geoteknik karena proses konsolidasi pada tanah tersebut memakan waktu yang lama. Salah satu permasalahan utama yang akan dibahas pada penelitian ini adalah kompresibilitas yang tinggi pada tanah lunak. Proyek yang ditinjau pada penelitian ini memiliki karakteristik tanah lempung dengan konsistensi lunak sehingga metode perbaikan tanah yang dilakukan pada proyek ini adalah vacuum preloading. Pada penelitian ini akan dilakukan back analysis berdasarkan data monitoring yang tersedia pada proyek ini dimana pemodelan yang akan digunakan berupa pemodelan dengan pendekatan finite element. Tujuan dari back analysis ini adalah untuk mendapatkan parameter yang sesuai berdasarkan data monitoring, parameter yang disesuaikan pada back analysis yaitu parameter konsolidasi berupa C_c, C_s, e_0, k_x, dan k_y. Pada penelitian ini, hanya berfokus pada salah satu parameter konsolidasi yang diperoleh dari back analysis yaitu parameter C_c dimana tujuan pengambilan parameter C_c pada penelitian ini adalah untuk mengukur tinggi atau rendahnya kompresibilitas yang terjadi pada tanah lunak pada proyek dalam penelitian ini. Berdasarkan hasil back analysis yang diperoleh, nilai Cc yang diperoleh dari 3 settlement plate berkisar antara 0,7 – 0,75 dimana nilai tersebut menunjukkan bahwa tanah lunak memiliki kompresibilitas yang tinggi.

Kata kunci: Tanah lunak; compression index; vacuum preloading

1. INTRODUCTION

Soft soils are a serious problem in construction because they have high moisture content, low bearing capacity, high compressibility, and can cause large settlement in buildings erected on them. According to Wardoyo et al. (2019), the distribution of soft soil in Indonesia reaches 20 million hectares or about 10% of the land in Indonesia.

According to Han (2015), the efforts made to overcome the problem of soft soil is to perform soil improvement methods in the form of preloading. However, along with the times, this method was developed by W. Kjellman into vacuum preloading in 1952. Vacuum preloading is more suitable for weak soil to support the structure.

Vacuum preloading is a method of soil improvement for fine-grained soils by applying vacuum pressure to the soil and adding other components such as PVD (Prefabricated Vertical Drain) which serves to accelerate the consolidation time of the soil by reducing the length of the water flow path in the soil drainage system (Andini et al., 2023).

The soil in this research project is characterized by clay with soft consistency so that the method of soil improvement carried out in this project is vacuum preloading. This research focuses on the compressibility that occurs in soft soil where the parameter to be identified is the C_c parameter which is one of the clay soil consolidation parameters where the parameter is obtained from back analysis conducted on monitoring data from 3 settlement plates.

This research is to determine the value of C_c in soft soil from back analysis and classify the compressibility of the soil.

Soft soil

Kristiadi et al. (2022) state that soft soils exhibit widely spaced particle interactions, leading to large void ratios. Water occupying these voids significantly reduces soil strength. Such soils typically have low permeability ($<10^{-5}$ cm/s), along with poor shear strength, low bearing capacity, and prolonged consolidation times (Edwin & Suhendra, 2019).

Consolidation

Consolidation is a process of reducing the volume of saturated soil with low permeability due to loading, where the process is influenced by the release of pressurized pore water from the soil cavity (Hardiyatmo, 2003). According to Das (2013), there are 3 phases that will occur in the consolidation process (Fig. 1), which are:

1. Initial loading, at this stage a gradual loading is given for a certain period of time so that there is a shrinkage of the pore void volume in the soil due to an increase in pore water pressure.
2. Primary consolidation, in the next stage the excess porewater pressure is gradually transferred into effective stress due to the release of pore water as a result of loading in the previous stage.
3. Secondary consolidation, the last stage is after the dissipation of excess porewater pressure and some deformations that occur due to structural adjustment of the soil.

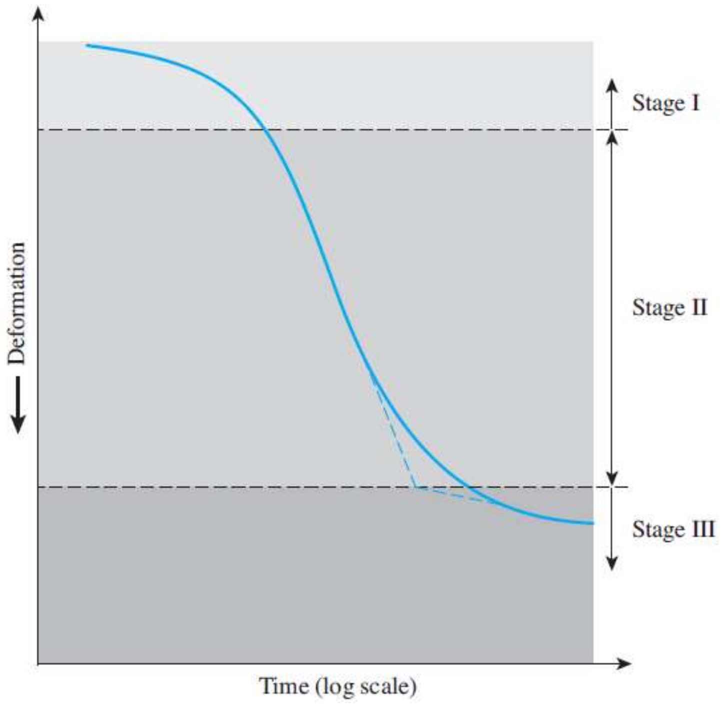

Figure 1. The graph generated at 3 phases in soil consolidation (Das, 2013)

Compression index (C_c)

The compression behavior of soil is a key mechanical property that describes how compressive stress influences a volumetric parameter of the soil. This behavior is typically represented by graphing the logarithm (usually base 10) of normal compressive stress (σ_o) against the soil's void ratio (e). When plotted this way, the curve shows two distinct phases an elastic rebound section at lower stress levels and a linear virgin compression section at higher stress. The slope of the virgin compression line is referred to as C_c (Table 1-2) (Gregory et al., 2006).

