Lecture Notes in Civil Engineering

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Prediction of Long Term Post Construction Settlement in Soft Soil Using Vacuum Preloading

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Abstract Soft soil problems are one of the most common problems in geotechnical engineering because the consolidation process in these soils takes a long time. One of the consequences of this problem is that the post-construction settlement caused is very large, affecting the stability of the building in the long term. The project reviewed in this study 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 conducted based on the monitoring data available in this project where the purpose of this back analysis is to obtain the appropriate parameters based on the monitoring data. The graph of the back analysis modeling results will be adjusted to the monitoring graph and an operational load will be placed in the form of road load to see the long-term settlement in a 10-year period with a target of < 10 cm. In this study, it can be seen that after vacuum preloading method on soft soil, the post-construction settlement in the long-term period is very small and meets the targeted settlement criteria for 10 years.

Keywords Soft soil · Settlement · Vacuum preloading

1 Introduction

Soft soils are a serious problem in construction because they have high moisture content, low bearing capacity, high compressibility, that can cause large settlement in buildings erected on them. The distribution of soft soil in Indonesia reaches 20 million hectares or about 10% of the land in Indonesia [1]. 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 [2]. Vacuum preloading is more suitable for weak soil to support the structure. Vacuum preloading is a method of

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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 [3].

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 impact after vacuum preloading where the part to be reviewed is the settlement after vacuum preloading on the soft soil in the research project with a target settlement at 10 years is < 10 cm. The reason for the settlement target is to avoid the overlay of the soil for the long term period.

1.1 Soft Soil

Soils with soft consistency have friction between particles that are far away, causing the soil to have large voids. Water contained in the void area will fill the voids in the soil resulting in the strength of the soil being reduced. Generally, permeability in soft soil has a low value of < 10–5 cm/s [4]. The characteristics of soft soil are low soil shear strength, small permeability value, low soil bearing capacity and the time required to consolidate is very long.

1.2 Soil Settlement

The calculation of soil settlement is divided into 3 namely immediate settlement, primary consolidation settlement, and secondary consolidation settlement but what will be used in this study is primary consolidation settlement. Primary consolidation settlement in clay soil can be formulated as follows [5]:

For Normally Consolidated Condition:

$$S_c = \frac{C_c \cdot H}{1 + e_0} \log\left(\frac{P'_0 + \Delta\sigma}{P'_0}\right) \tag{1}$$

For Over Consolidated Condition ($P'_0 + \Delta\sigma < P'_c$):

$$S_c = \frac{C_s \cdot H}{1 + e_0} \log\left(\frac{P'_0 + \Delta\sigma}{P'_0}\right) \tag{2}$$

For Over Consolidated Condition ($P'_0 + \Delta\sigma > P'_c$):

$$S_c = \frac{C_s \cdot H}{1 + e_0} \log\left(\frac{P'_c}{P'_0}\right) + \frac{C_c \cdot H}{1 + e_0} \log\left(\frac{P'_0 + \Delta\sigma}{P'_c}\right) \tag{3}$$

With C_c = Compression Index, C_s = Swell Index, e_0 = Initial void ratio, H = Soil layer thickness (m), P'_o = Effective overburden pressure (kN/m^2), P'_c = Preconsolidation stress (kN/m^2), $\Delta\sigma$ = Change in pressure (kN/m^2).

1.3 Vacuum Preloading

Vacuum preloading 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 to 80 kPa [2]. 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 [6]. Vacuum pressure should remain constant regardless of depth and is typically constrained by the installation depth of vertical drains. However, a widely observed limitation is that effective vacuum application is often restricted to approximately 10 m below ground level (bgl), irrespective of the drain's length [7].

2 Research Method

This research will consist of several stages starting from the beginning of the research process until the results of the research are obtained. Here are some of the stages that will be carried out: Literature study stage, at this stage a literature study will be carried out to get some references regarding the research topic to be discussed. Data collection stage, the data obtained in this study comes from monitoring data in the form of settlement plate data and CPTe data. Analysis stage, at this stage Back Analysis is carried out to obtain appropriate soil parameters based on Monitoring data that has been obtained and modeling on Back Analysis based on CPTe data using the Finite Element Method approach. After obtaining the appropriate soil parameters, the operational load can be modeled and will be evaluated for long term settlement in the operational load.

Report writing and conclusion stages, based on the results obtained in the analysis, the report will be compiled and conclusions drawn. The flowchart of research can be seen at Fig. 1.

