FINAL PROJECT

ANALYSIS OF SOIL IMPROVEMENT WITH COMBINATION OF PREFABRICATED VERTICAL DRAIN AND VACUUM CONSOLIDATION USING PROGRAM

(STUDY CASE: PALEMBANG – INDRALAYA TOLL ROAD SECTION 1 STA 0+000 – 1+000)

Submitted to Universitas Islam Indonesia Yogyakarta to Fulfil the Requirements for Bachelor's Degree in Civil Engineering

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CIVIL ENGINEERING STUDY PROGRAM

FACULTY OF CIVIL ENGINEERING AND PLANNING

UNIVERSITAS ISLAM INDONESIA

YOGYAKARTA

2022

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LETTER OF AUTHENTICITY

The author hereby declare that the Final Project report arranged as a requirement to fulfil one of the requirements in Civil Engineering Study Program Universitar Islam Indonesia is an authentic report written by the author himself. As for certain parts of the Final Project report that the writer referenced from other sources will be listed along with its source properly according to the rule, principle, and ethics pf scientific writing. If, however in the future some parts or all of the Final Project report is discovered to be plagiarized, the writer is willing to receive sanctions, including revocation of academic degree of the writer based on the applicable regulations.

Yogyakarta, 13 December 2022

Author

Ichlasul Pratama Daun

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PREFACE

Assalamualaikum wr. wb.

Alhamdulillah thank God for all the blessings of Allah SWT. With the permission from Allah SWT, the author could finish this Final Project Proposal with title *Analysis of Soil Improvement with Combination of Prefabricated Vertical Drain and Vacuum Consolidation Using Program*. Shalawat and salam to our beloved prophet, Prophet Muhammad SAW. This Final Project Proposal is one of the requirements in completing undergraduate studies at the Civil Engineering Program, Faculty of Civil Engineering and Planning, Islamic University of Indonesia, Yogyakarta.

There are many obstacles for the author when making this Final Project Proposal but thanks to the support, and encouragement from various parties for the author, this Final Project Proposal can be finished. The author expresses appreciate and gratitude towards:

1. Mr. Muhammad Rifqi Abdurrozak S.T., M.Eng as the supervising lecturer which has given many support, guidance, and advice for the author so the author can finish this Final Project.
2. Mrs. Anisa Nur Amalina, S.T., M.Eng. as examiner 1 and Mrs. Hanindya Kusuma Artati, S.T., M.T. as examiner 2.
3. Yunalia Muntafi S.T., M.T., Ph.D. as the Head of Program Study Civil Engineering in Islamic University of Indonesia.
4. Both author's parents Rachmat Daun, S.T., M.T., and Mrs. Merry Sry Nurlianty, S.KM., M.M. Kes., and also author's mom who has passed away Mrs. Hastuti Tolat. Without their support, sacrifice, guidance and love the author can't finish this Final Project.
5. The entire academic community within the Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia, Yogyakarta.

6. The author’s friends from Civil Engineering 2017 students who always give support to the author.
7. The author’s friends from Civil Engineering International Program (IP) 2017.

The author is fully aware that this Final Project Proposal is far from perfect, caused by the lack of experience and knowledge from the author. The author hope that this Final Project Proposal can benefit and help other academic writer and serve as reliable reference for the sake of knowledge.

Amen.

Wassalamualaikum Wr. Wb.

Yogyakarta, 13 December 2022

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(17 511 044)

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NOTATION LIST

Cc	= compressibility index
Ch	= horizontal consolidation coefficient (m^2/day)
Cv	= vertical consolidation coefficient (m^2/day)
De	= range diameter of PVD (m)
D_w	= diameter of PVD (mm)
eo	= pore value
Fr	= friction ratio
F(n)	= resistance factor
H	= soil layer thickness (m)
H_R	= Height plan of land fill (m)
H_{dr}	= flow length
K	= permeability coeeficient of the soil
LL	= liquid limit
l	= width of PVD (mm)
mv	= volume coefficient of compressibility
OCR	= over consolidation ratio
Pc’	= preconsolidation pressure (t/m^2)
Po	= effective overburded pressure (t/m^2)
PVD	= prefabricated vertical drain
qc	= conus pressure
Sp	= primary consolidation (m)
T	= consolidation time (days)
Th	= horizontal factor time
Tv	= time factor
U	= degree of consolidation
Uh	= degree of consolidation in horizontal direction
Uv	= degree of consolidation in vertical direction

Δp = additional vertical pressure

γw = specific gravity of water (t/m^3)

GWL = ground water level (m)

ABSTRACT

Palembang - Indralaya toll road that located in Kab. Ogan Komering Ilir, Sout Sumatera was built on soft soil. Soft soil with its characteristic such as low permeability, high compressibility and low bearing capacity is not suitable for construction since soil settlement can occured and become a threat for the structure above it. So, a soil improvement action is needed in order to meet the criteria of the construction.

The method that will be used is combination of vacuum consolidation method with PVD and soil preloading with PVD to accelerate the consolidation of the soil. This method is done by applying the vacuum pressure to the soil through the PVD that has been installed. It goes the same with preloading where the soil fill will act as additional load to the soil. This research aim is to determine the consolidation time and soil settlement value.

The result for this research that were obtained shows that combination of vacuum consolidation method and prefabricated vertical drain can accelerate the consolidation time. The result is soil settlement of 0.387 m for 47 days on 90% consolidation by using PVD triangle pattern with 1 m space while without PVD took 21.9 years. From the result, the PVD triangle pattern with 1 m space is the most effective PVD pattern.

Key words: prefabricated vertical drain, vacuum consolidation, soil settlement

CHAPTER I

PRELIMINARY

1.1 Background

Indonesia as a developing country currently has many infrastructure projects such as toll roads, ports, airports, and others. Projects like this aim to help community's economic growth. With this kind of infrastructure, it is hoped that it will make it easier for people to carry out their activities, as well as make traveling easier. One of the most important factors that must be put into consideration for the infrastructure is soil, where soil based on its characteristics and condition can affect the design and analysis of the infrastructure. However, it is not uncommon for project like this to be built on soft soil for technical, economic, social and other reasons.

Soft soil is not safe and suitable to be used in a construction due to the characteristics it has. For example, high compressibility, low shear properties, low permeability, and low bearing capacity. Because of these problems, soft soil is unable to withstand the load above it, results in poor construction. For this reason, prior to the construction of an infrastructure, it is necessary to improve the soil for the soft soil so that it can meet the criteria of an ideal soil.

Prefabricated Vertical Drains have other names such as Band Drains or Wick Drains. *Prefabricated Vertical Drains* are plastic strips wrapped with prefabricated geotextile filter with formed channels. *Prefabricated Vertical Drain* (PVD) method used in soil improvement is a method to accelerate the consolidation time (Haussmann, 1990).

Vacuum Consolidation is one of the alternatives for soil improvement that was introduced by Kjellman in 1952. This method is to accelerate the consolidation process by using the force of vacuum pump. This method works by using the vacuum pump to suck water and air in the soil that has been given an airtight sheet on it. This method has several benefits for example cheaper than preloading, reducing the settlement that occurs after construction, and shorten the construction time.

The project location in this final project assignment will be in Palembang – Indralaya toll road which is located in Ogan Komering Ilir regency, South Sumatera Province. This toll road has long span for 22 km, from Palembang city to Indralaya city. In the location where this project located, which is in southern Sumatera, most of the soil condition is soft soil. This is a problem for the toll road construction and hence requires a solution which is soil improvement to prevent consolidation. This research intends to see the result of soil settlement and consolidation time by using *Prefabricated Vertical Drain* (PVD) and *Vacuum Consolidation* for the soil improvement purposes. The map location of the Palembang – Indralaya toll road can be seen in the **Figure 1.1** below.

Figure 1.1 Palembang – Indralaya Toll Road Map Location

(Source: Google Maps, 2022)

1.2 Problem Statement

Below are the problem statements for this research, which is shown below.

1. How is the soil settlement and consolidation time of the soil on 90% consolidation using Preloading method without PVD by using manual calculation (Terzaghi method)?
2. How is the soil settlement and consolidation time using Vacuum method with PVD on 90% consolidation by using manual calculation (Terzaghi method)?
3. How is the soil settlement and consolidation time on consolidation 90% using Preloading method with PVD by calculating using Finite element method?
4. How are the comparison between Vacuum method and Preloading method?

1.3 Objective

Based on the problem statement above, the objectives can be seen below.

1. Determine the consolidation time and soil settlement of the soil using Preloading method without PVD on 90% consolidation by using manual calculation (Terzaghi method).
2. Determine the consolidation time and soil settlement using the combination method of Vacuum consolidation and Prefabricated Vertical Drain (PVD) by using manual calculation (Terzaghi method).
3. Determine the consolidation time and settlement soil using the combination method of Preloading and Prefabricated Vertical Drain (PVD) by using Finite element method.
4. Comparing the result between Vacuum method with manual calculation (Terzaghi method) and Preloading method with Finitie element method calculation.

1.4 Benefits

The benefits of this research can be seen below.

1. Knows the consolidation time and soil settlement of the soil using Preloading method without PVD on 90% consolidation by using manual calculation (Terzaghi method).
2. Knows the differences of consolidation time and settlement of the soil using combination method of PVD and Vacuum consolidation by calculating manually (Terzaghi method).
3. Knows the differences of consolidation time and settlement of the soil using combination method of PVD and Preloading method by calculating using Finite element method.
4. Knows the comparison between Vacuum consolidation method and Preloading method.

1.5 Limitations

The limitations for this research are stated below.

1. The project location is at Palembang-Indralaya road project.
2. The data that will be used are from PT. Hutama Karya.
3. In this research, the program that will be used to calculating the consolidation is Plaxis 2D v8.2.
4. The method used in this research will be combination of Vacuum consolidation and Prefabricated Vertical Drain (PVD) using manual calculation and combination of Preloading method with PVD using Finite element method.
5. The data that will be used in this research is only from BH-1.
6. The settlement result that will be used is from primary consolidation calculation.

CHAPTER II

LITERATURE REVIEW

2.1 General

Soil improvement is an effort that aims to improve the original characteristics of the soil in order to meet the requirements for a construction. The purposes of soil improvement are to improve the engineering characteristics of the soil such as strength, reduced compressibility, and reduced permeability.

According to Darwis (2017), the objectives of soil improvement are as follows:

1. increase the bearing capacity and shear strength,
2. increase the shear strength of the soil,
3. reduces compressibility and soil settlements,
4. reduces soil permeability (case: embankment),
5. increase soil permeability (case: dewatering and sand lens),
6. minimize the potential for swelling and shrinkage of the soil (swelling potential), and
7. ensuring the sustainability of natural resources and the environment.

There are many methods that can be used in order to carried out the soil improvement effort. One of those methods are combination of vacuum consolidation and Prefabricated Vertical Drain (PVD). The reason to combinated the two methods together is to reduce the consolidation time. The PVD will accelerate the flow of ground water to the surface.

Below is the description of previous studies.

2.1.1 Analysis of Consolidation Time and Settlement

Atmaja (2021) condicted a research about the analysis of settlement value and consolidation time on soil improvement using combination of PVD and preloading. This research was conducted using manual calculation and plaxis program. The location was in Raya Klampok road, Kec. Wanasari, Tegal, Central Java Province. The purpose of the research is to calculate and analize the consolidation time and settlement on 90% using combination of preloading with PVD and without PVD and then compare the results between manual calculation and plaxis program. The consolidation used in this research is primary consolidation without considering the safety factor from the soil pile. The research using PVD with 2 types of pattern which are rectangle and triangle with different spacing of 1 m, 1.2 m, 1.4 m, and 1.6 m. The research stated that the triangle PVD pattern are more effective than the rectangle pattern.

2.1.2 Influence of Preloading to Consolidation Time and Settlement

Wulandari (2017) conducted a research about *Perbandingan Analisis Penurunan Konsolidasi dengan Menggunakan Metode Elemen Hingga Manual dan Plaxis*. The research location was in Gondang, Karanganyar, Central Java. The purpose of the research is to determine the difference in value of settlement and consolidation time with different height of land fill by using manual and Plaxis. According to the result, the height of the land fill can affect the settlement value and consolidation time. It can be seen in the result where 1 m and 2 m land fill with 5 m soil layer has the settlement value of 0.185 m and 0.275 m. It also appears that the height of land fill affects the consolidation time where 1 m and 2 m land fill with 5 m soil layer has the consolidation time of 1.215 days and 1.315 days.

2.1.3 Influence of PVD to Consolidation Time and Settlement

Setiawan (2019) conducted a research about Analysis of Settlement and Consolidation Time Using Preloading and Prefabricated Vertical Drain with Mohr Coulomb. The research location was in Banyumas, Central Java. The purpose of the research is to determine the settlement value and consolidation time by using preloading and PVD. This research using the preloading method with PVD. The

PVD that are used has different pattern and spacing. According to the result, preloading without PVD has the settlement value of 0.345 m with consolidation time of 95000 days. While the fastest preloading method with PVD is PVD with triangle pattern for 155 days with same settlement value as the preloading without PVD. So based on the result, this research stated that PVD combinated with preloading can accelerate the consolidation time.

2.1.4 Influence of Vacuum to Consolidation Time and Settlement

Fadhillah (2018) conducted a research about soft soil improvement planning on cluster D of Bandung Summarecon construction site using combination of vacuum consolidation and PVD. This location was in Gedebage, Bandung, West Java. This research purposes are to analize the consolidation using combination of vacuum consolidation and PVD method. The vacuum pressure will serve as the additional load to the soil. With the effectivity of the vacuum on 80%, the vacuum pressure became 74 kPa or equivalent with 4.625 m soil pile. According to the result, the most effective design pattern is triangle pattern with 1.2 m space. The consolidation time needed by using the same PVD pattern on 90% consolidation is 22 weeks compare to the result from without the soil improvement which is 194 years. So, the vacuum pressure is the same with preloading, the only difference is that vacuum pressure uses the pressure that equal to the soil pile with certain height depends on the vacuum pressure kPa.

2.2 Research Authenticity

Below is the comparison between the previous research and this research, it can be seen in Table 2.1

Table 2.1 Comparison with Previous Research

Research	Atmaja (2021)	Setiawan (2019)	Oktavian (2019)	Fadhillah (2018)	Wulandari (2017)	Daun (2022)
Title	Analisis Penurunan Dan Waktu Konsolidasi Pada Perbaikan Tanah Lunak Dengan Metode Prefabricated Vertical Drain Dan Preloading	Analisis Penurunan Dan Waktu Konsolidasi Pada Perbaikan Tanah Lunak Dengan Metode Preloading dan Prefabricated Vertical Drain Dengan Pemodelan Mohr Columb	Perencanaan Perbaikan Tanah Pada Pembangunan Jalan Tol Pematang Panggang – Kayu Agung, Sumatera Selatan Dengan Metode Preloading Kombinasi Prefabricated Vertical Drain Dan Prefabricated Horizontal Drain	Perencanaan Perbaikan Tanah Lunak Pada Pembangunan Cluster D Kawasan Kota Summarecon Bandung Menggunakan Kombinasi Metode Vacuum Consolidation Dengan Prefabricated Vertical Drain	Perbandingan Analisis Penurunan Konsolidasi dengan Menggunakan Metode Elemen Hingga Manual dan Plaxis	Analysis of Soil Improvement with Combination of Prefabricated Vertical Drain and Vacuum Consolidation Using Plaxis 2D Program

Research	Atmaja (2021)	Setiawan (2019)	Oktavian (2019)	Fadhillah (2018)	Wulandari (2017)	Daun (2022)
Research Purposes	To calculate and analize the soil settlement and consolidation time	To determine the settlement and consolidation time using preloading and Prefabricated Vertical Drain	To analize and planning the PVD and PHD method combinated with preloading with planned time	To analize the compressed soil time and to analize the foundation bearing capacity	To Determine the consolidation time and settlement value	To analize and compare the settlement value and consolidation time of the soil by using several methods
Method	Combination of PVD and Preloading using Terzaghi and Plaxis Program	Combination of Preloading and PVD using analitik calculation and plaxis	Combination of PVD and PHD with preloading method	Combination of Vacuum Consolidation and PVD	Combination of Preloading and PVD using terzaghi method and plaxis	Using combination of PVD with preloading and vacuum consolidation with terzaghi method and Plaxis

Research	Atmaja (2021)	Setiawan (2019)	Oktavian (2017)	Fadhillah (2018)	Wulandari (2018)	Daun (2022)
Result	The soil settlement value using preloading method without PVD on 90% consolidation is 0.154 m on 54 years in manual calculation and 0.205 m on 54 years with plaxis. With PVD it became 0.155 m on 57 days in manual calculation and 0.208 m on 43 days in plaxis program.	By using combination of preloading and PVD, it helps accelerate the consolidation time. Without PVD the time needed is 260 years while by using PVD is only 3 – 19 months depend on the PVD pattern and spacing	The PVD installation using rectangle pattern with space of 0.8 m accelerate the consolidation time from 130 years to 19 weeks with total of soil pile used is 8.69 m.	Using the PVD with triangle pattern and spacing 120 cm as the most efficient installation pattern, the consolidation time for 90 % without soil improvement is 194 years and with soil improvement is 22 weeks	The biggest settlement difference happened on land fill with 1 m height which is 85.829%. While the biggest time difference happened on land fill with 4 m height which is 114.320%	The soil settlement and consolidation time without PVD is 0.388 m in 21.9 years while the most effective is using PVD with triangle pattern 1 m space, the time consolidation and soil settlement is 0.388 in 47 days

CHAPTER III
THEORETICAL BASIS

3.1 Soil

According to Hardiyatmo (2002), in civil engineering terms, soil is a collection of material, organic matter, and sediment that are relatively loose that located in top of bedrock. The bonds between the grains are relatively weak caused by carbonates, organic matter, or oxides that settle between the particles. The forming process of soil from rocks as the main material, can be divides into 2 which are physical process and chemical process. For physical process, the soil was formed through the influence of erosion, wind, water, ice, human, temperature, and weather. In chemical process, soil was formed through the influence of oxygen, carbon dioxide, water (that contains acid or alkali) and other chemical process.

According to Bowles (1984), the definition of soil is some particles consisting of the following types.