Table 1. C_c Values for saturated soils (Briaud, 2023)

Soil	C_c
Peat	10 – 15
Organic Clays	2 – 8
Sensitive Clays	1 – 4
High – plasticity clays	0.5 – 0.9
Low – plasticity clays	0.15 – 1.2

Table 2 Compressibility classification (Ameratunga et al., 2016)

Compressibility	C_c
Slight or low	< 0.2
Moderate or intermediate	0.2 – 0.4
High	> 0.4

Prefabricated vertical drain (PVD)

According to Radhakrishnan & Gunasekaran (2019), PVD is one of the most important factors in accelerating consolidation in soft consistency clay and is an economical component with proven efficiency. The equivalent diameter for each vertical drain can be estimated based on the area of influence of each vertical drain with the following equation (Han, 2015):

For square pattern use Eq. 1.

$$d_e = 1.13 \text{ s} \tag{1}$$

For triangle pattern use Eq. 2.

$$d_e = 1.06 \text{ s} \tag{2}$$

with d_e = Equivalent diameter influence (m), S = Spacing between vertical drain (m).

According to Radhakrishnan & Gunasekaran (2019), the time required for the drainage process to occur using a vertical drainage system without considering the effect of soil disturbance (smear) use Eq. 3.

$$\text{t} = \frac{D^2}{8c_h} \text{ F(n)ln} \frac{1}{1 - U_r} \tag{3}$$

with t = time required to reach U_r (minute), c_h = Coefficient of Consolidation in horizontal direction, F(n) = Drain spasing factor U_r = Derajat konsolidasi in horizontal direction, D = Diameter of cylinder affected by vertical drain (m)

Preloading

Preloading is a method of applying a surcharge load before construction begins which aims to trigger soil settlement, especially primary consolidation settlement (Lay et al., 2020). According to Han (2015), the concept of preloading is to reduce the void ratio in the soil through the consolidation process, which is dissipation of excess pore water pressure. Preloading is widely used to improve soft soils that are still underconsolidated.

Vacuum preloading

Vacuum preloading (Fig. 2) is a soil improvement method that uses atmospheric pressure on an airtight system installed in the field by applying vacuum pressure to the system, the vacuum pressure applied ranges from 60-80 kPa (Han, 2015). According to Wang et al. (2021), the total stress that occurs in the soil during the vacuum preloading process is fixed and unchanged while the pore water pressure decreases which causes the effective stress in the soil to increase. This increase in effective stress is equivalent to applying additional load to the soil to achieve the desired settlement as quickly as possible.

According Badan Standardisasi Nasional (2017), the purpose of vacuum preloading is:

1. Accelerates the soil consolidation process and increases the bearing capacity of the soil.
2. Minimize post-construction settlement.
3. Increase the stability of the embankment.
4. Replacing part or all of the backfill material used in conventional preloading methods with atmospheric pressure generated from vacuum preloading.
5. Eliminate the use of embankment material as a counterweight to prevent landslides at the edge of the repair area.