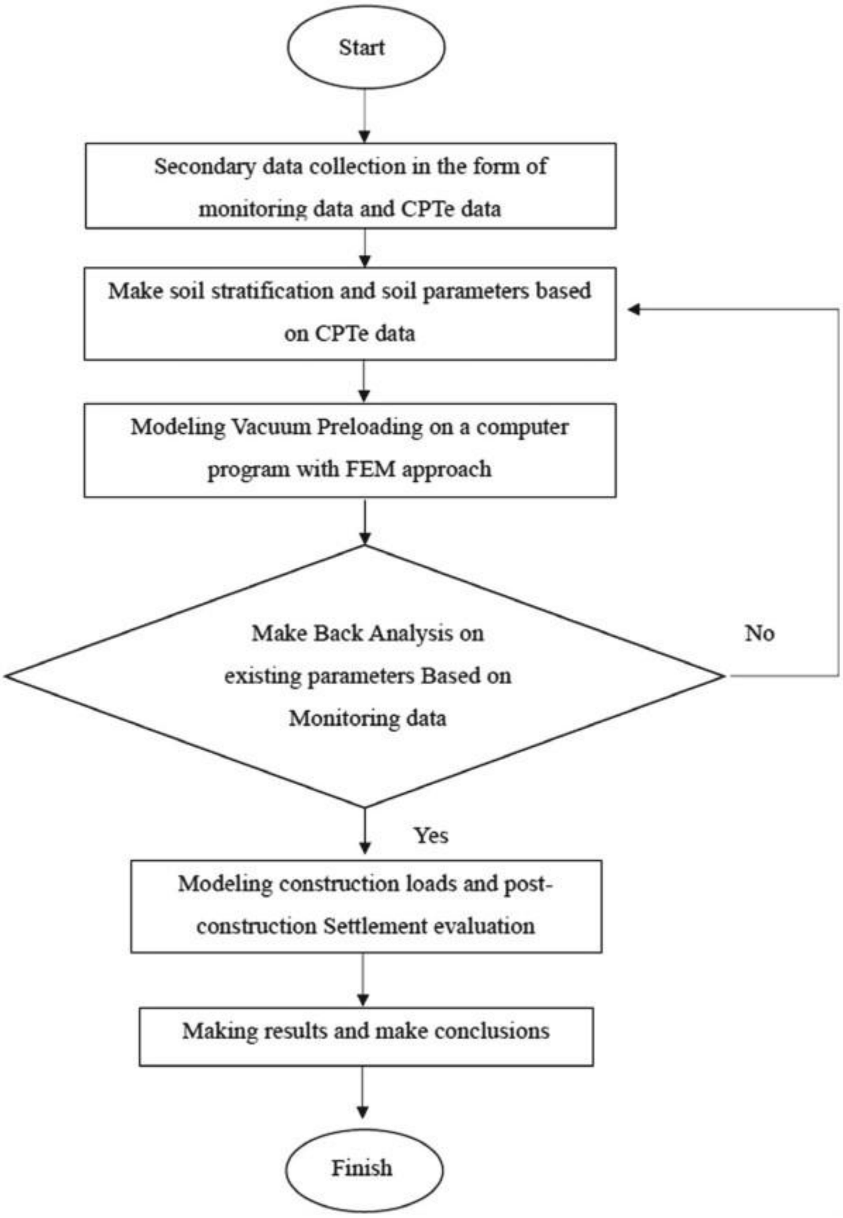

Fig. 1 Flowchart of research

3 Results and Analysis

3.1 Road Section Data

The road section data in this project was taken in the North Jakarta Area. The road section data to be reviewed in this project is taken at STA2+475 which is located between STA2+450 and STA2+500 where at this point there is settlement plate data and CPTe data. The road section data can be seen at Fig. 2.

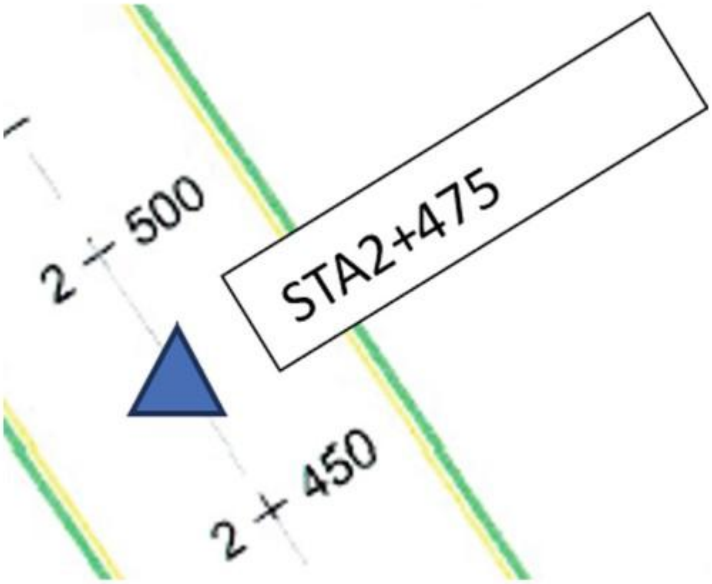

Fig. 2 Road section data at STA2+475

3.2 Soil Data

CPTe is a conus penetration tool that uses an electrical system where the rate of push on this system is more constant than mechanical CPT. In the electrical system, the cable from the penetrometer on the CPTe is connected to the computer via a conical hollow rod for easy access to data [8]. The soil data to be used is CPTe data taken at the beginning of the soil investigation in this project at STA2+475 and in this project there is a 2 m embankment used as a work platform. The CPTe data can be seen at Fig. 3 and for the interpretation from CPTe data can be seen at Table 1.