1. Boulders (*Berangkal*) is a rock that have a size bigger than gravel rocks which is 150 mm – 250 mm. The shards of these rocks also called pebbles (*kerakal)*.
2. Gravel (*Kerikil*) is a particles, shards, or fractions of a rock with the size of 5 mm – 150 mm.
3. Sand (*Pasir*) is an aggregate with the size of 0,074 mm – 5 mm with the roughness size is 3 mm – 5 mm and the finest size less than 1 mm.
4. Silt (*Lanau*) is rock particle with size of 0,002 mm – 0,0074 mm.
5. Clay (*Lempung*) is a particle with the size of 0,002 mm that sourced from cohesion on cohesive soil.
6. Colloids (*Koloid*) is mineral particle with the size smaller than 0,001 mm.

3.2 Soil Classification

There are 2 ways to classify the type of soil which are by laboratorium test and field tes. In field test, data that obtained from sondir test can be used to classify the type of soil in the field. This method usually used to determine the soil below the surface by penetrating on at the specified location. The data that will be obtained are conus pressure (qc = qt) and friction ratio (Fr). The soil classification will use graph that were publicated by **Robertson et al (1986)** that can be seen in **Figure 3.1** and **Table 3.1** below.

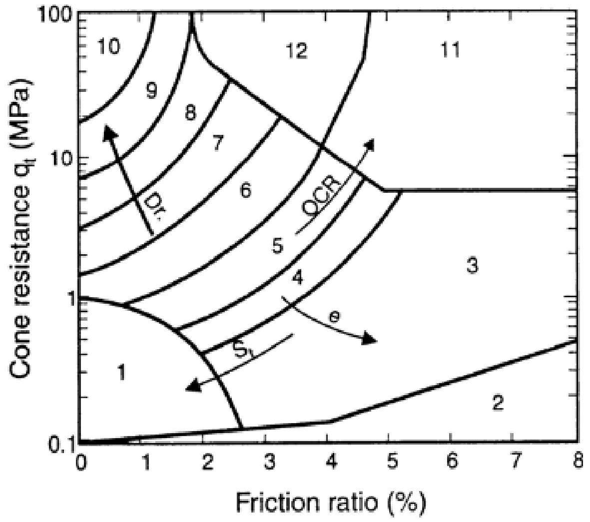

Figure 3.1 The qt-Fr soil type zone

(Source: Robertson et al, 1986)

Table 3.1 Soil Classification Table according to qt-Fr

Zone	Soil Behaviour Test
1	Sensitive fine grained
2	Organic material

Zone	Soil Behaviour Test
3	Clay
4	Silty clay to clay
5	Clayey silt to silty clay
6	Sandy silt to clayey silt
7	Silty sand to sandy silt
8	Sand to silty sand
9	Sand
10	Gravelly sand
11	Very stiff fine grained
12	Sand to clayey sand

(Source: Robertson et al, 1986)

3.3 Soft Soil

In Geoteknik I with title of "*Proses Pembentukan dan Sifat – Sifat Dasar Tanah Lunak* (2002)", the term of "soft soil" is related to soil which, if not identified and investigated carefully, can cause problems of intolerable long-term instability and settlement, have low shear strength and high compressibility. According to Setiawan (2019) the characteristics of soft clay are low bearing capacity, low coefficient of permeability, high compressibility, and high shear forces.

In *Panduan Geoteknik 1 Proses Pembentukan dan Sifat-Sifat Dasar Tanah Lunak* book by *Departemen Permukiman dan Prasarana Wilayah*, there are 2 types of soft soil which are as explained below.

1. Peat

Peat is a soil types that are formed from the remains of plants that are already half-rot. In Geotechnical, there are 3 classification and divided based on the organic content which can be seen in the **Table 3.2** below.

Table 3.2 Soil with Organic Content

Consistency	**Organic Content (%)**
Clay	<25
Organic clay	25 – 75
Peat	>75

(Source: *Departemen Permukiman dan Prasarana Wilayah*, 2002)

2. Soft Clay

Soft clay soil has a high content of water and clay minerals that caused the weak shear strength of the soil. In geotechnical, the terms of "soft" and "very soft" specifically defined for clay soil with shear strength. The shear strength of the soft clay soil with its consistency can be seen in the **Table 3.3** below.

Table 3.3 Shear Strength of Soft Clay Soil

Soil Consistency	Shear Strength (kN/m^2)
Soft	12,5 – 25
Very Soft	<12,5

(Source: *Departemen Permukiman dan Prasarana Wilayah*, 2002)

Table 3.4 Field Indicator on Soft Clay Soil

Consistency	Indicator
Soft	Can be formed easily with hand
Very Soft	Leak out between hand fingers when being squeezed in hand

(Source: *Departemen Permukiman dan Prasarana Wilayah*, 2002)

3.4 Soil Settlement

Soil settlement is an event where the soil moving downward due to the increasing of stress on the soil because of the load that applied on top of the soil. During this the water and air in the soil pores will come out and cause a decrease in volume of the soil resulting in settlement. According to Liu and Evett (2018) in Soils and Foundations, the soil settlement can be classified into two which are as follows.

1. Immediate (or elastic) settlement

   It takes place rapidly after adding loads without and change in moisture content and volume.

2. Consolidation

   This type includes two phases which are primary consolidation phase and secondary consolidation phase. For primary consolidation phase, this phase is a consolidation settlement results from the change of volume due to water extrusion from soil pores. For secondary consolidation phase, it is an extra deformation of soil occurs due to constant adding of loads.

Relationship of deformation and time can be seen in **Figure 3.2** below.

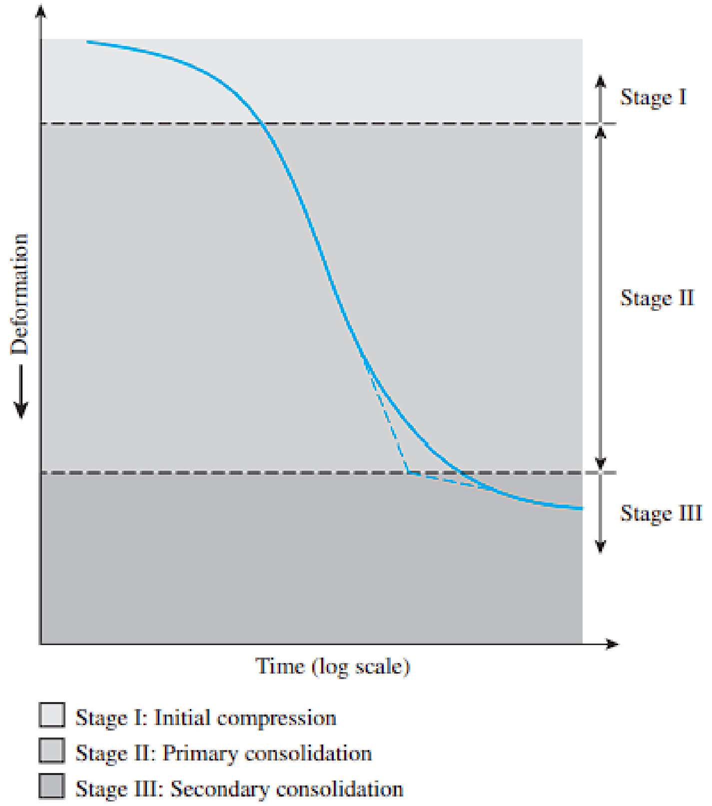

Figure 3.2 Relationship of Time (Log Scale) and Deformation during Consolidation for a given Load

(Source: Das, 2013)

In primary consolidation phase, it is a settlement caused by changes in soil volume that occur during the period of pore water flow. There are 2 types of consolidation that can occur during the primary consolidation. First is normally consolidated. Normally consolidated occur when the soil effective overburden pressure that occur now is the maximum that ever occurred on the soil or the soil never had bigger pressure than the one that occur now. Second is overly consolidated that can occur when the current effective overburden pressure that soil experienced is less than the effective overburden pressure that was experienced by the soil before. In order to categorized whether a soil is on normally consolidated or overly consolidated condition is from the Over Consolidation Ratio (OCR) value. The equation to obtained the OCR value can be seen in **Equation 3.1** below.

$$OCR = \frac{Pc\prime}{Po} \qquad \textbf{(3.1)}$$

Where:

Pc’ = Preconsolidation pressure, and

Po = Effective overburden pressure

If the value of the OCR = 1, then the soil is in normally consolidated condition. The principle for effective stress and the value of normally consolidated settlement can be seen in **Equation 3.2** below.

1. Normaly Consolidated

Below is the equation for Normally Consolidated condition.

$$Sp = \frac{Cc\ x\ H}{1+e_0} log \frac{Po\ x\ \Delta p}{Po} \qquad \textbf{(3.2)}$$

Where:

Cc = Compressibility index,

Po = Effective overburden pressure,

Δp = Additional vertical pressure,

eo = Pore value,

H = Soil layer thickness, and

Sp = Primary consolidation

2. Over Consolidated

If the value of OCR > 1, then the soil is on overly consolidated condition. The equation to calculated the overly consolidated soil can be seen in **Equation 3.3** and **Equation 3.4** below.

If Po + ΔP ≤ Pc’, thus

$$Sp = \frac{Cs\ x\ h}{1+e0}\ Log\ (\frac{Po+\ \Delta P}{Po}) \qquad \textbf{(3.3)}$$

If Po + ΔP ≥ Pc', thus

$$Sp = \frac{Cs\ x\ h}{1+e0}\ Log\ \left(\frac{Pc'}{Po}\right) + \frac{Cc\ x\ h}{1+e0}\ Log\ \left(\frac{Po+\Delta P}{Pc'}\right) \quad \textbf{(3.4)}$$

The method to calculate Pc' can be seen in **Figure 3.3** below.

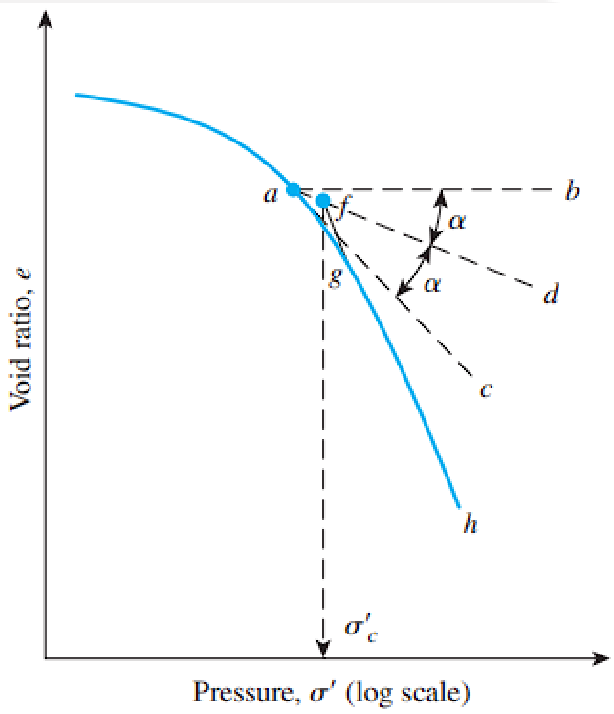

Figure 3.3 Cassagrande Method

(Source: Das, 2013)

The graph that will be used to determine the Pc' is a graph from the laboratory e – log σ' curve. The steps in this method can be seen below.

1. Establish the point of the curve, or the point where the curve changes slope the most. In this graph the point represented as point a.
2. Draw horizontal line from point a to get line a-b.
3. Draw a tangent line a-c.
4. Draw the line a-d, this line devide line b-c-a in equal size.
5. Draw straight line of the curve back until it intersects with line a-d. The intersection of the line called point f.

6. From point f, draw a straight line downwards to determine the Pc' value.

In order to calculate the additional vertical pressure (ΔP), the equation can be seen in **Equation 3.5** and **3.6** below.

$$\Delta P = 2 \times q_o \times I \quad \textbf{(3.5)}$$

$$q_o = \gamma_{\text{land fill}} \times H \quad \textbf{(3.6)}$$

Where:

ΔP = Additional vertical pressure,

q_o = Weight of preloading,

$\gamma_{\text{land fill}}$ = Volume weight of land fill,

H = Height of Preloading, and

I = Influence factor.

The Influencec Factor (I) can be obtained by using the Osterberg graph that can be seen in **Figure 3.4** below.

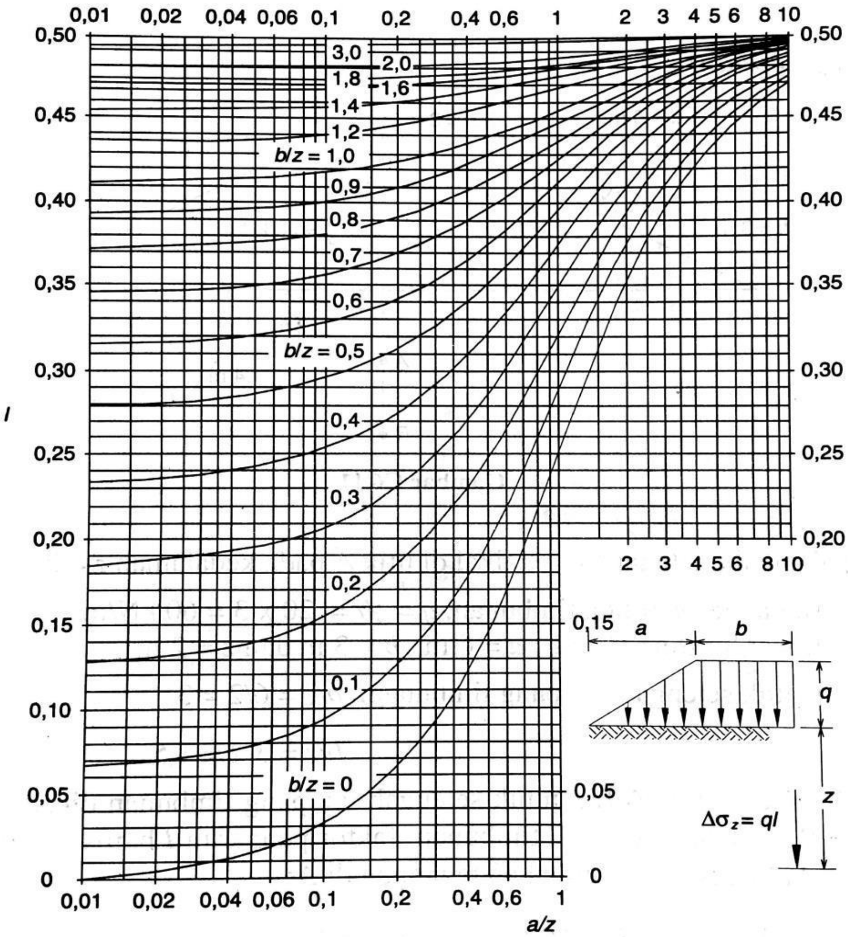

Figure 3.4 Influence Factor Caused by Land Fill Load (Osterberg, 1957)

(Source: Hardiyatmo, 2002)

The curve for consolidation characteristic of normally consolidated and overconsolidated can be seen in **Figure 3.5** and **Figure 3.6** below.

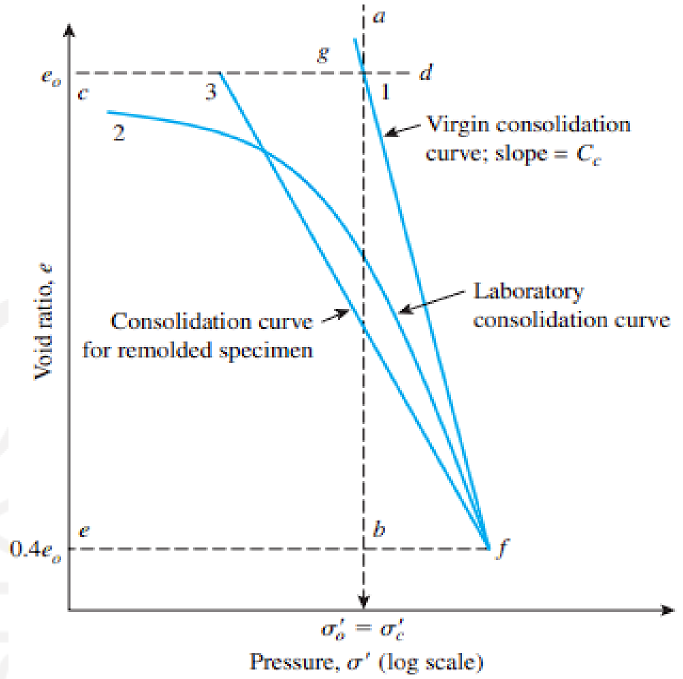

Figure 3.5 Characteristics of Normally Consolidated Clay of Low to Medium Sensitivity

(Source: Das, 2013)

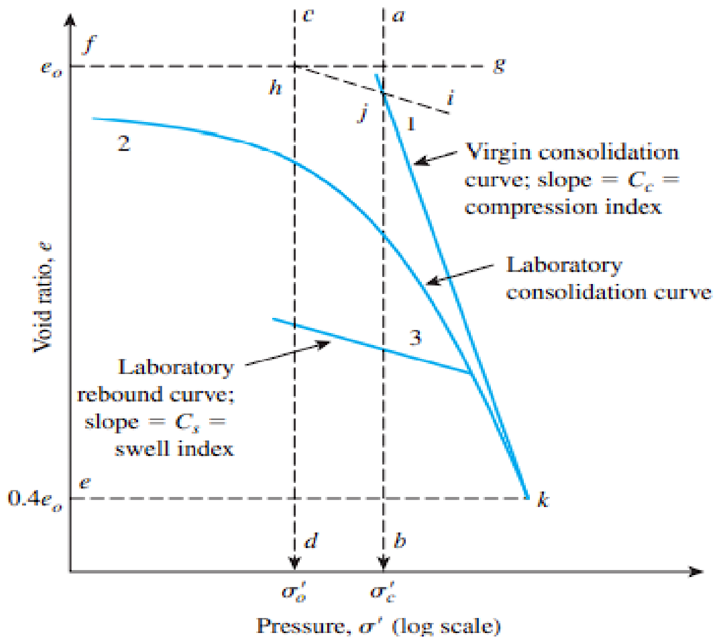

Figure 3.6 Characteristics of Overconsolidated Clay of Low to Medium Sensitivity

(Source: Das, 2013)

3.5 Consolidation

Calculating consolidation time for soil can be calculated using equation from Terzaghi to determine the degree of consolidation in vertical direction (Uv). The equation to obtain Uv can be seen in **Equation 3.7** below.

$$Uv = \frac{\sqrt{\frac{4\ x\ Tv}{\pi}}}{(1+(\frac{4\ Tv}{\pi})^{2,8})^{0,179}} \quad \textbf{(3.7)}$$

Where:

Uv = Degree of consolidation in vertical direction, and

Tv = Time factor

Terzaghi (1943) in Barimbing (2017), time factor of consolidation settlement can be calculated by using the **Equation 3.8**.

$$T_v = \frac{T\ x\ Cv}{Hdr^2} \quad \textbf{(3.8)}$$

Where:

T = Consolidation time,

T_v = Time factor,

H_{dr} = Flow length, and

Cv = Vertical Consolidation Coefficient

3.6 Soil Parameter

For calculating the soil settlement value, several parameters are needed. Below are the parameters that needed to calculate the consolidation settlement.