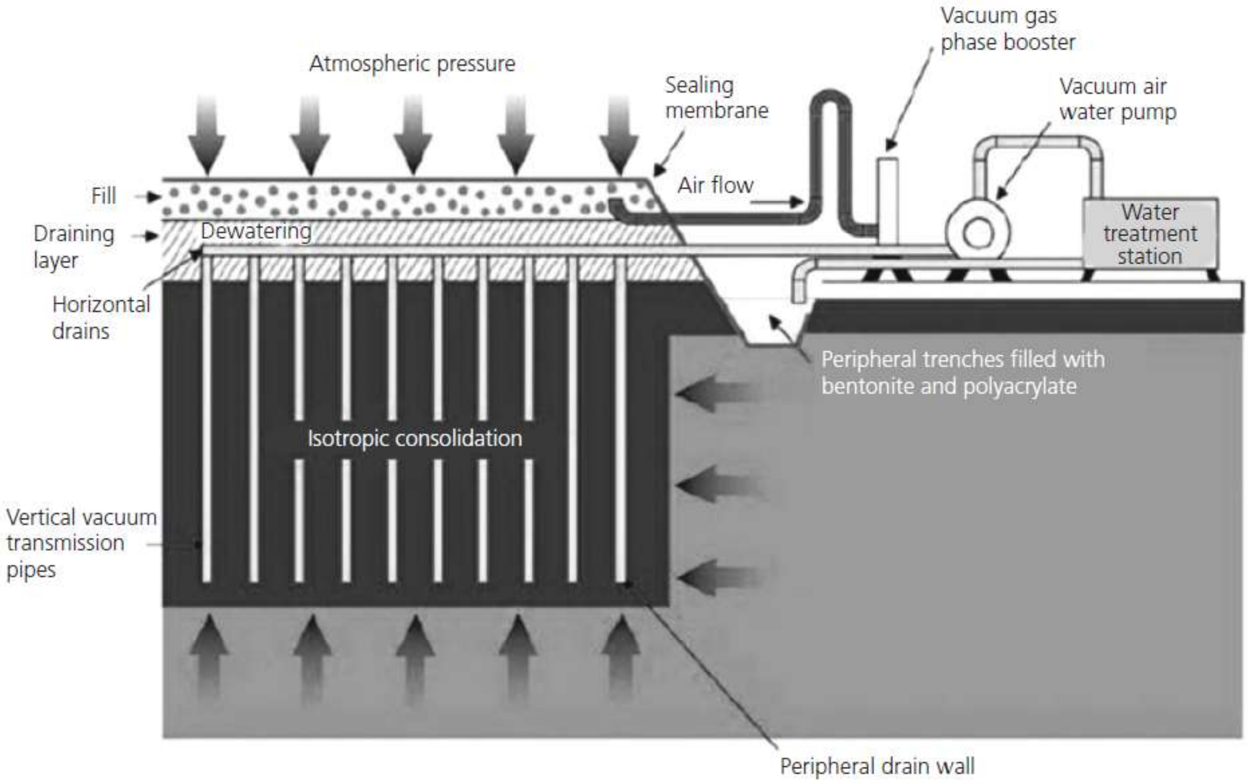

Figure 2. Illustration of vacuum preloading (Griffin & O'Kelly, 2014)

2. RESEARCH METHOD

Based on the flowchart shown in Figure *3*, this research will be conducted in several stages, beginning with the initial research process and continuing until the final results are obtained. The key stages include:

1. Literature review stage, at this phase, a review of existing literature will be conducted to gather relevant references related to the research topic.
2. Data collection stage, the data used in this research will be sourced from monitoring records, including settlement plate measurements and CPTe data.
3. Analysis stage, this stage involves performing back analysis to determine suitable soil parameters based on the collected monitoring data. The analysis will also include modelling using finite element method (FEM) with CPTe data. After obtaining parameters that are in accordance with the back analysis, then parameter identification will be carried out, namely the Cc parameter in order to determine the soil compressibility classification.
4. Report writing and conclusion stages, based on the results obtained in the analysis, the report will be compiled and conclusions drawn.

3. RESULTS AND DESCRIPTION

Data analysis

In this research, back analysis will be performed using software with a finite element approach. The soil layers contained in the CPTe from the initial soil investigation will be modeled through the software. The output that will be issued from the software is a settlement vs time graph that will be adjusted to the monitoring graph to obtain parameters, especially the C_c parameter.

Road section data

The road section data to be reviewed in this project is taken at STA2+375, STA2+475, STA2+575 which is located between STA2+350 and STA2+600 where at this point there is settlement plate data and CPTe data (Fig. 4).

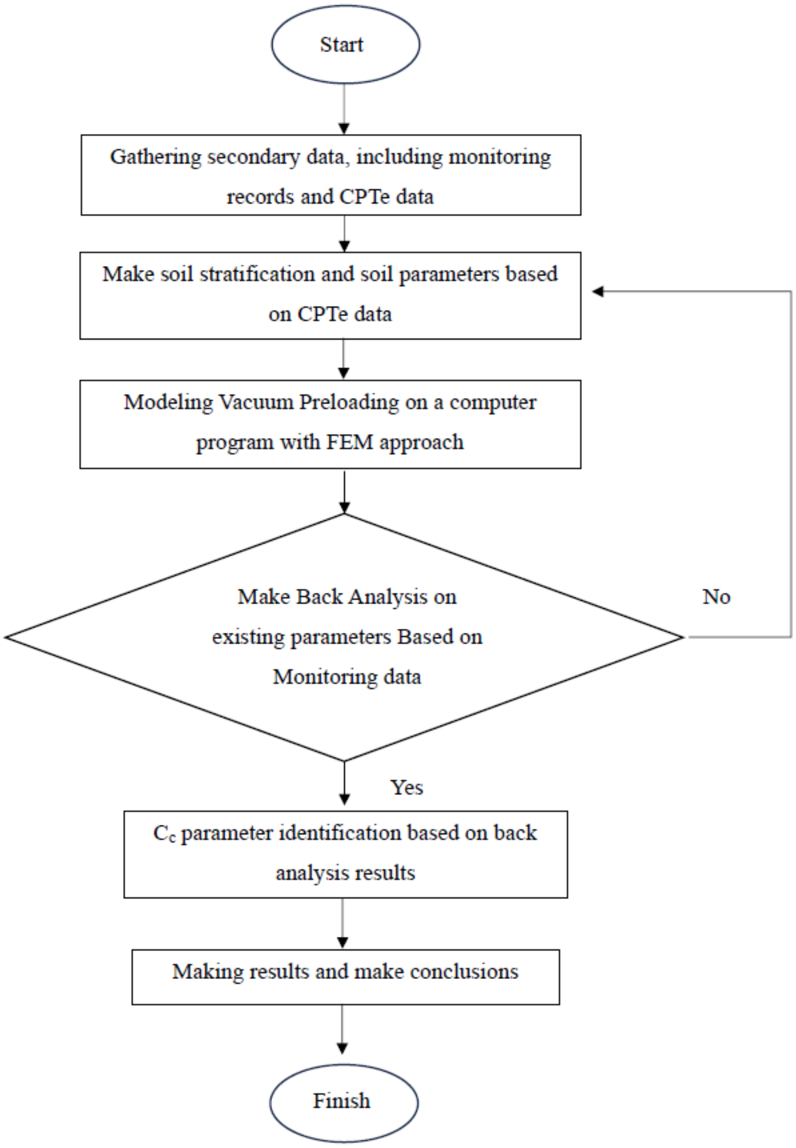

Figure 3. Flowchat of research

Soil data

The soil data to be used is CPTe data taken at the beginning of the soil investigation in this project at STA2+375, STA2+475, STA2+575 and in this project there is a 2 m embankment used as a work platform (Fig. 5 and Table 3-5).