3.3 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 up to a depth of 9.5 m and a water surcharge load as high as 1.5 m during the vacuum preloading process. Vacuum preloading process was running up to 117 days based on monitoring data in this research project.

Vacuum was modeled through PVD which is a drain element in the finite element and the behavior of the PVD is made into a vacuum drain when which can be seen in the Fig. 4 and the soil profile can be seen at Fig. 5. The vacuum pressure was modeled gradually from 40, 60, to 80 kPa and when it reached 80 kPa on day 36, a water surcharge load was added.

Back Analysis Result

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

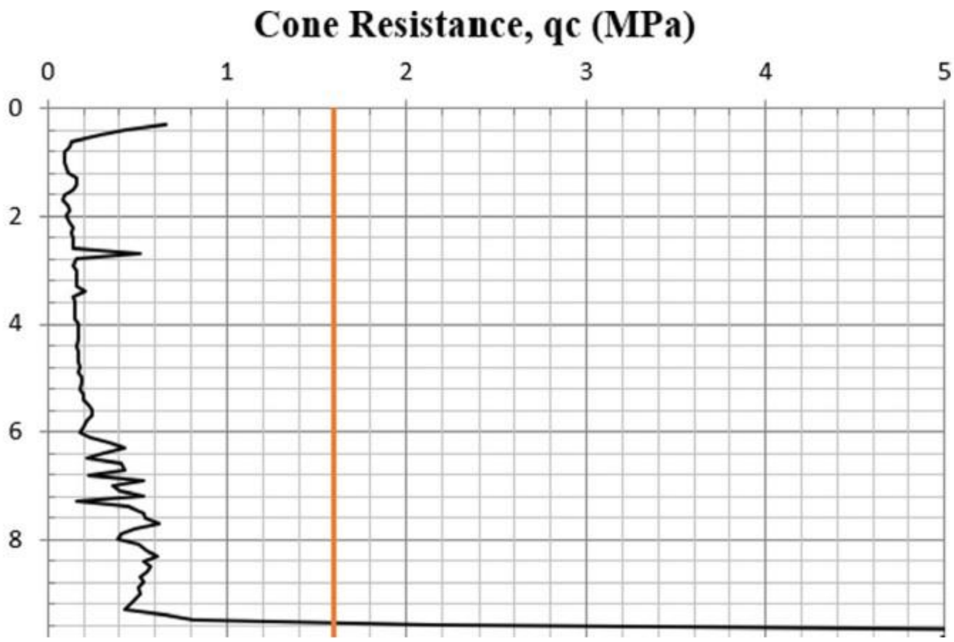

Fig. 3 CPTe data

Table 1 Soil interpretation from CPTe data

Depth (m)	Soil type	Consistency
0–2	Clay (Platform)	Stiff
2–7	Clay	Soft
7–9	Clay	Medium Stiff
9–10	Clay	Stiff