3.6.1 Vertical Consolidation Coefficient (Cv)

Vertical consolidation coefficient determines the time of consolidation in the vertical direction on the soil. The vertical consolidation coefficient (Cv) will decrease with the increasing of liquid limit (LL) of the soil. Consolidation coefficient effect the speed of consolidation. The equation to calculate vertical consolidation coefficient (Cv) are shown in the **Equation 3.9** below.

$$Cv = \frac{k}{\gamma w \ x \ mv} \qquad \textbf{(3.9)}$$

Where:

Cv = Vertical consolidation coefficient,

k = Permeability coefficient of the soil,

γw = Specific gravity of water, and

mv = Volume coefficient of compressibility

3.6.2 Horizontal Consolidation Coefficient (Ch)

Horizontal consolidation coefficient can be calculated using the value of Cv that are obtained. Based on Journal Aspects on the Modeling of Smearzone around Vertical Drain The equation for determining the Ch value can be seen in the **Equation 3.10** below.

$$Ch = 1 \ s/d \ \ 2 \ Cv \qquad \textbf{(3.10)}$$

Where:

Ch = Horizontal consolidation coefficient,

Cv = Vertical consolidation coefficient

3.6.3 Horizontal Time Factor (Th)

The equation used to obtain the horizontal time factor can be seen in the **Equation 3.11** below.

$$T_h = \frac{Ch \ x \ t}{De^2} \qquad \textbf{(3.11)}$$

Where:

Th = Horizontal Factor Time,

Ch = Horizontal Consolidation Coefficient

De = Range Diameter of PVD, and

T = n time

3.6.4 Degree of Consolidation in Horizontal Direction (Uh)

The equation used to obtain Uh can be seen in **Equation 3.12** below.

$$Uh = 1 - exp^{(\frac{-8 \, x \, Th}{F(n)})} \quad \textbf{(3.12)}$$

Where:

Uh = Degree of consolidation in horizontal direction,

Th = Horizontal time factor, and

F(n) = Resistance Factor

3.6.5 Compressibility Index (Cc)

Compressibility index affect the settlement that occur due to the consolidation process of the supporting soft soil. The equation to calculate the Cc can be seen on **Equation 3.13** below.

$$Cc = 0{,}009 \times (LL - 10) \quad \textbf{(3.13)}$$

Where:

Cc = Compressibility index, and

LL = Liquid limit

3.6.6 Volume Coefficient of Compressibility (mv)

Volume coefficient of compressibility (mv) is defined as the ratio of unit volume change per unit increase in stress. The equation to calculate the mv can be seen on the **Equation 3.14** below.

$$mv = \frac{Sp}{\Delta P} \quad \textbf{(3.14)}$$

Where:

Sp = Primary consolidation settlement,

mv = Volume coefficient compressibility, and

ΔP = Additional vertical stress

3.6.7 Degree of Soil Consolidation

Degree of soil consolidation (U) is a ratio between pore water pressure decreases after some time with the total decreases. According to Carillo (1942) in Barimbing (2017) the equation for degree of soil consolidation that has been stabilized using prefabricated vertical drain method are using **Equation 3.15** below.

$$U = 1 - (1 - U_v) \times (1 - U_h) \quad \textbf{(3.15)}$$

Where:

U = Average Consolidation degree,

U_v = Degree of consolidation in vertical direction, and

U_h = Degree of consolidation in horizontal direction

3.7 Prefabricated Vertical Drain (PVD)

Prefabricated vertical drain (PVD) is method to speed up the consolidation process along the vertical drain. PVD is a man-made drainage system that are installed vertically in the soft soil layer. The technical requirements for PVD can be seen in **Table 3.5** below.

Table 3.5 Techincal Requirements of PVD

Property	Requirement	Testing Method
Width	Minimum 100 mm	
Thickness	Minimum 3.3 mm	
Tensile Strength	Bigger than 2000 N	ASTM D-4595

Property	Requirement	Testing Method
Strength at 10% elongation, dry and wet condition	Bigger than 1000 N	ASTM D-4595
Filter Permeability	Minimum $1x10^{-4}$ m/second	ASTM D-4491
Opening Size	Smaller than 90 microns	ASTM D-4751
Discharge Capacity at 300 Kpa straight	Minimum $35x10^{-6}$ m^3/second	ASTM D-4716
Discharge Capacity at 200 Kpa, buckled	Minimum $35x10^{-6}$ m^3/second	ASTM D-4716
Discharge Capacity at 100 Kpa, buckled	Minimum $40x10^{-6}$ m^3/second	ASTM D-4716

(Source: Barimbing, 2017)

There are factors that affect the consolidation process which are the distance between PVD and the length of the PVD. The cross section of the PVD is modelled as a circle with the assumed equivalent calculation of the perimeter of the rectangle. Assumption is based on the equation of **Equation 3.16** and **Equation 3.17** below.

Perimeter of rectangle = perimeter of circle

$$\pi \ d_w = 2\ (p + 1) \tag{3.16}$$

$$d_w = \frac{2\ (p+l)}{\pi} \tag{3.17}$$

Where:

d_w = diameter of PVD (cm),

p = length of PVD (cm), and

l = width of PVD (cm)

Pattern and distance of the PVD are depends on the installation. There are two types of pattern of PVD installation, which are triangle pattern and rectangle pattern. The example of the pattern can be seen in **Figure 3.7** below. To calculate the effect of PVD installation pattern using the equation on **Equation 3.18** and **Equation 3.19** below.

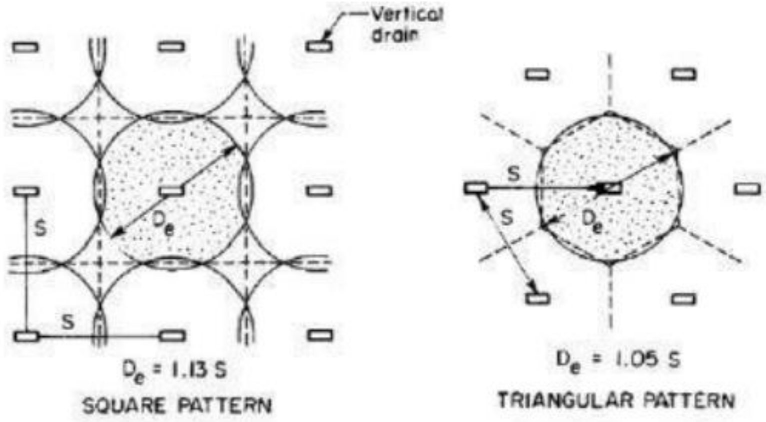

Figure 3.7 Square and Triangle Pattern of Prefabricated Vertical Drain (PVD)

(Source: Barimbing, 2017)

De = 1,05 S (triangle pattern) **(3.18)**

De = 1,13 S (square pattern) **(3.19)**

Where:

De = equivalent diameter, and

S = Distance between PVD

The resistance factor from the distance between the PVD can be calculated using the **Equation 3.20** below.

$$Fn = \ln\frac{De}{dw} - \frac{3}{4} \qquad \textbf{(3.20)}$$

Where:

Fn = Resistance factor,

De = Working range diameter of PVD, and

dw = Equivalent diameter of PVD

3.8 Vacuum Consolidation

Vacuum consolidation is a method that involves installation for man-made vertical drain in the soil layer in order to lowering the atmospheric pressure. This can lead into the speed up of consolidation process in the soil. This method by using vacuum has more advantages compare to conventional preloading method. Vacuum consolidation method is cheaper and safer compare to conventional preloading method because conventional preloading method cost a huge amount of fee for landfill transferring and also this method is vulnerable to landslide. The illustration of vacuum consolidation method can be seen in the **Figure 3.8** below.

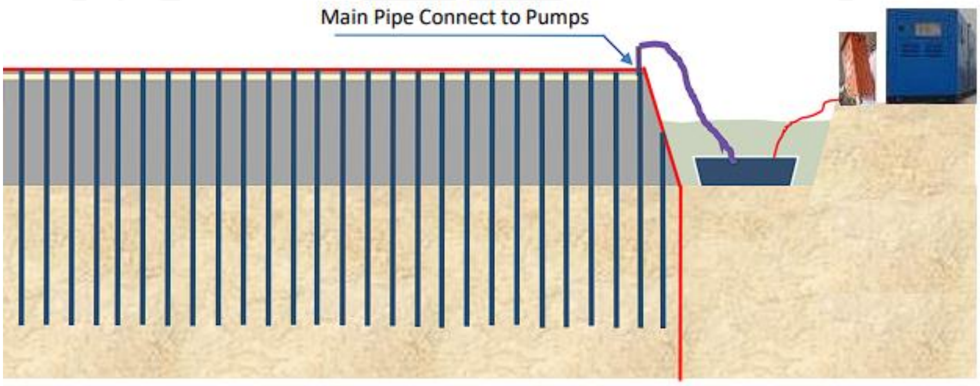

Figure 3.8 Illustration of Vacuum Consolidation System

(Source: PT. Hutama Karya Infrastruktur, 2017)

The installation of vacuum system begins with spreading a sand layer on top of the soil as a platform that has a function as a drain layer. After that, install the PVD followed by installation of prefabricated horizontal drainage (PHD). PVD can be installed using triangle or square pattern.

3.9 Preloading

Preloading method is a process of soil compression that works by applying vertical pressure to the construction soil. This method uses a load that is the same the construction load. In order to calculate the preloading, it is required to calculate the height plan of the preloading. The equation to calculate the height plan of the preloading can be seen in **Equation 3.21** below.

$$H_R = \frac{q}{\gamma \, land \, fill} \tag{3.21}$$

Where:

H_R = Height plan of preloading,

q = Plan load, and

γ land fill = Volume weight of land fill

3.10 Plaxis Program

Plaxis is a program that were developed in 1987 at Delft University of Technology in Netherlands. Plaxis itself is a program that were used for geotechnical engineering simulation to analize the deformation and stability of soils and rock. The calculation process is based on numerical procedures and also fully automated. The ability of the program to create graphical model from the simple one to the complex one makes it easier to understand and operate the program. There are 4 sub programs in Plaxis program which are input, calculation, output and curve. In Plaxis, there are several kind of soil models, the soil models can be seen below.

1. Linear Elastic

   This model involves two basic elastic parameters, which are Young's modulus (E) and Poisson's ratio (v). This model is not suitable for soil modelling since it's used to model stiff volumes like concrete walls, or intact rock formations.

2. Mohr-Coulomb model (MC)

   This model is generally used for soil modelling. The parameters used in this model are Young's modulus (E), Poisson's ratio (v), dilactancy angle (y), and Friction angle (f).

3. Hardening Soil (HS)

This model is for soil with Friction hardening plasticity and used for modelling gravel.

4. Soft Soil (SS)

This model is used for modelling soil like peat.

Below are the steps to conduct an analysis by using Plaxis program.

1. Input

In this step, the parameter such as soil parameter, and load model must be inputted to the program in order to conduct the analysis.

2. Calculation

In this step, the program will execute the calculation phases. This calculation can be an excavation phase, consolidation period, safety analysis or loading analysis.

3. Output

After conducting the calculation, the output will be available for evaluation. The output can be settlement, safety factor or deformation.

4. Curve

The result of the calculation will show 2 different parameters that can be compared to each other.

CHAPTER IV

RESEARCH METHODOLOGY

4.1 Research Location

The research location of the project will be located in Palembang – Indralaya toll road which is in Ogan Komering Ilir Regency, South Sumatera Province. This toll road has a long span of 22 km, start frin Palembang city to Indralaya city. The location of the project can be seen in **Figure 4.1** below.

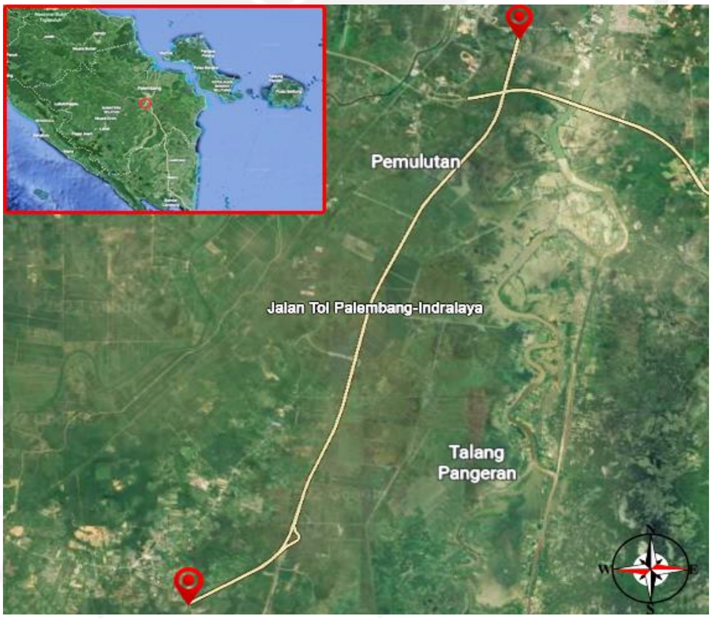

Figure 4.1 Map Location of Palembang – Indralaya Toll Road
(Source: Google Maps, 2022)

4.2 Tools

In analysing the soil settlement, the tools and materials that will be used are as shown below.

1. Hardware Laptop Acer Predator Nitro-5 with specification of Processor Ryzen 5, VGA AMD Radeon RX series, 8GB DDR4 Memory, and 1TB HDD.
2. Hardware Personal Computer (PC) with specification of Processor Ryzen 3 2200 G, VGA AMD Radeon Rx 570 8GB, 16GB DDR4 Memory, and 1TB HDD.
3. Software Microsoft Excel 2010 and Plaxis 2D on OS Windows 2010.

4.3 Procedure of Analysis

4.3.1 Data Collection

Collecting the data for research is one of the most important steps, because in this step the data will be used to conduct the research in order to obtain the desired result for analysis. In this research, the data that will be used will be the secondary data that are obtained from PT. Hutama Karya Infrastruktur. The data that will be used are as follows:

1. Data from laboratorium test
    a. Specific gravity,
    b. Water content,
    c. Pore value, and
    d. Compression index.
2. Data from field test
    a. Cone Penetration Test (CPT), and
    b. Standard Penetration Test (SPT).

4.3.2 Data Analysis

In this research, the data analysis is done by conducting analysis through program/software and manually. Steps for manual calculation (Terzaghi method) can be seen below.

1. Determine the OCR value to find out the soil consolidation type condition by using the equation from **Equation 3.1**.

2. Determine the primary consolidation value by using **Equation 3.2**, **Equation 3.3**, and **Equation 3.4** depend on the OCR value.
3. Determine the consolidation time.

In the manual calculation, there will be two modelling that will be used, which are the preloading without PVD and combination of vacuum pressure and PVD.

The software that will be used are Plaxis 2D. The model will be made using the same program. Below are the steps for conducting the analysis by using Plaxis 2D software.

1. Preparing the soil data from the laboratorium test.
2. Setting the Plaxis 2D program to start the analysis. The setting steps will be as follows.
   a. Make a new file for the analysis on Plaxis 2D program.
   b. Arrange the tab projection and dimension for modelling in the Plaxis 2D program.
   c. Setting the geometry of the project.
   d. Set up the material parameter.
   e. Calculating the initial condition that were being reviewed from the construction.
   f. Calculating what have been defined on the construction and the types.
3. There are several things that must be paid attention to when conducting the analysis with Plaxis 2D program which are shown below.
   a. Reviewing the result from the analysis with analythical model.
   b. Reviewing the result from the analysis of the soil improvement with combination of PVD and vacuum.

4.3.3 Modelling

The geometry of the project will be based on the soil profile in the construction site. The soil profile in construction site can be seen in the **Figure 4.2** below.

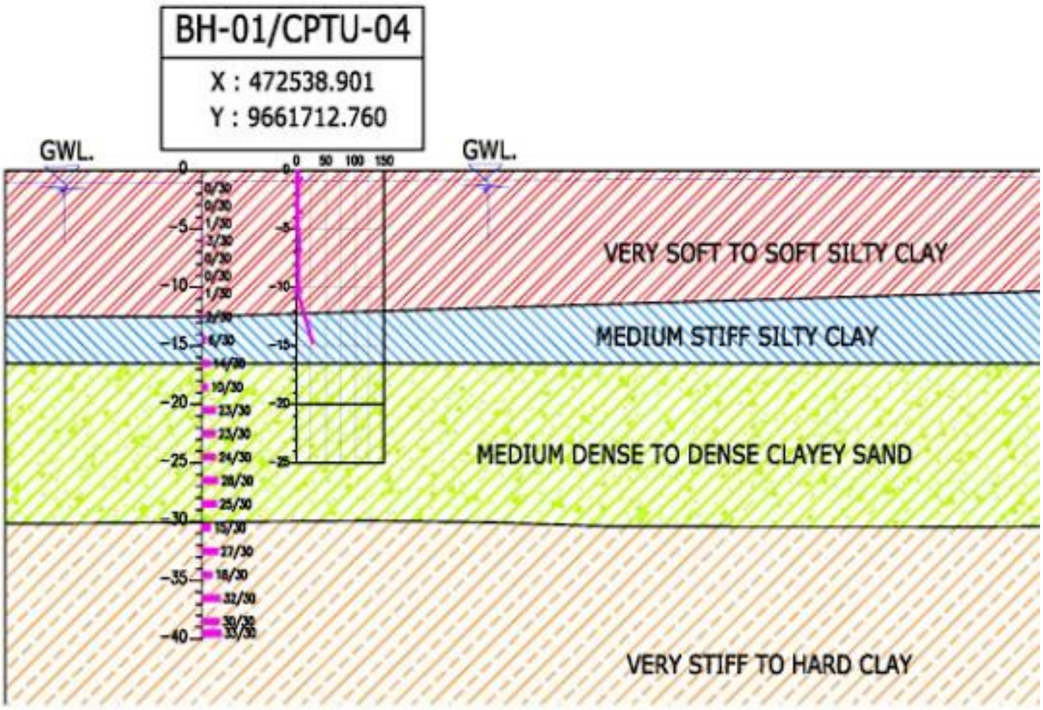

Figure 4.2 Soil Profile in the Construction Site at Section BH-01
(Source: PT. Hutama Karya Infrastruktur)

Based on the soil layer shown in the **Figure 4.2** above, the geometry drawing will be drawn according to the soil layer characteristics shown in the **Figure 4.2**. The geometry drawing will be consisted of the soil layers, where the soil layers will be soil type. In order to distinguished the soil type from one and another, each soil type will have different colour. There are 3 model that will be used in this project. The models are as follows.