Back analysis modeling

The back analysis modeling in the study was performed using the finite element method approach where in this model there is a PVD and a water surcharge load as high as 1.5 m during the vacuum preloading process (Fig. 6). Vacuum preloading process was running up to 117 days based on monitoring data in this research project. Vacuum pressure was modeled gradually from 40 kPa, 60 kPa, to 80 kPa and when it reached 80 kPa on day 36, a water surcharge load was added.

Back analysis results

The results of the back analysis modeling performed will be in the form of a settlement graph during the vacuum preloading process and will be adjusted to the graph from the monitoring data in the form of settlement plate data in order to obtain the appropriate soil parameters (Fig. 7-10 and Table 6-11).

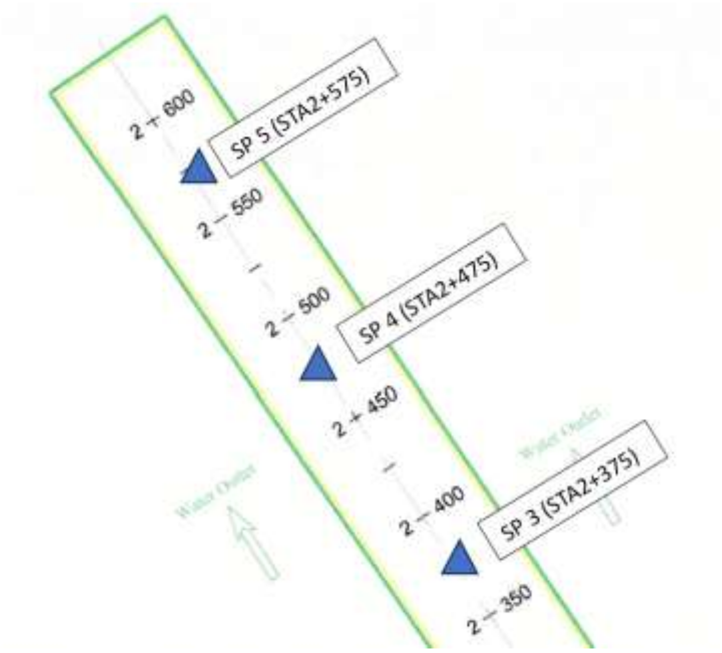

Figure 4. Road section data at STA2+375, STA2+475, STA2+575

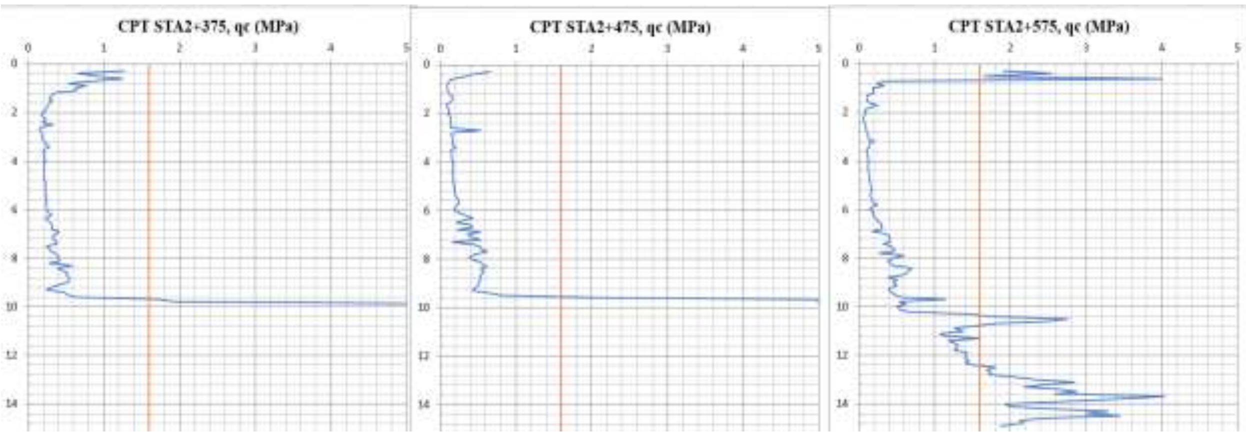

Figure 5. CPTe data at STA2+375, STA2+475, STA2+575

Table 3 Soil classification from CPTe data at STA2+375

Depth (m)	Soil type	Consistency
0 - 2	Clay (Platform)	Stiff
2 - 8	Clay	Soft
8 - 9.5	Clay	Medium Stiff
9 - 12	Clay	Stiff

Table 4 Soil classification from CPTe data at STA2+475

Depth (m)	Soil type	Consistency
0 - 2	Clay (Platform)	Stiff
2 - 7	Clay	Soft
7 - 9	Clay	Medium Stiff
9 - 12	Clay	Stiff