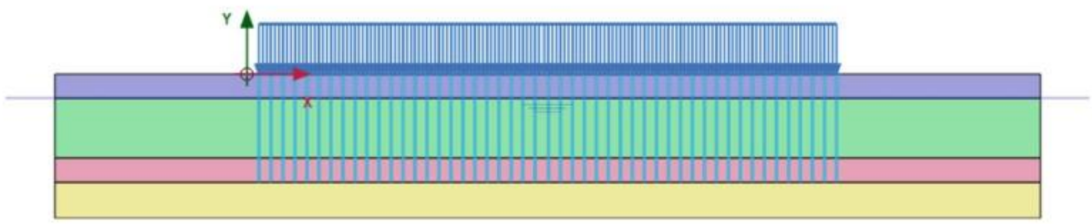

Fig. 4 Modeling back analysis using finite element method

Fig. 5 Soil profile in back analysis modeling

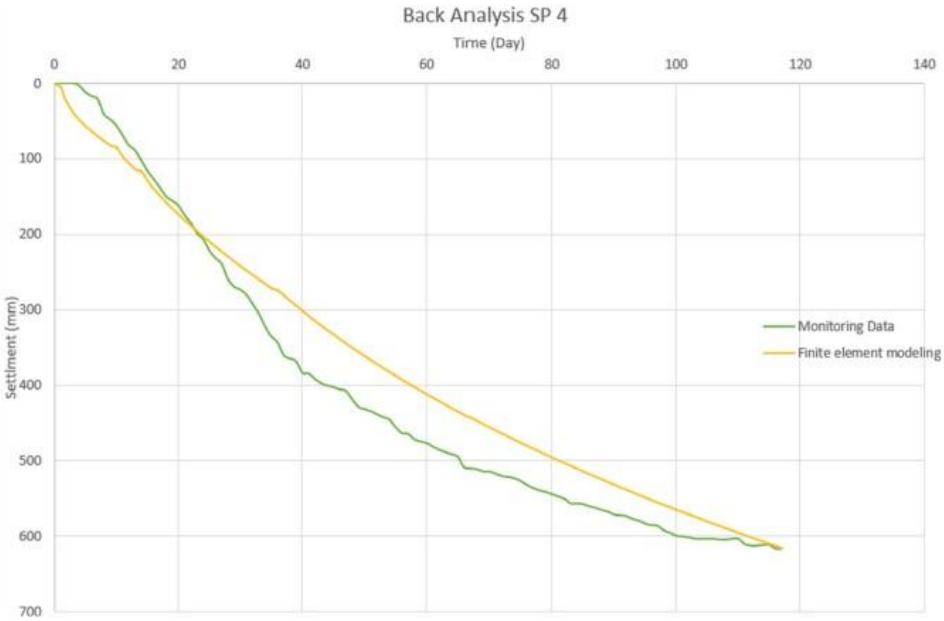

Fig. 6 Back analysis graph result

Table 2 Summary of parameter back analysis result

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
9–10	Clay	Stiff	16.5			0.7

monitoring data in the form of settlement plate data in order to obtain the appropriate soil parameters which can be seen at Fig. 6. After that, parameters are obtained based on the results of back analysis where the parameters that influence the graph adjustment are consolidation parameters which can be seen in the Table 2. For 2–7 m depth, we modelled the soft soil using soft soil model so there is only a consolidation parameter and don't have a stiffness parameter. For modeling medium stiff and stiff soils, a hardening soil model is used so that there is no consolidation parameter like C_c, C_s but a stiffness parameter which can be seen in the Table 3. For the Permeability result from back analysis can be seen at Table 4.

3.4 *Operational Load Modeling*

After obtaining the appropriate parameters with back analysis, the operational load will be modeled in the form of a road load of 15 kPa to determine the long term

Table 3 Summary of parameter back analysis result (continued)

Depth (m)	E_{50} (kPa)	E_{oed} (kPa)	E_{ur} (kPa)	c'	ϕ'
0–2	10,000	10,000	30,000	5	25
2–7				1	23
7–9	8000	8000	24,000	3	25
9–10	24,000	24,000	72,000	5	26

Table 4 Summary of parameters back analysis results (continued)

Depth (m)	k_x (m/day)	k_y (m/day)
0–2	7×10^{-6}	7×10^{-6}
2–7	7×10^{-6}	7×10^{-6}
7–9	7×10^{-6}	7×10^{-6}
9–10	7×10^{-6}	7×10^{-6}

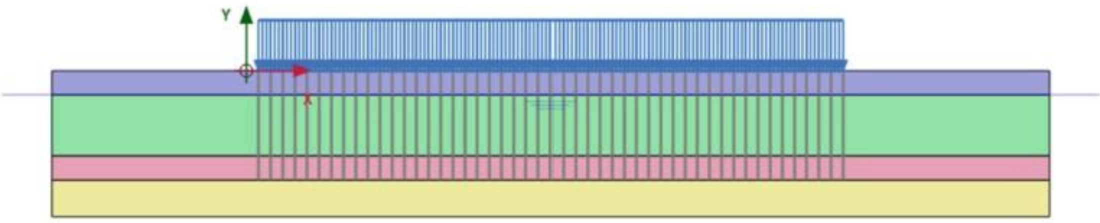

Fig. 7 Modeling operational load of 15 kPa

Table 5 Post settlement results after operational load modeling

Time (year)	S_c (cm)
1	0.39
10	3.37

settlement for 1 year and 10 years which can be seen at Fig. 7. For the result of the post settlement can be seen at Table 5.

4 Conclusion

The conclusions obtained from this research are as follows.

Based on the results of the analysis, it can be obtained that the settlement after being given an operational load for 10 years is 3.37 cm where the settlement results obtained are smaller than the predetermined settlement target as discussed in the previous preliminary chapter. This settlement number indicate that vacuum preloading is one of the soil improvement solutions for settlement problems in soils with soft clay characteristics for the long term period. Because based on back analysis results, soft soil have high compressibility between 0.7 and 0.75 and have low permeability which makes the consolidation process of the soil take a long time.

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