1. Preloading without PVD

The first model is preloading without PVD where in this project, the preloading will be used to calculate the settlement value. The preloading in this project will be 5 m high. Preloading in this project will serve as additional vertical stress that applied to the soil below it in order to remove pore water. Example of preloading without PVD geometry drawing can be seen in **Figure 4.3** below.

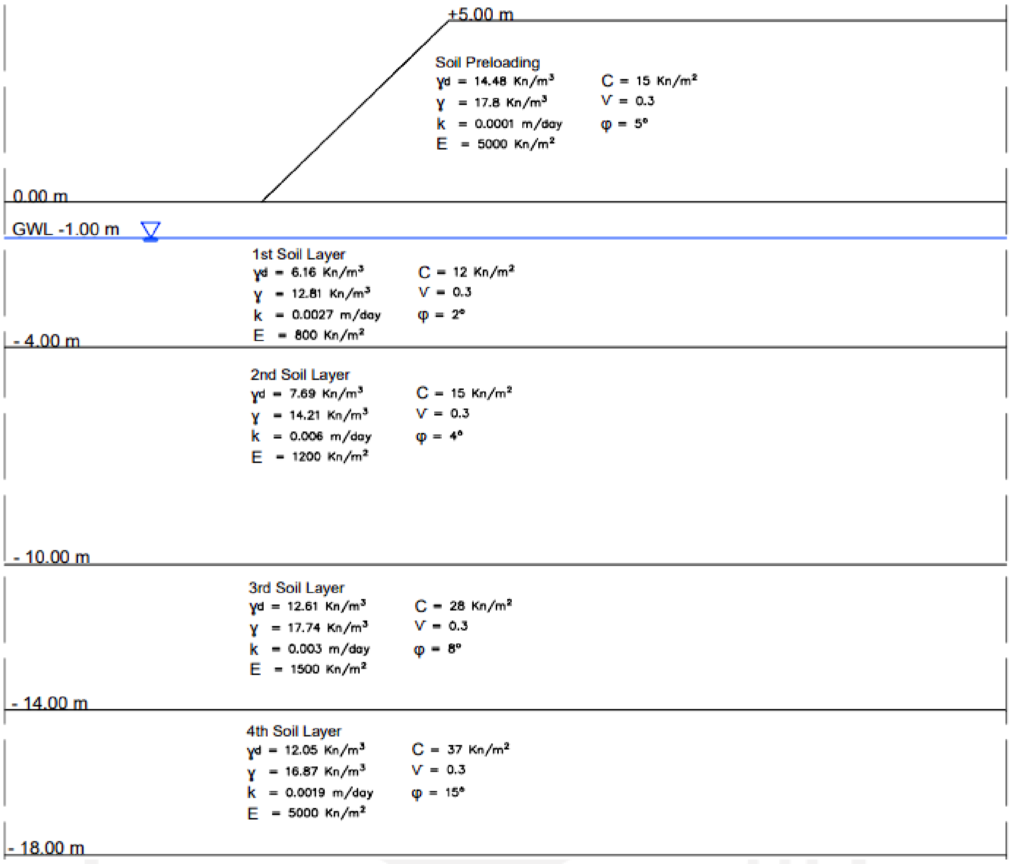

Figure 4.3 Example of Preloading without PVD

2. Preloading with PVD

The second model is preloading with PVD where besides preloading, drain system will be added in order to accelerate the time of consolidation. With PVD, the time of consolidation will be shortened due to the pore water move through the drain. PVD also can reduce the amount of additional load with same consolidation time. Example of preloading with PVD geometry drawing can be seen in **Figure 4.4** below.

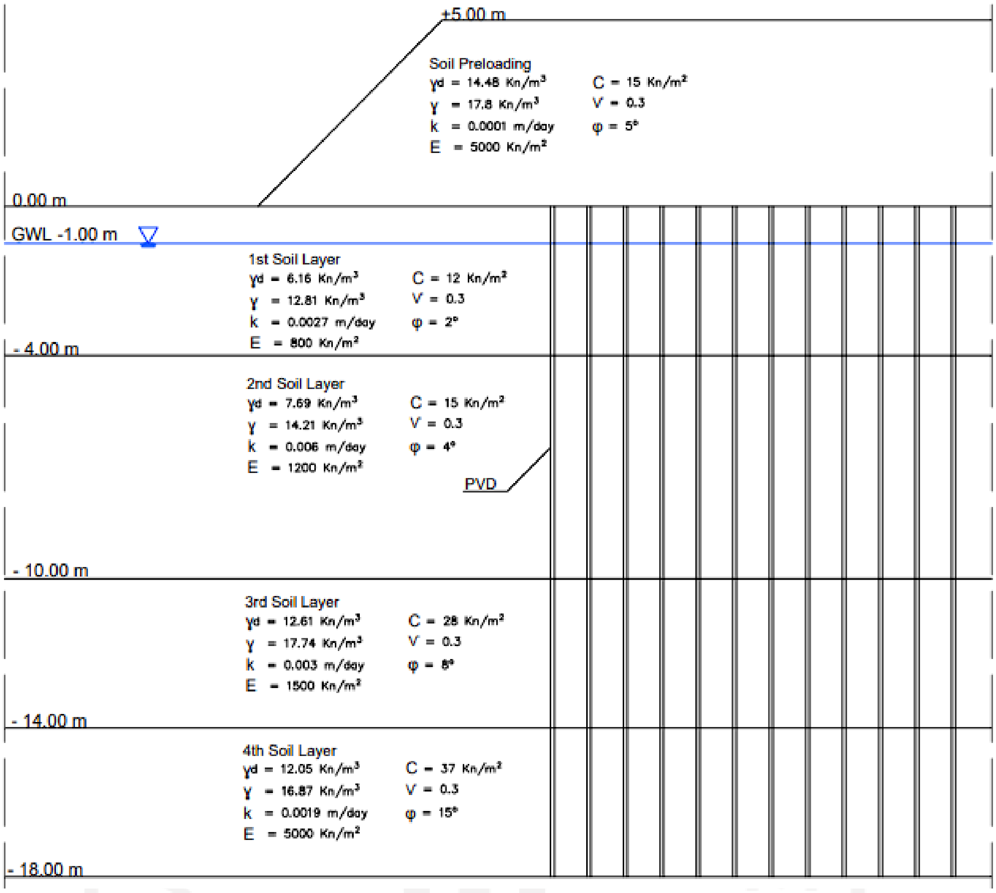

Figure 4.4 Example of Preloading with PVD

3. Vacuum with PVD

The third model is vacuum with PVD, where the vacuum will serve as the additional load. Both vacuum and preloading has the same function which is to remove the pore water from the soil. But for vacuum, it works by sucking the water and air from the soil. The vacuum pressure used in this project is 80 kPa.

4.4 Flow Chart

Steps for this research can be seen in the **Figure 4.5** and **Figure 4.6** below.

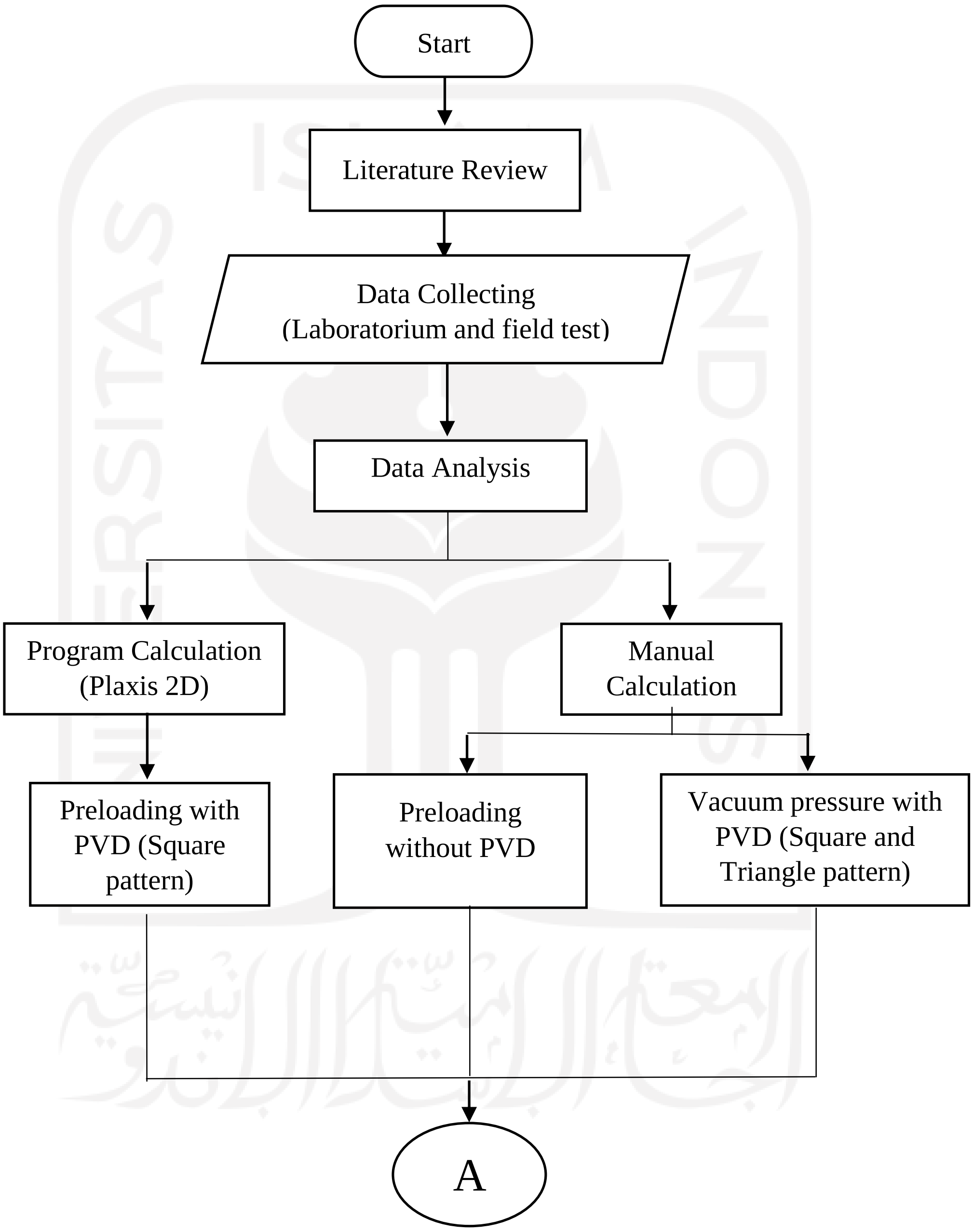

Figure 4.5 Flow Chart (Part 1)

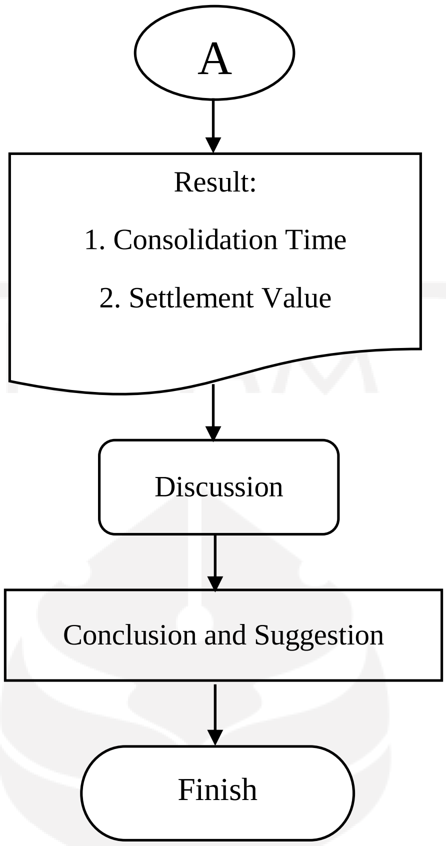

Figure 4.6 Flow Chart (Part 2)

4.5 Discussion and Conclusion

After conducting the analysis either using the Plaxis 2D program or manually, next is discussion and conclusion. The discussion based on the result from the analysis of soil settlement and consolidation time using PVD and vacuum consolidation, both manually and by using Plaxis 2D program.

CHAPTER V
ANALYSIS AND DISCUSSION

5.1 General

The analysis of soil settlement and consolidation time are using combination of Prefabricated Vertical Drain (PVD) and Vacuum Consolidation method. The analysis process will be separated into two ways which are manual calculation using Microsoft Excel and calculation using PLAXIS 2D program. The manual calculation will be using the 1-D Terzaghi method.

5.2 Research Data

The data that will be used in order to conduct this research are the secondary data that were obtained. The location that the data was taken from is from BH-1 location that can be seen on **Figure 5.1** below.

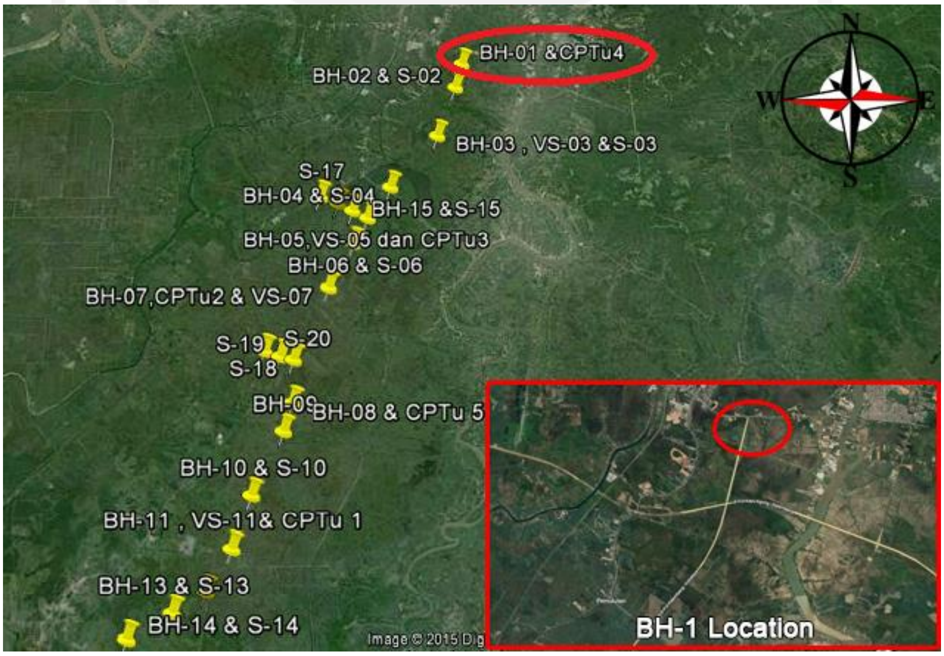

Figure 5.1 BH-1 Location

The soil parameter data that will be used from BH-1 can be seen in **Figure 5.2** below.

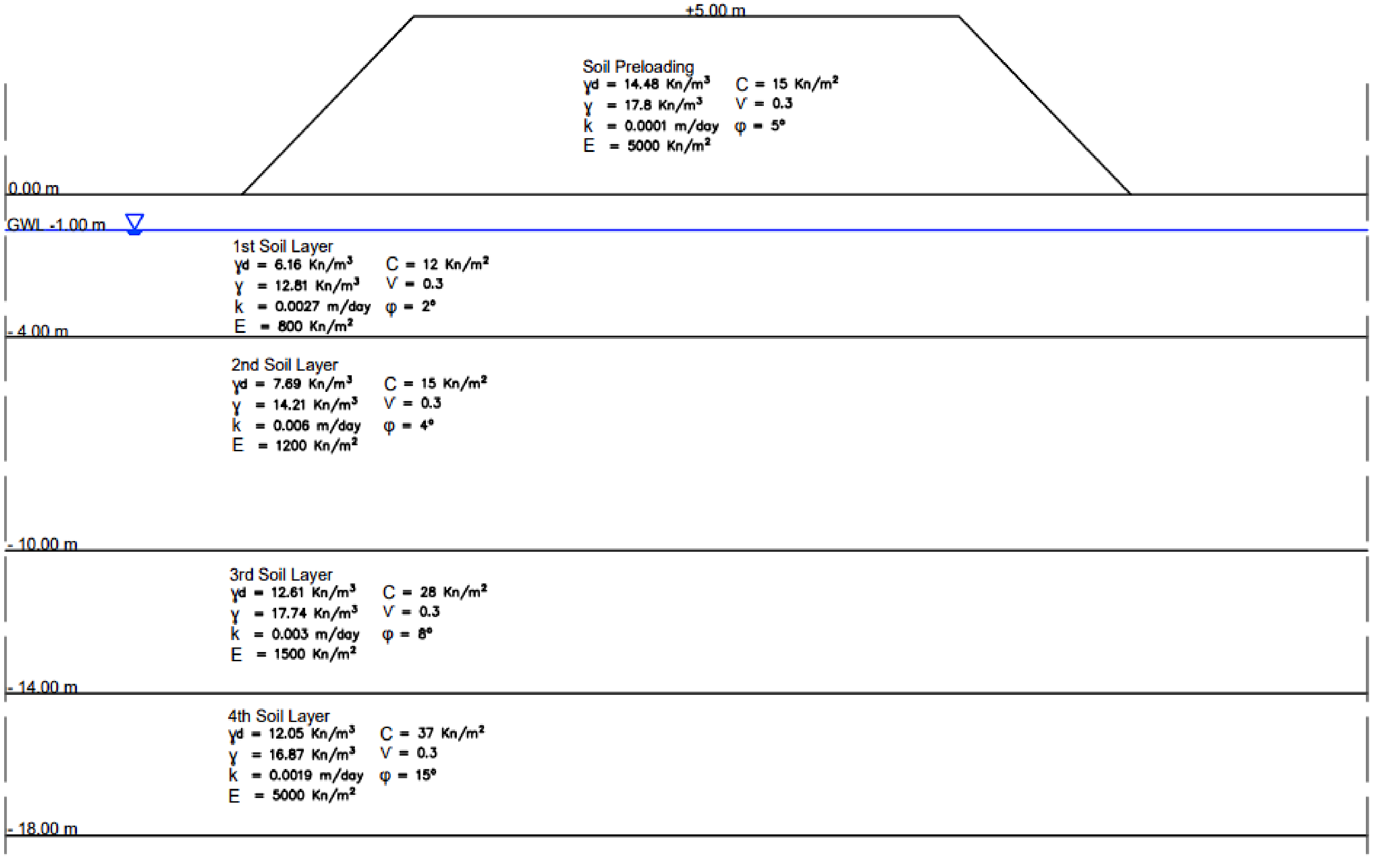

Figure 5.2 Soil Modelling and Parameter

The PVD specification data are obtained from the project. The PVD data that are installed in the field can be seen below.