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Table 5 Soil Classification from CPTe data at STA2+575

Depth (m)	Soil type	Consistency
0 - 2	Clay (Platform)	Stiff
2 - 8	Clay	Soft
8 - 10	Clay	Medium Stiff
10 - 14	Clay	Stiff

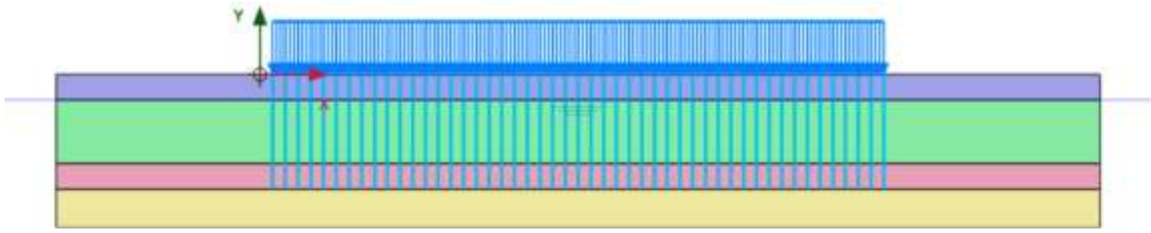

Figure 6. Example modeling back analysis using finite element method at STA2+475

Figure 7. Soil Profile in back analysis modelling at STA2+475

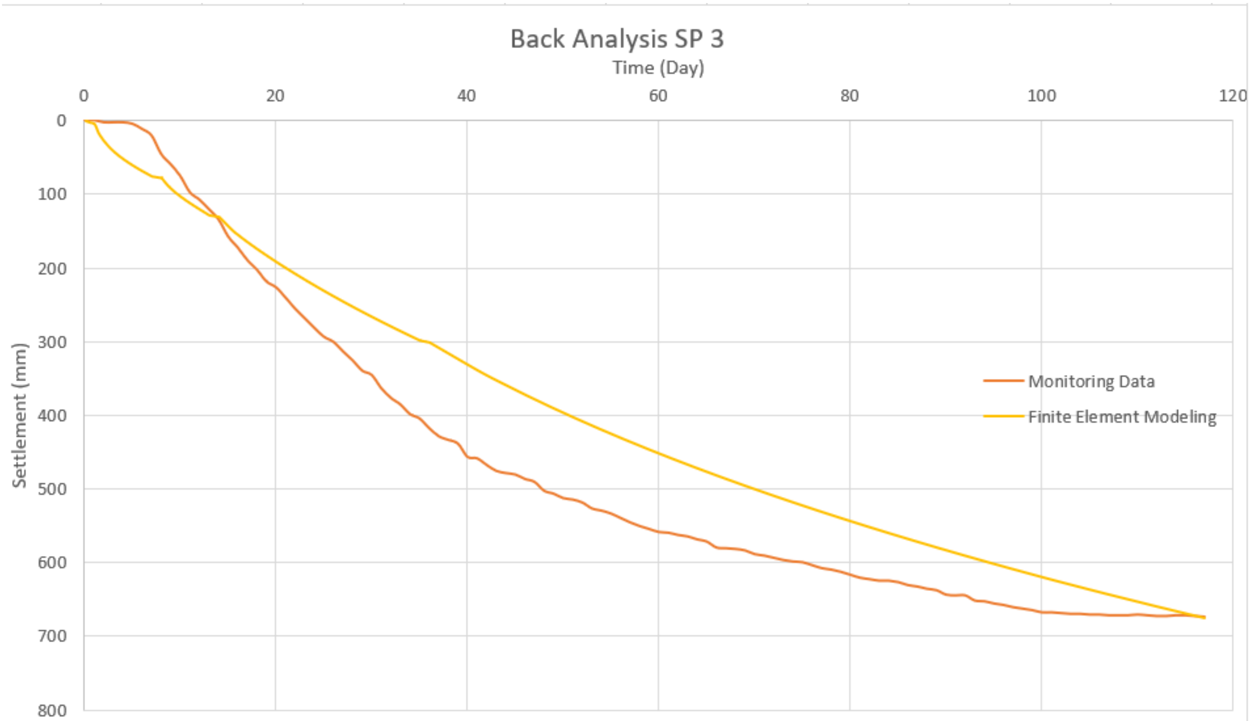

Figure 8. Back analysis graph result at STA2+375

Table 6. Summary of parameter back analysis results at STA2+375

Depth (m)	Soil type	Consistency	γ (kN/m³)	C_c	C_s	e_0
0 - 2	*Clay (Platform)*	*Stiff*	16			0.8
2 - 8	*Clay*	*Soft*	15	0.7	0.07	2.5
8 - 9.5	*Clay*	*Medium Stiff*	16			0.8
9 - 12	*Clay*	*Stiff*	16.5			0.7

Table 7. Summary parameter of back analysis results at STA2+375 (continued)

Depth(m)	E_{50} (kPa)	E_{oed} (kPa)	E_{ur} (kPa)	c’	ϕ'	k_x (m/day)	k_y (m/day)
0 - 2	10000	10000	30000	5	25	7×10^{-6}	7×10^{-6}
2 - 8				1	23	7×10^{-6}	7×10^{-6}
8 - 9.5	8000	8000	24000	3	25	7×10^{-6}	7×10^{-6}
9 - 12	24000	24000	72000	5	26	7×10^{-6}	7×10^{-6}

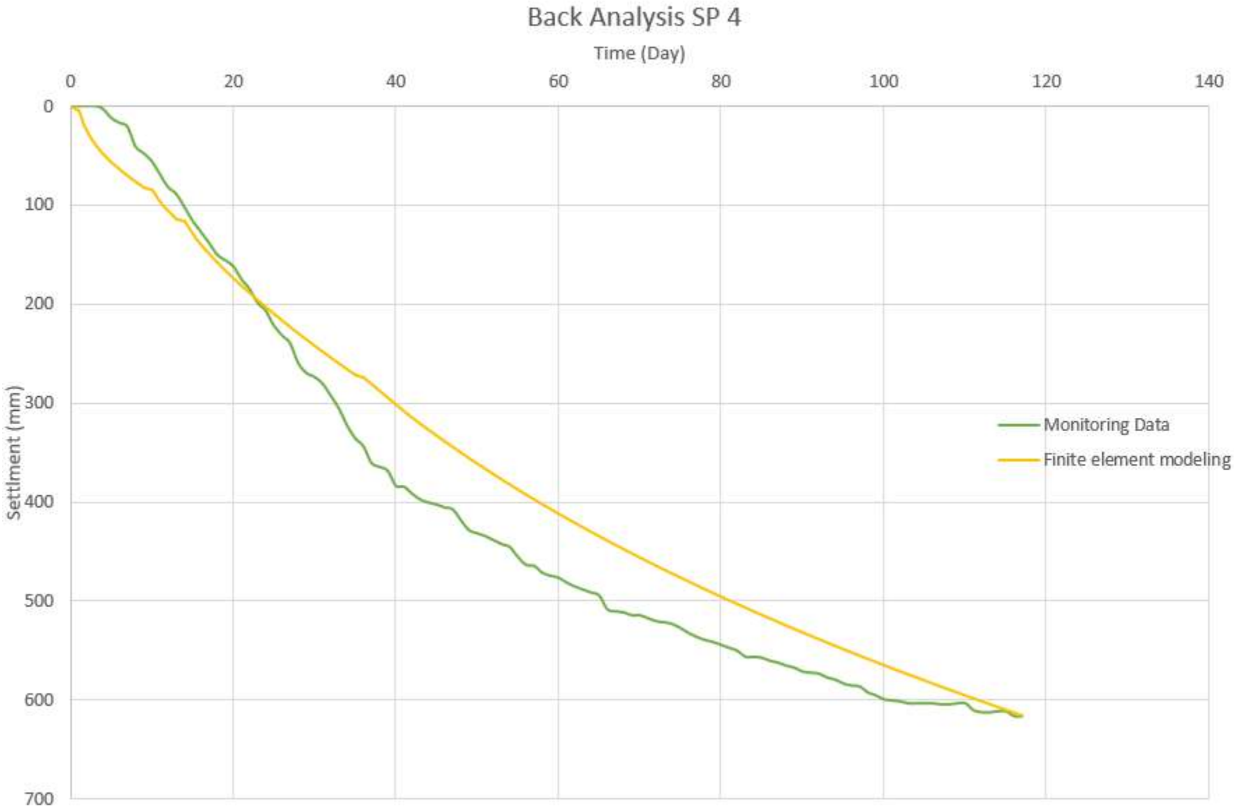

Figure 9. Back analysis graph result at STA2+475

Table 8. summary of parameter back analysis results at STA2+475

Depth (m)	Soil type	Consistency	γ (kN/m^3)	C_c	C_s	e_0
0 - 2	*Clay (Platform)*	*Stiff*	16			0.8
2 - 7	*Clay*	*Soft*	15	0.75	0.075	2.5
7 - 9	*Clay*	*Medium Stiff*	16			0.8
9 - 12	*Clay*	*Stiff*	16.5			0.7

Table 9 summary of parameter back analysis results at STA2+475 (continued)

Depth(m)	E_{50} (kPa)	E_{oed} (kPa)	E_{ur} (kPa)	c’	ϕ'	k_x (m/day)	k_y (m/day)
0 - 2	10000	10000	30000	5	25	7×10^{-6}	7×10^{-6}
2 - 7				1	23	7×10^{-6}	7×10^{-6}
7 - 9	8000	8000	24000	3	25	7×10^{-6}	7×10^{-6}
9 - 12	24000	24000	72000	5	26	7×10^{-6}	7×10^{-6}