1. PVD depth = 18 m
2. Installation pattern = Rectangular
3. PVD width = 100 mm
4. PVD thickness = 4 mm

5.3 Data Analysis

5.3.1 OCR Value

Before doing the calculation for consolidation. First, the OCR value must be obtained in order to determine whether the soil is on Normally Consolidated condition or Overly Consolidated condition. To determine the consolidation time, it is needed to calculate the OCR value. Before calculating OCR, it is required to find the Po value and the Pc' value. The calculation of OCR using **Equation 3.1** can be seen below.

Effective overburden stress (Po) for each layer can be calculated as follows:

Po (1st layer) $= 1 \times 0.629 + ((\gamma_{sat} - \gamma w) \times h)$

$= 1 \times 0.629 + ((1.357 - 0.981) \times 3)$

$= 1.757 \text{ t/m}^2$

Po (2nd layer) $= 2.806 \text{ t/m}^2$

Po (3rd layer) $= 3.092 \text{ t/m}^2$

Po (4th layer) $= 2.952 \text{ t/m}^2$

So, the Po_{total} is 10.607 t/m^2

To determine, the method that will be used is Cassagrande method as shown in chapter 3.

Pc' = 42.825 t/m^2

So, the calculation for OCR value will be as follows.

OCR = $\frac{Pc'}{Po}$

OCR = $\frac{42.825}{10.607}$ = 4.037

So, the OCR value obtained is 4.037. Based on the obtained OCR value, then the consolidation type is Overconsolidated because OCR > 1.

5.3.2 Analysis of Consolidation Settlement Using Terzaghi Method

1. Primary Consolidation

The primary consolidation will be conducted by using preloading without PVD. After obtained the OCR value and determine the soil consolidation type condition, first is to find the height plan of the land fill. The height plan of the land fill can be calculated by using **Equation 3.21**. The calculation for height plan of land fill can be seen below.

q = 815.7 gr/cm^2

$\gamma_{landfill}$ = 1.631 gr/cm^3

H_R = $\frac{815.7}{1.631}$

= 500.12 cm

= 5 m

1st layer

Cc = 0.88

e_0 = 3.065

The analysis will be conducted by using overconsolidated principal. The analysis will be using **Equation 3.2**, **Equation 3.5**, and **Equation 3.6**.

$q_o \quad = \gamma_{landfill} \text{ x } h$

$= 1.631 \text{ x } 5$

$= 8 \text{ t/m}^2$

$\Delta p \quad = 2 \text{ x } q_o \text{ x } I$

$= 2 \text{ x } 8 \text{ x } 0.5$

$= 8 \text{ t/m}^2$

$H \quad = 4 \text{ m}$

$$Sp = \frac{Cs \ x \ h}{1+e0} \log \left(\frac{Po + \Delta p}{Po}\right)$$

$$= \frac{0.146 \ x \ 4}{1+3.065} \log\left(\frac{1.757+8}{1.757}\right)$$

$= 0.107 \text{ m}$

The same calculation is done for the rest of the soil layers. The recapitulation of the calculation can be seen in **Table 5.1** below.

Table 5.1 Recapitulation of Primary Consolidation Calculation

Soil Layer	Cc	Cs	e_0	Po (t/m^2)	Δp (t/m^2)	S (m)
0 m- 4 m	0.88	0.146	3.065	1.757	8	0.107
4 m – 10 m	1.22	0.203	2.240	2.806	8	0.220
10 m – 14 m	0.33	0.055	1.006	3.092	8	0.060
14 m – 18 m	0.25	0.042	1.097	2.952	8	0.045
Total						0.431

After calculating the primary consolidation, next is to calculate the degree of consolidation on 90%. First, $Cv_{combined}$ is required in order to calculate Tv. The calculation for $Cv_{combined}$ can be seen below.

$$Cv_{combined} = \frac{(400+600+400+400)^2}{(\frac{400}{\sqrt{0.0157}}+\frac{600}{\sqrt{0.0263}}+\frac{400}{\sqrt{0.029}}+\frac{400}{\sqrt{0.0271}})^2}$$

$Cv_{Combined}$ = 0.001 cm^2/sec

= 0.00864 m^2/day

The calculation for Tv on the 1st day can be seen below.

$$Tv = \frac{t\ x\ Cv}{H^2}$$

$$Tv = \frac{1\ x\ 0.00864}{(18\ x\ 0.5)^2}$$

$$Tv = 0.000107$$

The calculation to obtain vertical consolidation degree on the 1st day can be seen below.

$$Uv = \frac{\sqrt{\frac{4\ x\ Tv}{\pi}}}{\left(1+\left(\frac{4\ x\ Tv}{\pi}\right)^{2.8}\right)^{0.179}}$$

$$Uv = 0.0117$$

$S = S_{total}$ x Uv

$$S = 0.431\ x\ 0.0117$$

$$= 0.005\ m$$

The result of calculating the vertical consolidation degree (Uv) without using Prefabricated Vertical Drain can be seen in the **Table 5.2** and **Figure 5.3** below.

Table 5.2 Recapitulation of Vertical Consolidation Degree Calculation without Prefabricated Vertical Drain

t (days)	Cv (m/day)	tv	Uv	s (m)	S (m)
1	0.00864	0.000107	0.0117	0.431	0.005
10	0.00864	0.001067	0.0369	0.431	0.016
100	0.00864	0.010667	0.1165	0.431	0.050
1000	0.00864	0.106667	0.3683	0.431	0.159
5000	0.00864	0.533333	0.7822	0.431	0.337
7500	0.00864	0.800000	0.8873	0.431	0.382
8000	0.00864	0.853333	0.9007	0.431	0.387
10000	0.00864	1.066667	0.9383	0.431	0.404
20000	0.00864	2.133333	0.9883	0.431	0.426
30000	0.00864	3.200000	0.9949	0.431	0.429
50000	0.00864	5.333333	0.9969	0.431	0.430
75000	0.00864	8.000000	0.9970	0.431	0.430
90000	0.00864	9.600000	0.9968	0.431	0.430
95000	0.00864	10.133333	0.9968	0.431	0.430

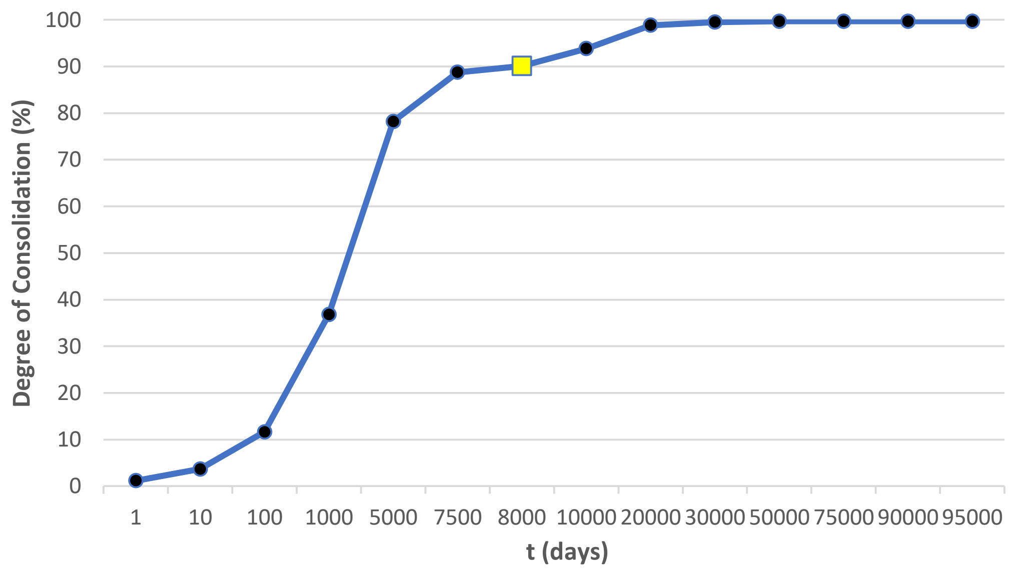

Figure 5.3 Graphic of Relation between Time and Vertical Consolidation Degree

From **Table 5.2** and **Figure 5.3** the time needed in order to reach the Vertical Consolidation Degree (Uv) at 90% is 8000 days or 21.9 years with the settlement of 0.388 m.

5.3.3 Analysis of Consolidation Settlement with Prefabricated Vertical Drain (PVD)

The calculation for consolidation settlement with Prefabricated Vertical Drain (PVD) will be divided into two according to the PVD patterns. The calculation of those two patterns can be seen below.

1. Triangle Patterns

Below is the modelling for PVD Triangle pattern with 1 m and 1.2 m space. The modelling can be seen on **Figure 5.4** and **Figure 5.5**

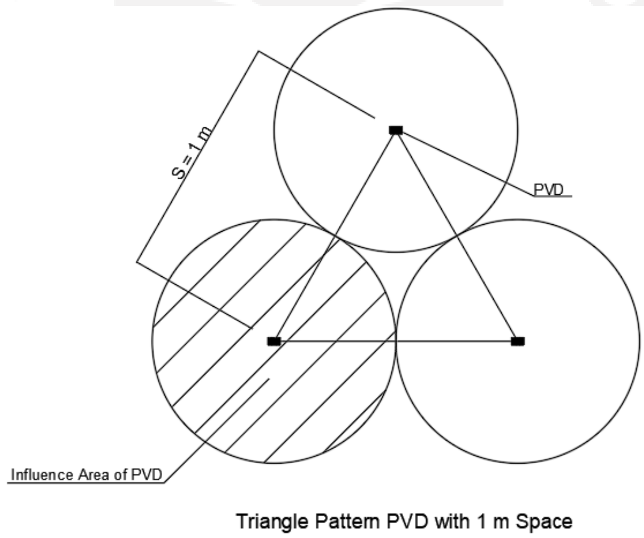

Figure 5.4 Modelling of PVD Triangle Pattern with 1 m Space

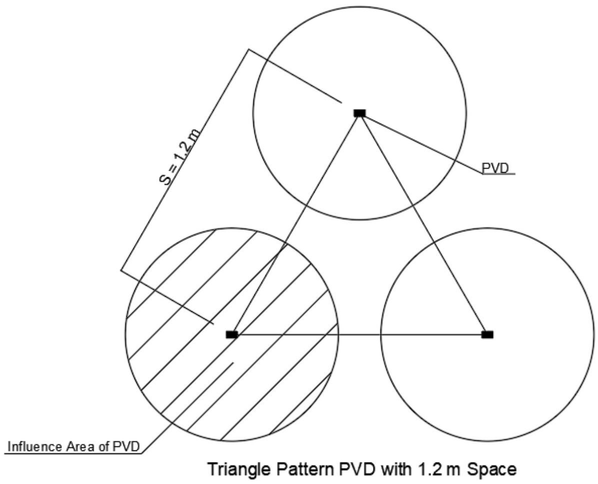

Figure 5.5 Modelling of PVD Triangle Pattern with 1.2 m Space

Triangle patterns are one of the patterns that will be used in this calculation. The calculation of the settlement consolidation using Prefabricated Vertical Drain (PVD) method with 1 m and 1.2 m space as assumption. The calculation can be seen below.

Calculation will be conducted on the first day (t = 1)

Cv_{Comb} = 0.001 cm^2/sec

= 0.00864 m^2/day

Tv = 0.000107

Uv = 0.0117

The calculation for Ch according to **Equation 3.8** can be seen below.

Ch = 1.5 x Cv

= 1.5 x 0.00864

= 0.013 m^2/day

Keep in mind that for this calculation, the pattern that are being used is triangle pattern with space of 1 m and 1.2 m. The triangle pattern with its space is based on assumption in order to compare between the two different patterns of PVD. The calculation for De or the diameter of the influenced zone according to **Equation 3.18** and **Equation 3.19** can be seen below.

De $= 1.05 \times 1$ m

$= 1.05$ m

De $= 1.05 \times 1.2$ m

$= 1.26$ m

Calculation to calculate the diameter equivalent (dw) according to **Equation 3.15.** The calculation can be seen below.

Dw $= \frac{2(0.01\ x\ 0.004)}{\pi}$

$= 0.0662$ m

The calculation of the resistance factor from the distance between PVD for triangle pattern with space of 1 m and 1.2 m according to **Equation 3.20** can be seen below.

Fn $= \ln \frac{1.05}{0.0662} - \frac{3}{4}$

$= 2.0137$

Fn $= \ln \frac{1.26}{0.0662} - \frac{3}{4}$

$= 2.1961$

The calculation for horizontal time factor (Th) of triangle pattern with space 1 m according to **Equation 3.9** can be seen below.

Th $= \frac{(0.013\ x\ 1)}{1.05^2}$

= 0.0118

The calculation for consolidation degree of horizontal (Uh) according to **Equation 3.10** can be seen below.

Uh = 1-exp ($\frac{-8\ x\ 0.0118}{2.0137}$)

= 0.046

The calculation for degree of consolidation (U) with Prefabricated Vertical Drain (PVD) method according to **Equation 3.13** can be seen below.

U = 1 – (1-0.0058) x (1-0.046)

= 0.056

The result of the consolidation degree calculation with Prefabricated Vertical Method (PVD) using triangle patterns with space of 1 m can be seen on **Table 5.3** and **Figure 5.6** below.

Table 5.3 Recapitulation of Consolidation Degree Calculation Result of Prefabricated Vertical Drain using Triangle Patterns with 1 m space

t (days)	Tv	Cv (m^2/day)	Uv	1-UV	Ch	Th	Uh	1-Uh	U	s
1	0.000107	0.00864	0.0117	0.9883	0.01296	0.0118	0.046	0.954	0.0567	0.024
10	0.001067	0.00864	0.0369	0.9631	0.01296	0.1176	0.373	0.627	0.3962	0.171
20	0.002133	0.00864	0.0521	0.9479	0.01296	0.2351	0.607	0.393	0.6275	0.270
30	0.0032	0.00864	0.0638	0.9362	0.01296	0.3527	0.754	0.246	0.7694	0.332
40	0.004267	0.00864	0.0737	0.9263	0.01296	0.4702	0.846	0.154	0.8569	0.369
47	0.005013	0.00864	0.0799	0.9201	0.01296	0.5525	0.889	0.111	0.8975	0.387
50	0.005333	0.00864	0.0824	0.9176	0.01296	0.5878	0.903	0.097	0.9112	0.393
75	0.008	0.00864	0.1009	0.8991	0.01296	0.8816	0.970	0.030	0.9729	0.419
100	0.010667	0.00864	0.1165	0.8835	0.01296	1.1755	0.991	0.009	0.9917	0.427
125	0.013333	0.00864	0.1303	0.8697	0.01296	1.4694	0.997	0.003	0.9975	0.430

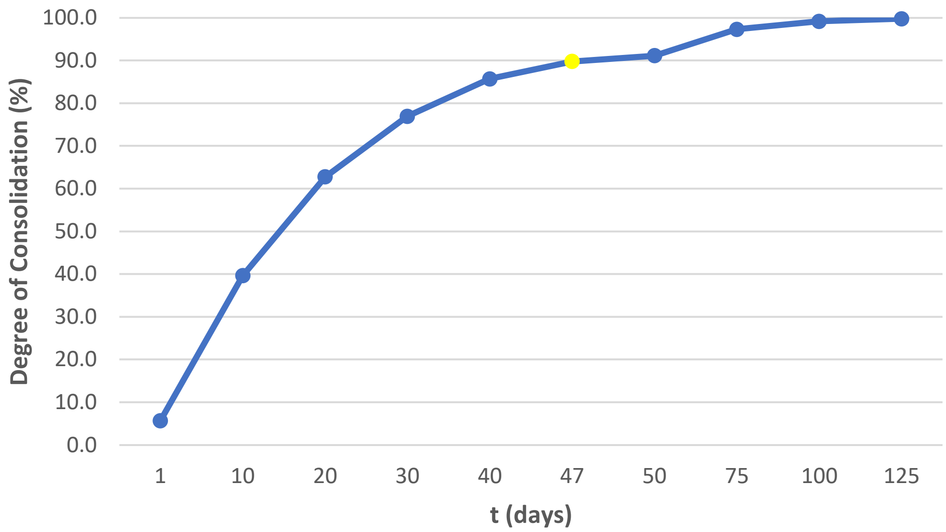

Figure 5.6 Graphic of Relation between Degree of Consolidation and Time using Triangle Pattern of Prefabricated Vertical Drain with 1 m space

According to **Table 5.3** and **Figure 5.6** it can be seen that the consolidation degree at 90% using triangle pattern PVD with 1 m space is 0.387 m in 47 days.

The calculation of consolidation degree at 90% using triangle pattern PVD with 1.2 m space is the same as the 1 m space. So, by using the same equation the result of the calculation for 1.2 m space of triangle pattern PVD can be seen on **Table 5.4** and **Figure 5.7** below.

Table 5.4 Recapitulation of Consolidation Degree Calculation Result of Prefabricated Vertical Drain using Triangle Pattern with 1.2 m space

t (days)	Tv	Cv (m^2/day)	Uv	1-UV	Ch	Th	Uh	1-Uh	U	s
1	0.000107	0.00864	0.0117	0.9883	0.01296	0.0082	0.029	0.971	0.0406	0.018
10	0.001067	0.00864	0.0369	0.9631	0.01296	0.0816	0.257	0.743	0.2846	0.123
20	0.002133	0.00864	0.0521	0.9479	0.01296	0.1633	0.448	0.552	0.4771	0.206
30	0.0032	0.00864	0.0638	0.9362	0.01296	0.2449	0.590	0.410	0.6164	0.266
40	0.004267	0.00864	0.0737	0.9263	0.01296	0.3265	0.696	0.304	0.7181	0.309
50	0.005333	0.00864	0.0824	0.9176	0.01296	0.4082	0.774	0.226	0.7926	0.342
73	0.007787	0.00864	0.0996	0.9004	0.01296	0.5959	0.886	0.114	0.8973	0.387
100	0.010667	0.00864	0.1165	0.8835	0.01296	0.8163	0.949	0.051	0.9548	0.412
125	0.013333	0.00864	0.1303	0.8697	0.01296	1.0204	0.976	0.024	0.9789	0.422

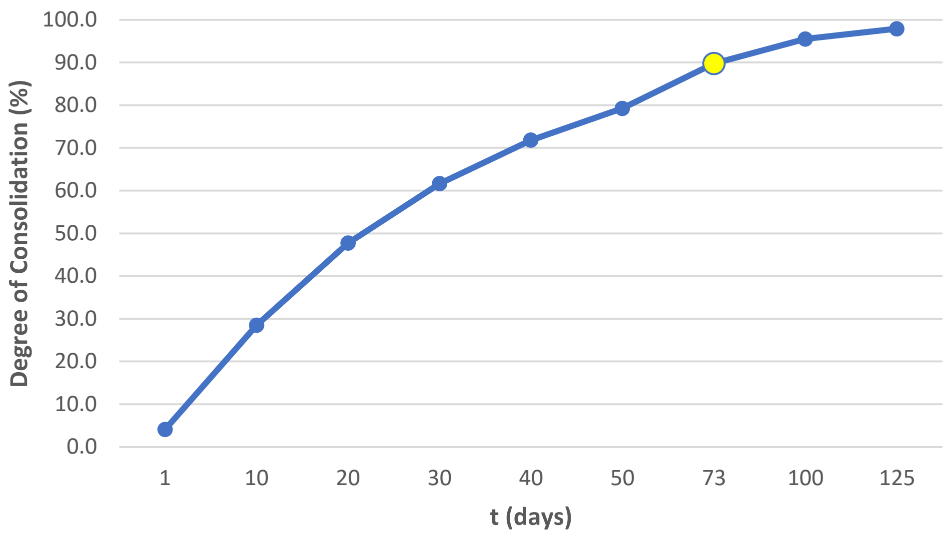

Figure 5.7 Graphic of Relation between Degree of Consolidation and Time using Triangle Pattern of Prefabricated Vertical Drain with 1.2 m space

So, according to the graphic the consolidation degree at 90% for PVD that using triangle pattern with space of 1 m is at 47 days with soil settlement of 0.387 m. While for PVD using triangle pattern with space of 1.2 m is at 73 days with soil settlement of 0.387 m.

2. Square Pattern

Below is the modelling for PVD Square pattern with 1 m space and 1.2 m space. The modelling can be seen in **Figure 5.8** and **Figure 5.9** below.

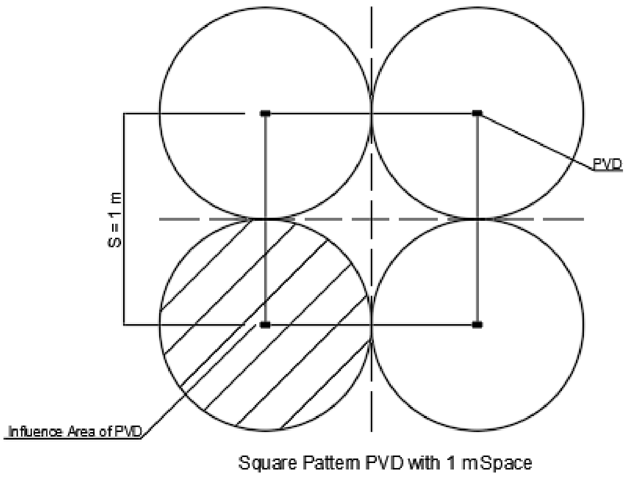

Figure 5.8 Modelling of PVD Square Pattern with 1 m Space

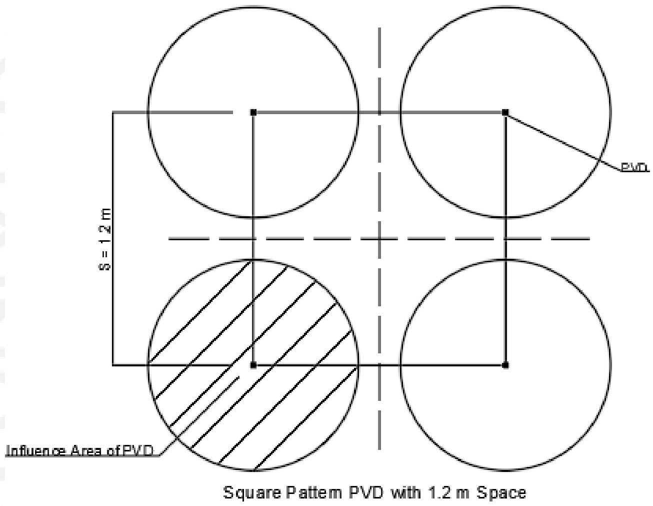

Figure 5.9 Modelling of PVD Square Pattern with 1.2 m Space

The calculation of consolidation degree at 90% for PVD with square pattern with space of 1 m and 1.2 m can be seen below.

Calculation will be conducted on the first day (t = 1)

Cv_{comb} = 0.001 cm^2/sec

= 0.00864 m^2/day

Tv = 0.000107

Uv = 0.0117

The calculation for Ch according to **Equation 3.8** can be seen below.

Ch = 1.5 x Cv

= 1.5 x 0.00864

= 0.013 m^2/day

For this calculation, the pattern that are being used is square pattern with space of 1 m and 1.2 m. The calculation to find De or the diameter of the influenced zone according to **Equation 3.18** and **Equation 3.19** can be seen below.

De = 1.13 x 1 m

= 1.13 m

De = 1.13 x 1.2 m

= 1,356 m

Next is calculation to calculate the diameter equivalent (Dw) according to Equation **3.15** the calculation can be seen below.

$$Dw = \frac{2\,(0.01\;x\;0.004)}{\pi}$$

= 0.0662 m

The calculation of the resistance factor from the distance between PVD for square pattern with space of 1 m and 1.2 m according to **Equation 3.20** can be seen below.

$$Fn = \ln \frac{1.13\;x\;1}{0.0662} - \frac{3}{4}$$

$= 2.0873$

Fn $= \ln \frac{1.356}{0.0662} - \frac{3}{4}$

$= 2.2696$

The calculation for horizontal time factor (Th) of square pattern with space of 1 m according to **Equation 3.9** can be seen below.

Th $= \frac{(0.013 \ x \ 1)}{1.13^2}$

$= 0.0101$

The calculation for consolidation degree of horizontal (Uh) according to **Equation 3.10** can be seen below.

Uh $= 1\text{- } \exp \left(\frac{-8 \ x \ 0.0101}{2.0873}\right)$

$= 0.038$

The calculation for degree of consolidation (U) with Prefabricated Vertical Drain (PVD) method according to **Equation 3.13** can be seen below.

U $= 1 – (1 – 0.0058) \text{ x } (1 – 0.038)$

$= 0.0494$

The result of the consolidation degree calculation with Prefabricated Vertical Drain (PVD) using square pattern with space of 1 m can be seen on **Table 5.5** and **Figure 5.10** below.

Table 5.5 Recapitulation of Consolidation Degree Calculation Result of Prefabricated Vertical Drain using Square Pattern with 1 m space

t (days)	Tv	Cv (m^2/day)	Uv	1-Uv	Ch	Th	Uh	1-Uh	U	S (m)
1	0.000106667	0.00864	0.0117	0.9883	0.01296	0.0101	0.038	0.962	0.0494	0.0213
10	0.001066667	0.00864	0.0369	0.9631	0.01296	0.1015	0.322	0.678	0.3472	0.1497
20	0.002133333	0.00864	0.0521	0.9479	0.01296	0.2030	0.541	0.459	0.5646	0.2434
30	0.0032	0.00864	0.0638	0.9362	0.01296	0.3045	0.689	0.311	0.7086	0.3054
40	0.004266667	0.00864	0.0737	0.9263	0.01296	0.4060	0.789	0.211	0.8046	0.3468
50	0.005333333	0.00864	0.0824	0.9176	0.01296	0.5075	0.857	0.143	0.8688	0.3745
56	0.005973333	0.00864	0.0872	0.9128	0.01296	0.5684	0.887	0.113	0.8967	0.3868
75	0.008	0.00864	0.1009	0.8991	0.01296	0.7612	0.946	0.054	0.9514	0.4100
100	0.010666667	0.00864	0.1165	0.8835	0.01296	1.0150	0.980	0.020	0.9819	0.4232
125	0.013333333	0.00864	0.1303	0.8697	0.01296	1.2687	0.992	0.008	0.9933	0.4281

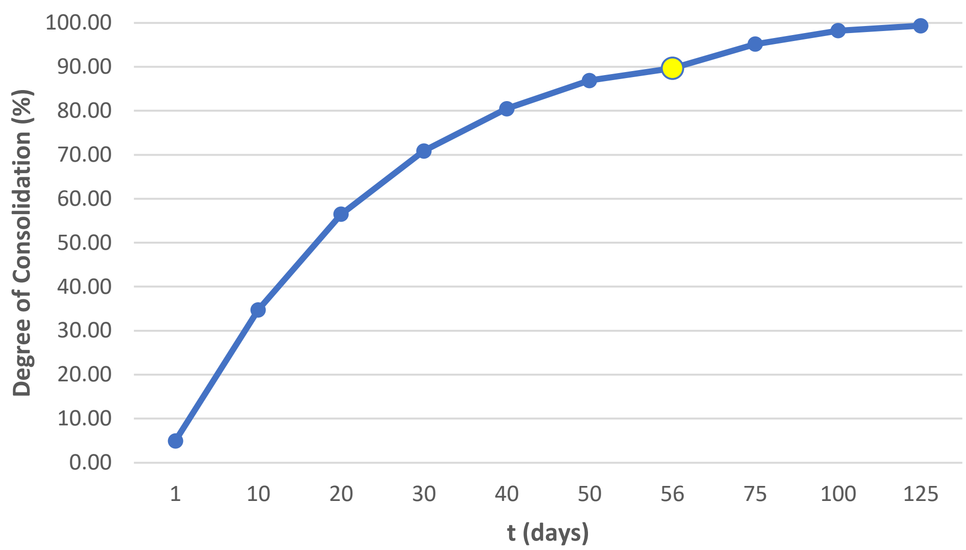

Figure 5.10 Graphic of Relation between Degree of Consolidation and Time using Square Pattern of Prefabricated Vertical Drain with 1 m space

According to **Table 5.5** and **Figure 5.10** it can be seen that the consolidation degree at 90% using square pattern PVD with 1 m space is 0.387 at 56 days.

The calculation of consolidation degree at 90% using square pattern PVD with 1.2 m space is the same as the 1 m space. So, by using the same equation the result of the calculation for 1.2 m space of square pattern PVD can be seen on **Table 5.6** and **Figure 5.11** below.

Table 5.6 Recapitulation of Consolidation Degree Calculation Result of Prefabricated Vertical Drain using Square Pattern with 1.2 m space

t (days)	Tv	Cv (m^2/day)	Uv	1-Uv	Ch	Th	Uh	1-Uh	U	S (m)
1	0.000107	0.0086	0.0117	0.9883	0.0130	0.0070	0.0245	0.9755	0.0359	0.0155
10	0.001067	0.0086	0.0369	0.9631	0.0130	0.0705	0.2200	0.7800	0.2487	0.1072
20	0.002133	0.0086	0.0521	0.9479	0.0130	0.1410	0.3916	0.6084	0.4233	0.1824
30	0.003200	0.0086	0.0638	0.9362	0.0130	0.2114	0.5254	0.4746	0.5557	0.2395
40	0.004267	0.0086	0.0737	0.9263	0.0130	0.2819	0.6298	0.3702	0.6571	0.2832
50	0.005333	0.0086	0.0824	0.9176	0.0130	0.3524	0.7113	0.2887	0.7350	0.3168
75	0.008000	0.0086	0.1009	0.8991	0.0130	0.5286	0.8448	0.1552	0.8605	0.3709
87	0.009280	0.0086	0.1087	0.8913	0.0130	0.6132	0.8848	0.1152	0.8974	0.3868
100	0.010667	0.0086	0.1165	0.8835	0.0130	0.7048	0.9166	0.0834	0.9263	0.3993
125	0.013333	0.0086	0.1303	0.8697	0.0130	0.8810	0.9552	0.0448	0.9610	0.4142
150	0.016000	0.0086	0.1427	0.8573	0.0130	1.0572	0.9759	0.0241	0.9794	0.4221

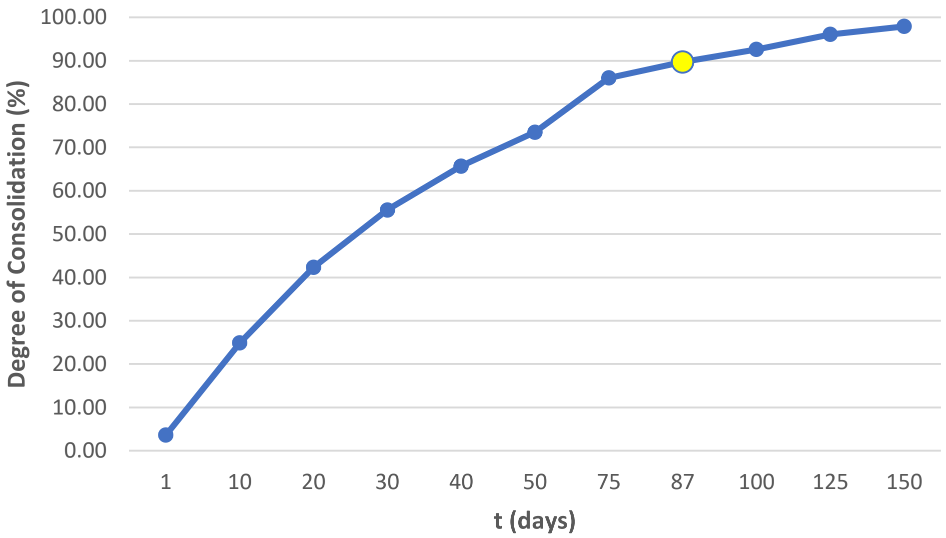

Figure 5.11 Graphic of Relation between Degree of Consolidation and Time using Square Pattern of Prefabricated Vertical Drain with 1.2 m space

So, according to the graphic the consolidation degree at 90% for PVD that using square pattern with space of 1 m is at 56 days with soil settlement of 0.3865 m. While for PVD using square pattern with space of 1.2 m is at 87 days with soil settlement of 0.387 m.

5.3.4 Analysis of Consolidation Settlement with Plaxis 2D Program

The analysis will be conducted by performing a geometry drawing of the soil, soil parameter input and then calculation. The result of the analysis will be shown in Plaxis 2D output in the form of deformed mesh and total displacement. The PVD specification and soil parameter that will be used in Plaxis 2D can be seen on **Table 5.7** and **Table 5.8** below.

Table 5.7 PVD Specification in Plaxis 2D

No.	PVD Pattern	PVD Space	PVD Length
1.	Square	1 m	18 m
2.	Square	1.2 m	18 m

Table 5.8 Soil Parameter Used in Plaxis 2D

Characteristics	Symbol	Unit	1st Soil Layer	2nd Soil Layer	3rd Soil Layer	4th Soil Layer	Soil Fill
Depth	H	m	4	6	4	4	5
Specific Gravity (Unsaturated)	γd	Kn/m^3	6.16	7.69	12.61	12.05	14.48
Specific Gravity (Saturated)	γ	Kn/m^3	12.81	14.21	17.74	16.87	17.8
Permeability Coefficient	k	m/day	0.0027	0.006	0.003	0.0019	0.0001
Poisson's Ratio	ν	-	0.3	0.3	0.3	0.3	0.3
Modulus Elasticity	E	Kn/m^2	800	1200	1500	5000	5000
Cohesion	C	Kn/m^2	12	15	28	37	15
Inner Shear Angle	φ	°	2	4	8	15	5
Dilatancy Angle	ψ	°	0	0	0	0	0

When drawing the the soil fill, it's the same as drawing the geometry of the soil. Use the same command as when drawing the geometry of the soil layer. Use command geometry line first to draw the soil fill geometry. The soil fill dimension will be based on the assumption. The soil must be constructed in phase because the soil fill with 5 m height cannot be built in one-go because it is prone to a soil failure or land slide. The dimension of the soil fill can be seen on **Figure 5.12** below.