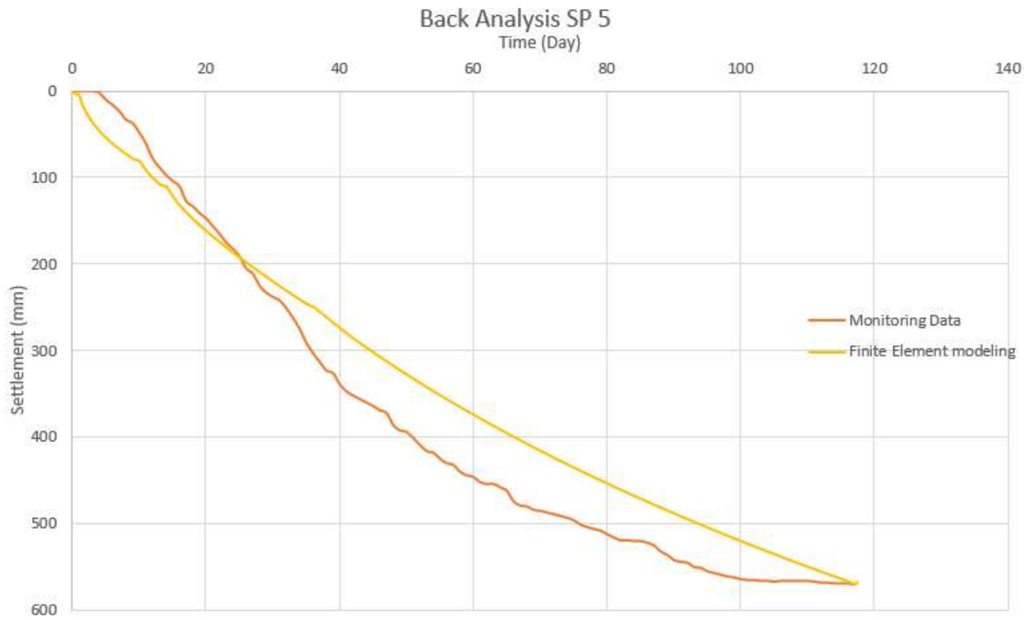

Figure 10. Back analysis result graph at STA2+575

Table 10. Summary of parameter back analysis results at STA2+575

Depth (m)	Soil type	Consistency	γ (kN/m^3)	C_c	C_s	e_0
0 - 2	*Clay (Platform)*	*Stiff*	16			0.8
2 - 8	*Clay*	*Soft*	15	0.73	0.073	2.5
8 - 10	*Clay*	*Medium Stiff*	16			0.8
10 - 14	*Clay*	*Stiff*	16.5			0.7

Table 11. Summary of parameter back analysis results at STA2+575 (continued)

Depth(m)	E_{50} (kPa)	E_{oed} (kPa)	E_{ur} (kPa)	c'	ϕ'	k_x (m/day)	k_y (m/day)
0 - 2	10000	10000	30000	5	25	4.5 x 10^{-6}	4.5 x 10^{-6}
2 - 8				1	23	4.5 x 10^{-6}	4.5 x 10^{-6}
8 - 10	8000	8000	24000	3	25	4.5 x 10^{-6}	4.5 x 10^{-6}
10 - 14	24000	24000	72000	5	26	4.5 x 10^{-6}	4.5 x 10^{-6}

Percentage deviation of back analysis

In Fig.11-13, between monitoring and modeling using finite element there is a deviation where the deviation becomes the percentage error between the monitoring graph and modeling using finite element. If the similarity of the monitoring graph and finite element modeling data reaches 100%, it means that the line equation obtained is y = x which has a gradient of 1. If the similarity does not reach 100%, the gradient obtained ≠ 1 and has a deviation where the deviation is a percentage error. Based on

Table 12 , it can be concluded that the percentage of error for each SP is less than 15 %.

Identification of C_c Parameter

After getting the parameters from back analysis results, then the identification of the C_c parameter for each settlement plate location under review will be made. In the 3 SP (STA2+375, STA2+475, STA2+575) reviewed, C_c values ranged from 0.7 – 0.75 (Table 13).