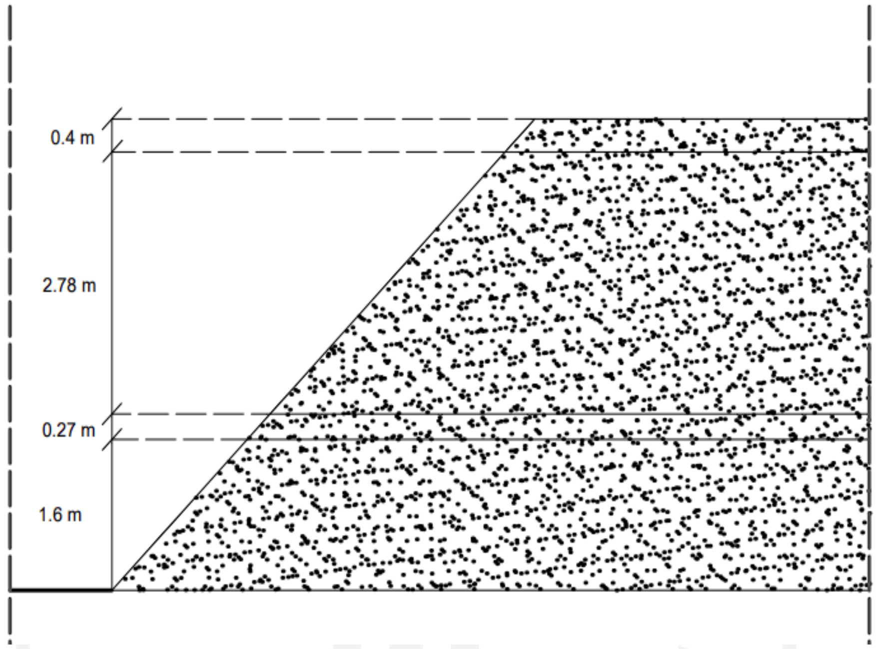

Figure 5.12 Dimension of Soil Fill on Plaxis 2D

Drawing the soil geometry by using the same command as drawing the soil layer. The command to draw the soil fill can be seen on **Figure 5.13** below.

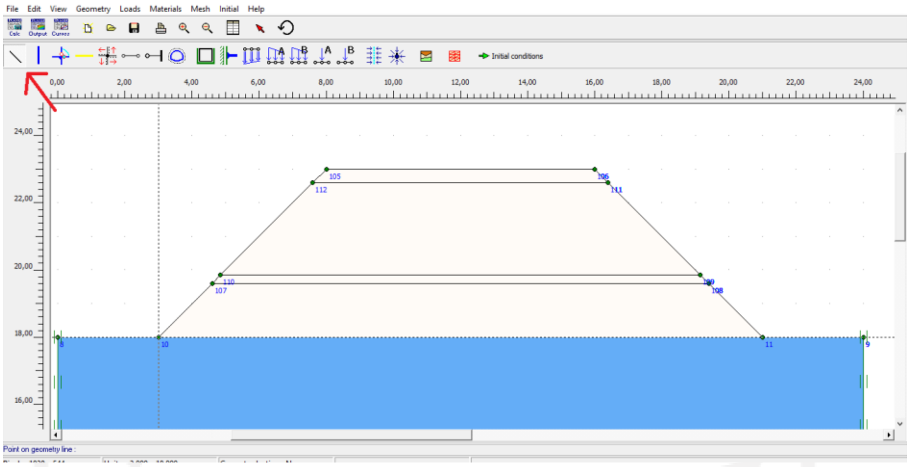

Figure 5.13 Drawing of the Soil Fill Model on Plaxis 2D

After clicking the command, choose the starting point and make a shape of the soil fill model. The height of the soil can be adjusted according to the dimension on the field.

Next after modelling the soil fill is to make a model according to the PVD pattern and space. First is to click on the PVD command. The command for PVD on Plaxis 2D can be seen on **Figure 5.14** below.

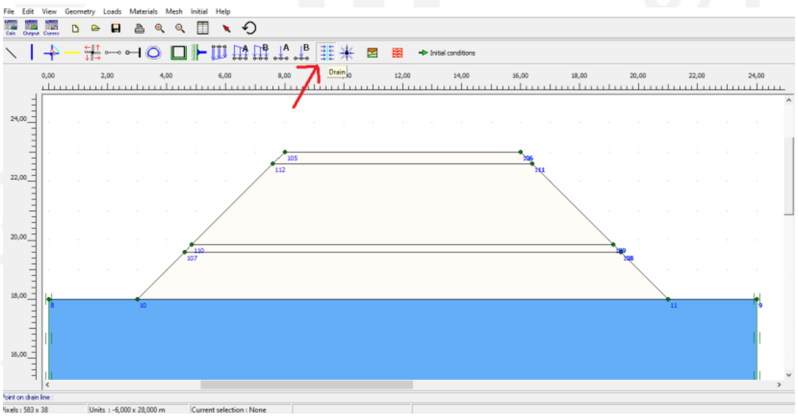

Figure 5.14 Modelling of PVD on Plaxis 2D

After clicking on the PVD command, simply click on the starting point of the PVD and then draw the PVD all the way down while maintain the distance of each PVD according to the data. The drawing of PVD can be seen on **Figure 5.15** below.

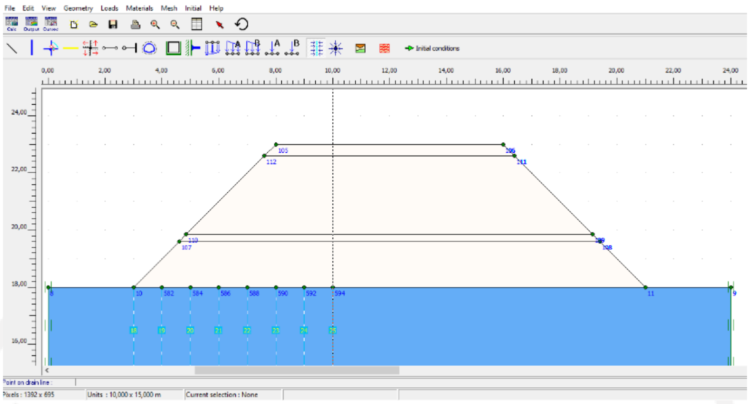

Figure 5.15 Drawing of PVD Model on Plaxis 2D

Next is to input the material data for the soil fill, the steps are the same as inputting the material data for the soil layer by clicking the material set command.

The result of Plaxis analysis can be seen below.

1. Square Pattern with 1 m Space

By using Plaxis 2D program, the soil settlement for square pattern with 1 m space is 0.390 m with the same time of soil settlement compared to manual calculation. The output results can be seen on **Figure 5.16**, **Figure 5.17**, **Figure 5.18**, **Figure 5.19** and **Figure 5.20** below.

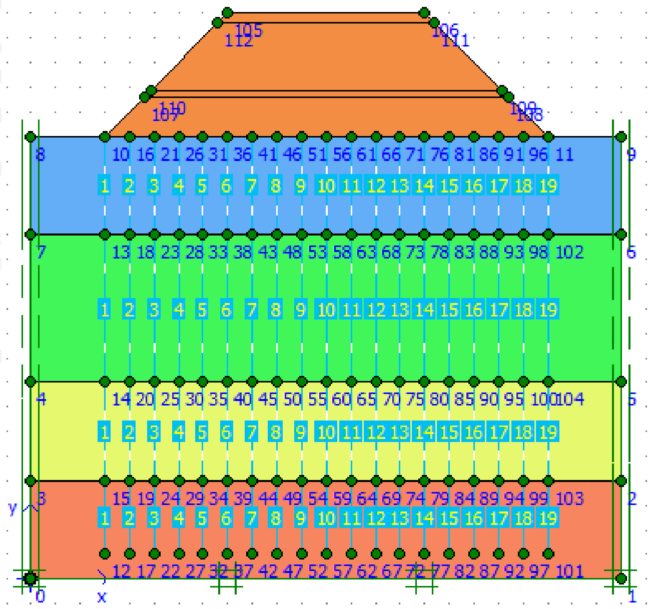

Figure 5.16 Modeling of PVD and Preloading Method using Square Pattern PVD with 1 m Space on Plaxis 2D Program

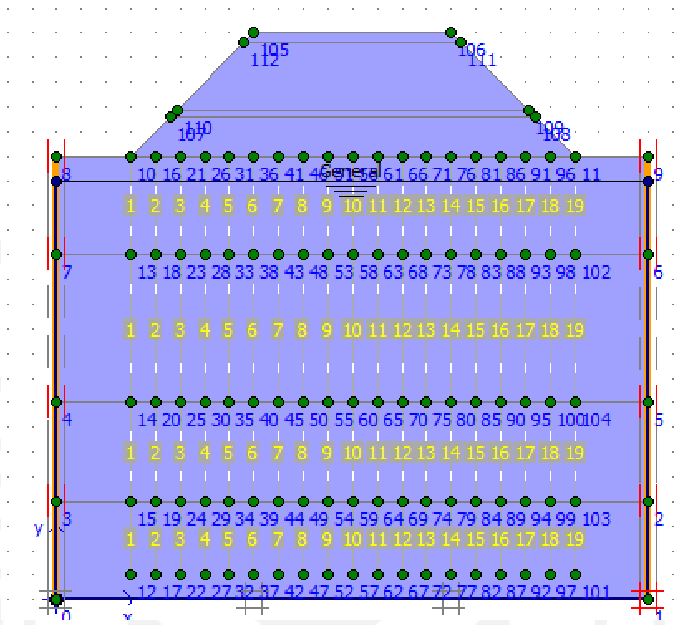

Figure 5.17 Modelling of GWL in Plaxis 2D for Square Pattern PVD with 1 m Space

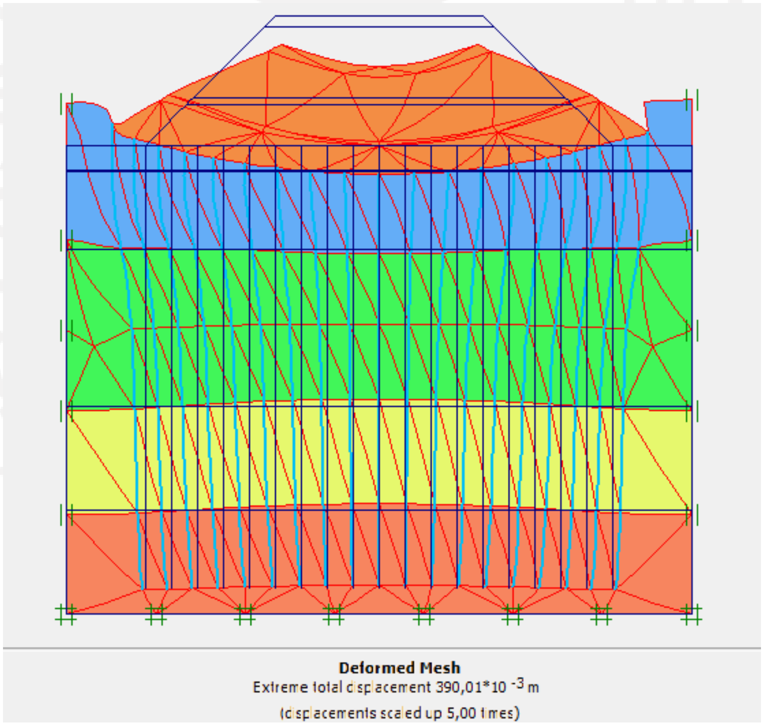

Figure 5.18 Deformed Mesh of PVD and Preloading Method using Square Pattern PVD with 1 m Space on Plaxis 2D Program

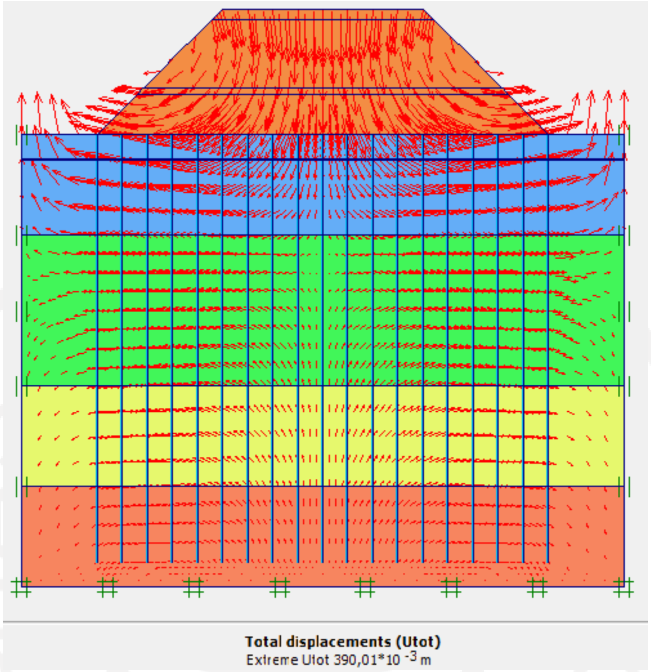

Figure 5.19 Direction of Total Displacements of PVD and Preloading Method using Square Pattern PVD with 1 m Space on Plaxis 2D program

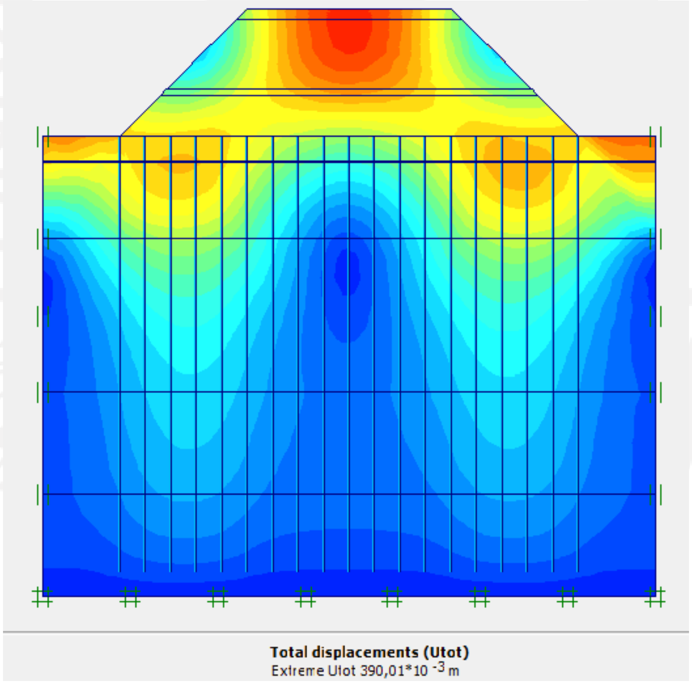

Figure 5.20 Total Displacements of PVD and Preloading Method using Square Pattern PVD with 1 m Space on Plaxis 2D Program

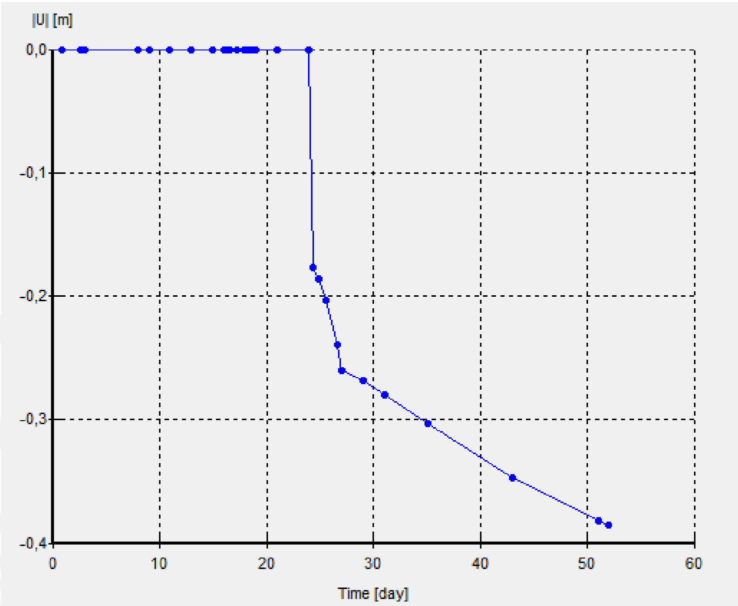

Figure 5.21 Graphic of Relation between Time and Displacements of PVD and Preloading Method using Square Pattern PVD with 1 m Space on Plaxis 2D Program

2. Square Pattern with 1.2 m Space

By using Plaxis 2D program, the soil settlement for square pattern with 1.2 m space is 0.388 m with the same time of settlement compared to manual calculation. The output results can be seen on **Figure 5.22**, **Figure 5.23**, **Figure 5.24**, **Figure 5.25**, and **Figure 5.26** below.