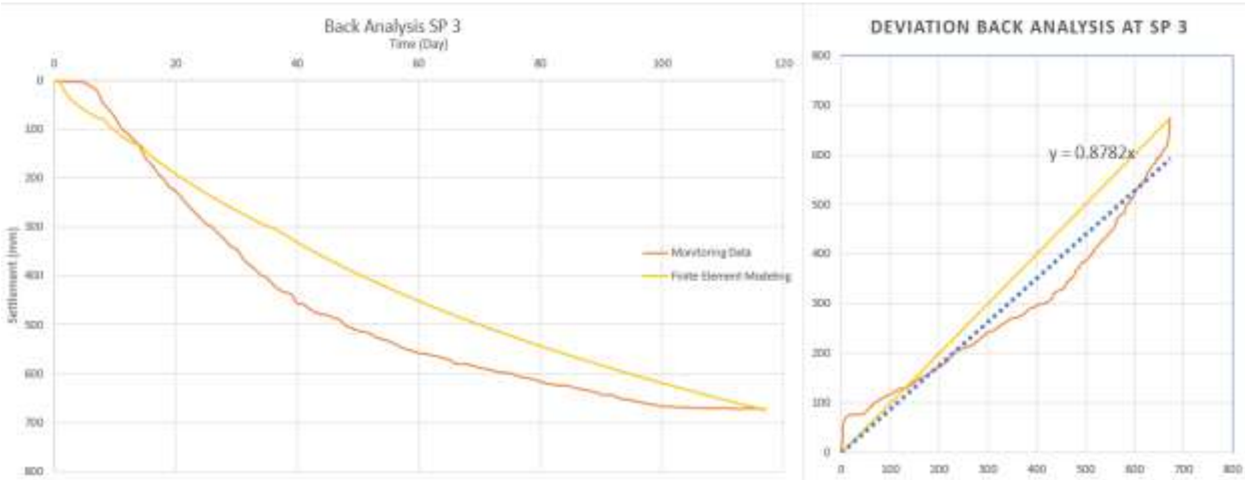

Figure 11. Back analysis deviation graph at STA2+375

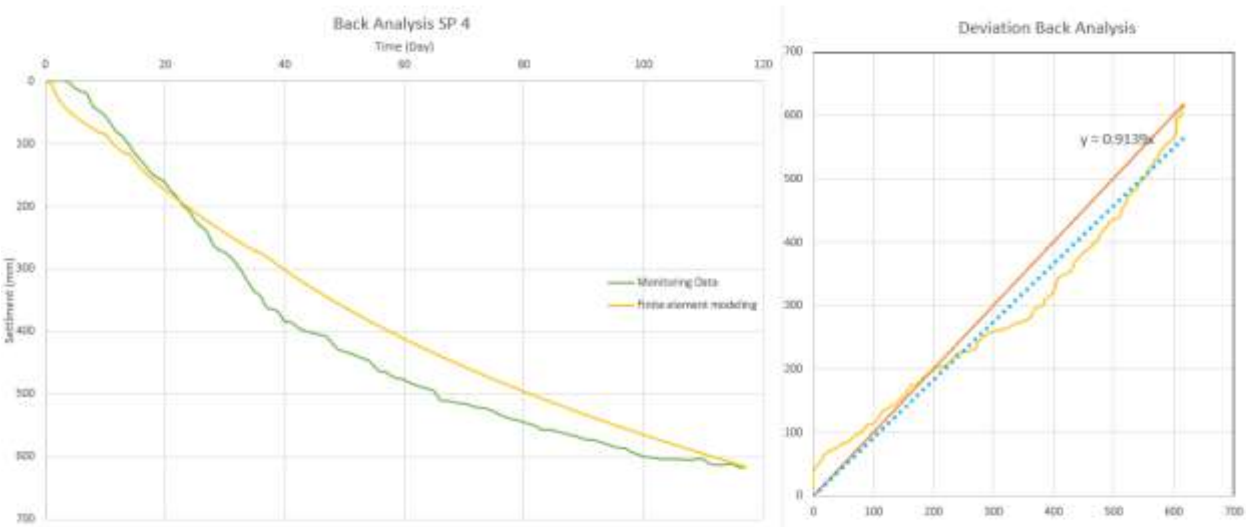

Figure 12. Back analysis deviation graph at STA2+475

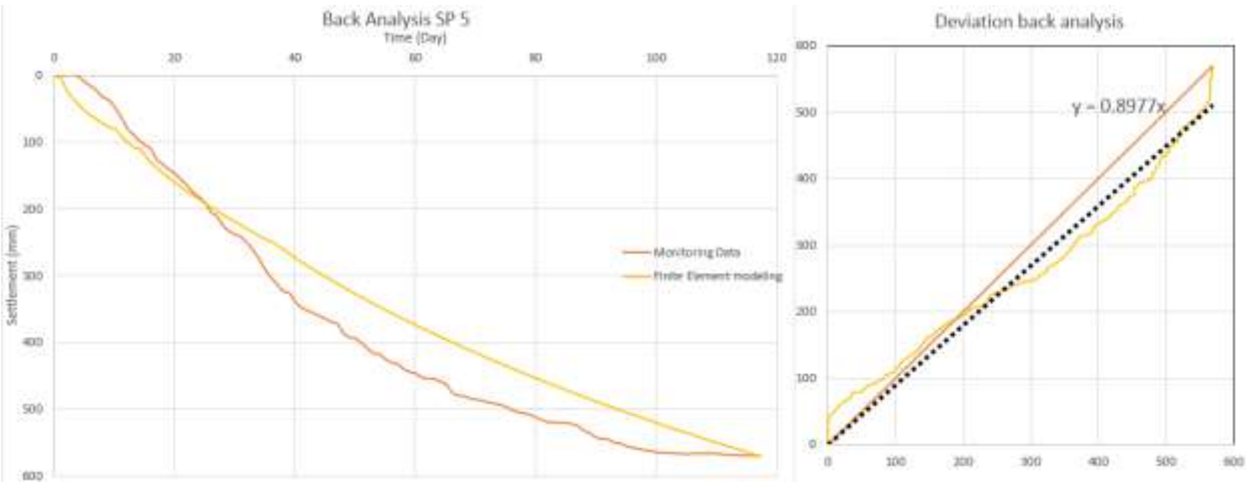

Figure 13. Back analysis deviation graph at STA2+575

Table 12. Percentage error from back analysis on every settlement plate

Type of SP	Percentage Error (%)
SP 3	12.18
SP 4	8.61
SP 5	10.23

Table 13. Summary parameter C_c on every settlement plate from back analysis

Type of SP	C_c
SP 3	0.70
SP 4	0.75
SP 5	0.73

4. CONCLUSION AND SUGGESTION

The conclusions obtained from this research are as follows:

1. Based on the results of the back analysis of all SP, the C_c parameter obtained ranges from 0.7 - 0.75 where the C_c value is classified as high compressibility based on the classification described in the previous discussion. Which means the soft soil in this study has a high compressibility problem with a range of C_c values of 0.7 - 0.75.
2. Based on the results of the back analysis deviation graph, it can be seen that the percentage error in all SP reviewed ranges from 8% - 12%. Therefore, it can be concluded that the modeling can't represent the conditions in the field 100% because there are many factors that occur during implementation in the field so that this back analysis is an analysis approach carried out to obtain appropriate soil parameters.

Based on the results of the analysis that has been obtained, the suggestions that can be given in this research are :

1. It is better to do a 3D analysis so that the results obtained are more accurate.
2. More complete data such as laboratory testing data is required to be able to adjust soil parameters more accurately.

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