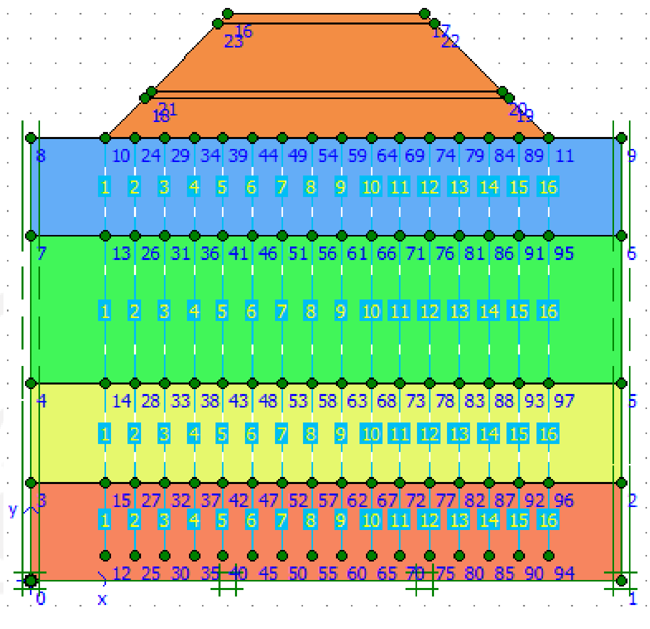

Figure 5.22 Modeling of PVD and Vacuum Combination Method using Square Pattern PVD with 1.2 m Space on Plaxis 2D Program

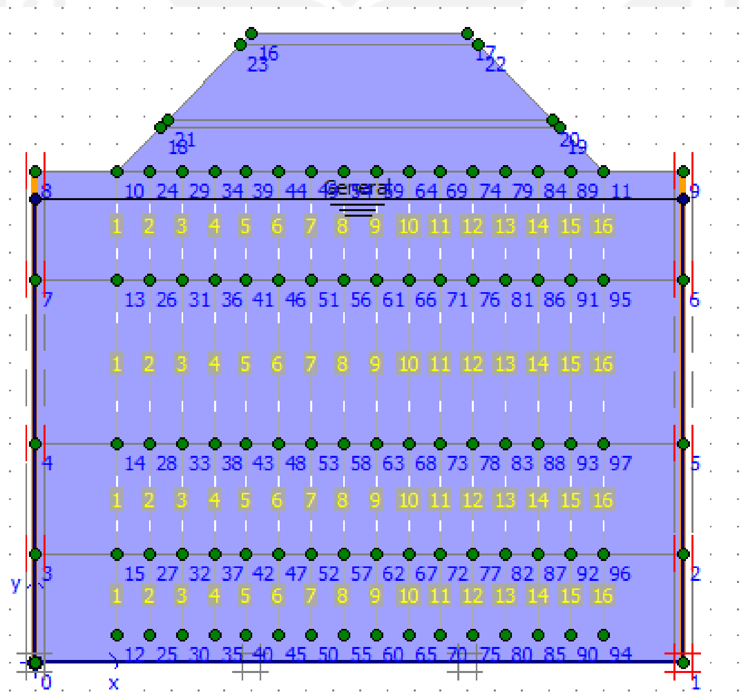

Figure 5.23 Modelling of GWL in Plaxis 2D for Square Pattern PVD with 1.2 m Space

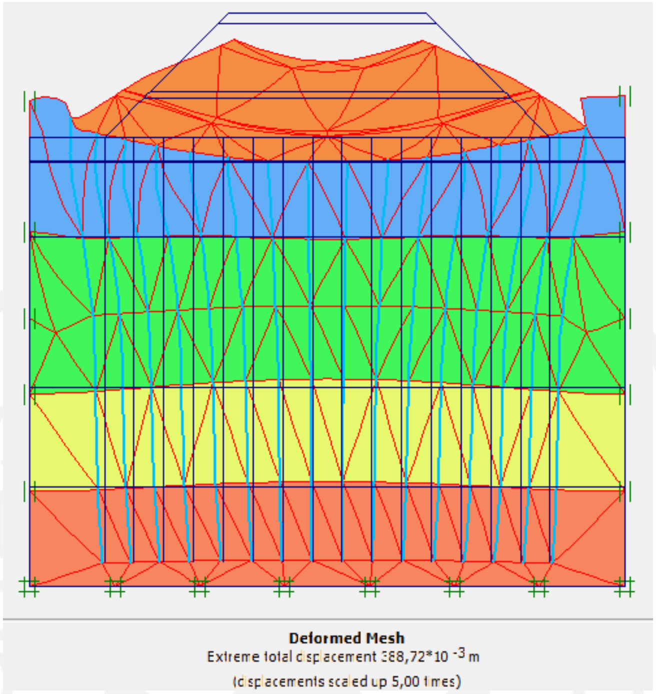

Figure 5.24 Deformed Mesh of PVD and Vacuum Combination Method using Square Pattern PVD with 1.2 m Space on Plaxis 2D Program

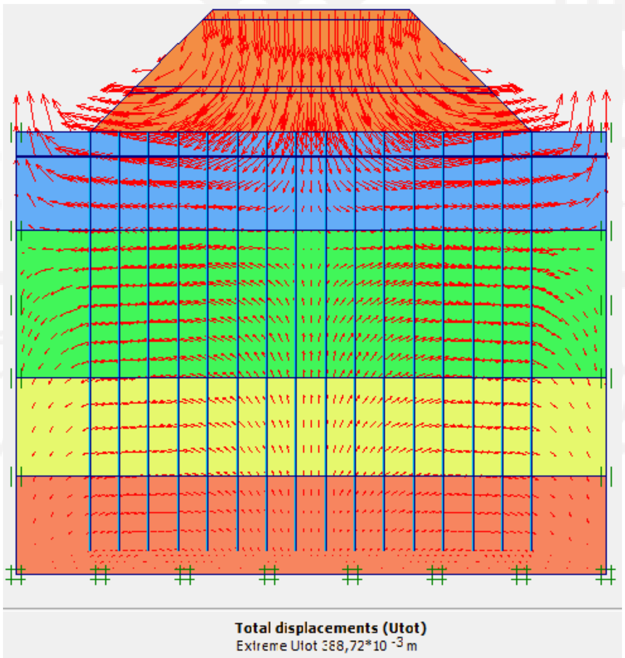

Figure 5.25 Direction of Total Displacements of PVD and Vacuum Combination Method using Square Pattern PVD with 1.2 m Space on Plaxis 2D Program

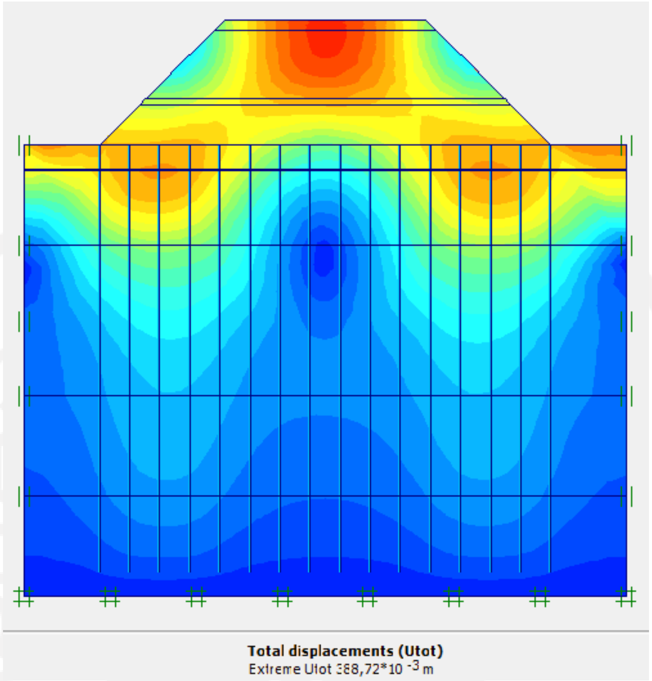

Figure 5.26 Total Displacements of PVD and Vacuum Combination Method using Square Pattern PVD with 1.2 m Space on Plaxis 2D Program

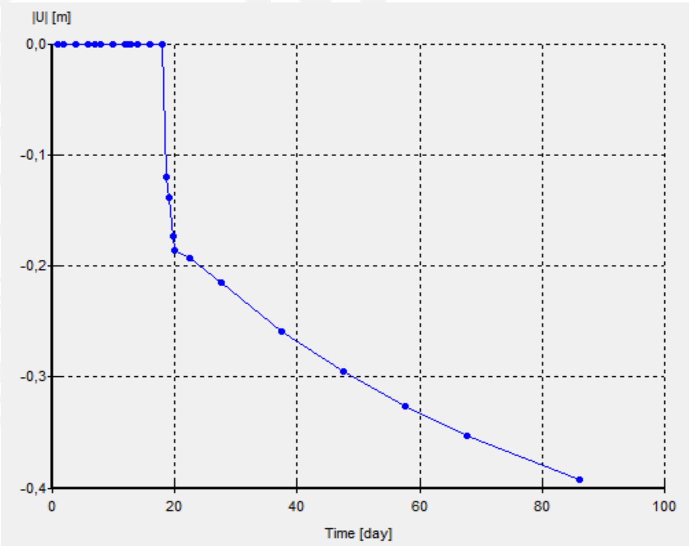

Figure 5.27 Graphic of Relation between Time and Displacements of PVD and Vacuum Combination Method using Square Pattern PVD with 1.2 m Space on Plaxis 2D Program

5.4 Discussion

The recapitulation of manual calculation and Plaxis 2D program calculation can be seen on **Table 5.9** below.

Table 5.9 Recapitulation of Manual Calculation and Plaxis 2D Program Calculation

No.	Condition	Time (Day)	Consolidation on 90%		Difference
			Manual	Plaxis 2D	
1	Preloading without PVD	8000	0.387 m	-	-
2	PVD triangle 1 m space and vacuum pressure	47	0.387 m	-	-
3	PVD triangle 1.2 m space and vacuum pressure	73	0.387 m	-	-
4	PVD square 1 m space and vacuum pressure	56	0.3865 m	0.3901 m	3 mm
5	PVD square 1.2 m space and vacuum pressure	87	0.3865 m	0.3887 m	2 mm

On **Table 5.9** above shows the result about the soil settlement that happened on 90 % consolidation for each PVD variant. Comparing between the manual analysis result and the result from using Plaxis 2D program shows that, the difference on soil settlement value are not reduced significantly with the biggest difference in soil settlement is 0.003 m and the lowest is 0.002 m.

The time setting of the settlement consolidation for both manual calculation and Plaxis 2D program is the same. Based on both calculations, the time needed to reach 90% consolidation is the same with the time range between 2 – 3 months. The recapitulation graphic can be seen on **Figure 5.28** below.

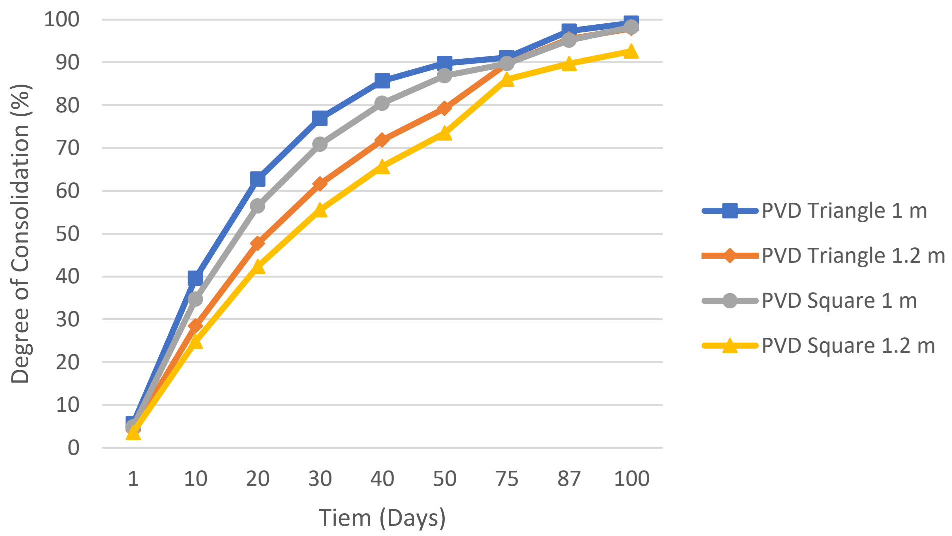

Figure 5.28 Graphic Recapitulation of Relation between Degree of Consolidation and Time

Based on the **Figure 5.28** above, it can be seen that the blue line which is representation of PVD Triangle with 1 m space has the fastest time to reach 90% consolidation. It means that the less that space between the PVD, then the faster the consolidation. This can be proven from the **Figure 5.28** above where it shows that PVD triangle pattern with 1 m space are more effective than others. Since its PVD space are closer between one to antoher, the triangle pattern PVD with 1 m space only take 47 days to reach 90% consolidation while square pattern PVD with 1 m space took 56 days. In case of the pattern of PVD, the most effective pattern is triangle because triangle has a lot more area that are being covered by the PVD influence rather than rectangle pattern. The result of this research is the same as the previous studies. According to Atmaja (2021) the closer the installation space between each PVD, the faster the consolidation process happen.

The result difference on the analysis calculation according to Atmaja (2021) can be caused by the difference in consolidation direction between Terzaghi method and Plaxis 2D program. Since in the Terzaghi method the direction of the consolidation is only on vertical while in Plaxis 2D program the direction is on horizontal and vertical.

CHAPTER VI
CONCLUSION AND SUGGESTION

6.1 Conclusion

Based on the result from manual calculation and Plaxis 2D program, it can be concluded as follows.

1. Based on the calculation, the result of soil settlement using preloading without PVD is 0.387 m on 90% consolidation and the time needed to reach 90% consolidation condition is 8000 days or 21.9 years.
2. Based on the manual calculation, the result of soil settlement for combination method of vacuum and PVD on 90% condition is 0.387 m and it is the same for all the PVD pattern. In details, PVD with triangle pattern on 1 m space PVD soil settlement is 0.387 m on 90% consolidation for 47 days, while PVD with triangle pattern on 1.2 m space PVD soil settlement is 0.387 m for 73 days, PVD with square pattern on 1 m space PVD soil settlement is 0.387 m on 90% consolidation for 56 days, PVD with square pattern on 1.2 m space PVD soil settlement is 0.387 m on 90% consolidation for 87 days.
3. Based on the calculation by using Plaxis 2D program, the soil settlement results vary depending on the installation pattern and distance. The pattern and distance that are used for calculation on Plaxis 2D program is square pattern with distance of 1 m and 1.2 m. For square pattern, the results for 1 m PVD distance is 0.3901 m on 56 days while for 1.2 m PVD distance is 0.3887 m on 87 days.
4. Based on the results obtained, the vacuum method with PVD and preloading method with PVD is almost the same. It can be said that vacuum method with PVD is the same with preloading with PVD in terms of consolidation time and soil settlement.

6.2 Suggestion

1. Some of the soil parameter data are missing or not complete. In the future, it might be best to prepare and complete the data in each location and soil layer in case there are condition or calculation that requires those data.
2. The consolidation calculation can be done on another similar program too such as GeoStudio in order to get the more accurate results.
3. The vacuum method and preloading have big difference in terms of operational cost and preparation. For next study, the cost estimation can be added to show the difference between those two methods.

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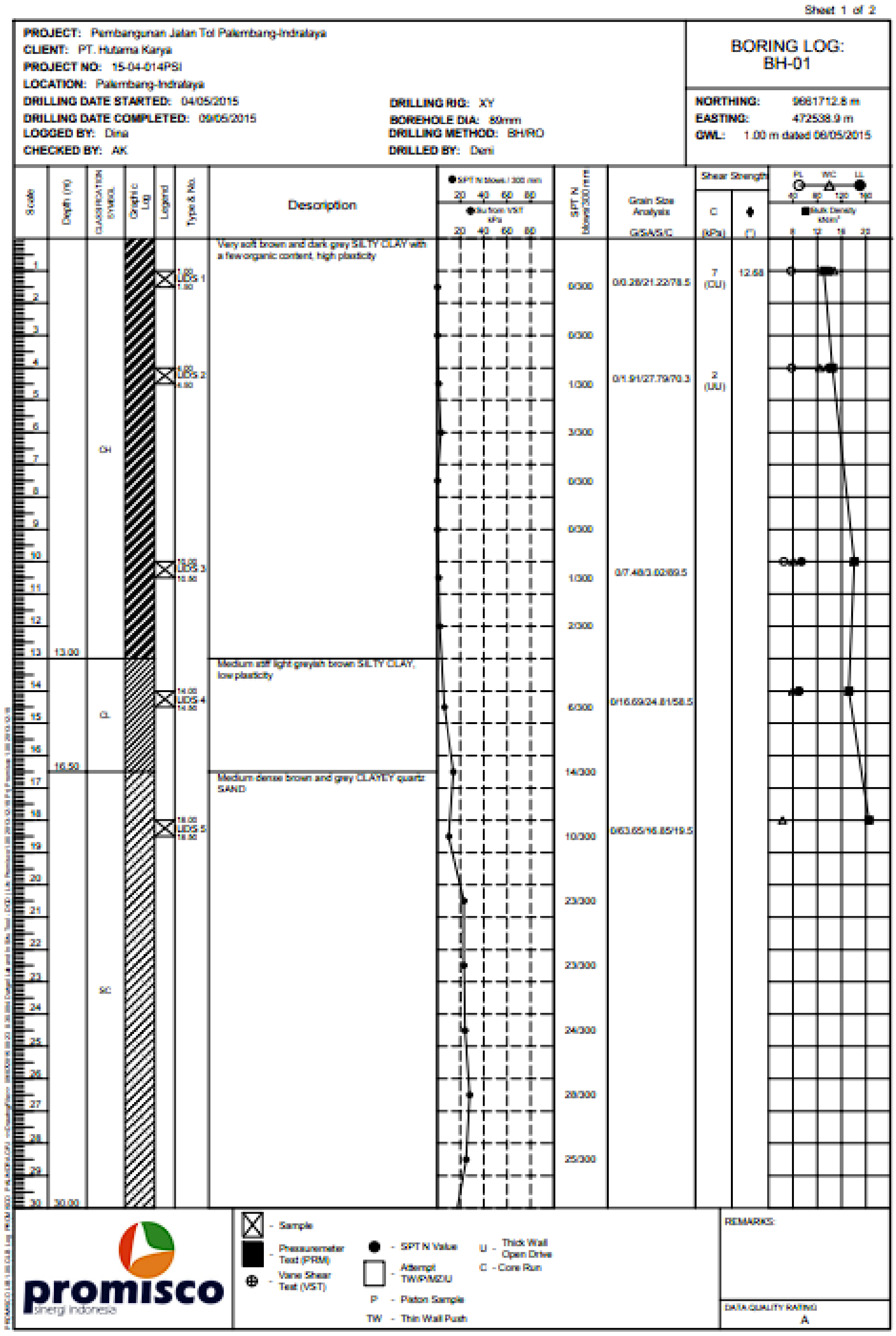
Attachment 1 Boring Log BH-1 Data



PROJECT: Pembangunan Jalan Tol Palembang-Indralaya
CLIENT: PT. Hutama Karya
PROJECT NO: 15-04-014PSI
LOCATION: Palembang-Indralaya
DRILLING DATE STARTED: 04/05/2015
DRILLING DATE COMPLETED: 09/05/2015
LOGGED BY: Dina
CHECKED BY: AK

DRILLING RIG: XY
BOREHOLE DIA: 89mm
DRILLING METHOD: BH/RO
DRILLED BY: Deni

BORING LOG: BH-01

NORTHING: 9661712.8 m
EASTING: 472538.9 m
GWL: 1.00 m dated 06/05/2015

Scale	Depth (m)	Classification Symbol	Graphic Log	Legend	Type & No.	Description	SPT N blows/300 mm (20 40 60 80); Su from VST kPa (20 40 60 80)	SPT N blows/300 mm	Grain Size Analysis G/S/A/S/C	Shear Strength C (kPa)	Shear Strength φ (°)	PL WC LL (40 80 120 160); Bulk Density kN/m³ (8 12 16 20)
31						Very stiff to hard grey CLAY		15/300				
32												
33								27/300				
34												
35		CL						18/300				
36												
37								32/300				
38												
39								30/300				
40	40.00							33/300				
41						Hole Terminated at 40.00 m						
42												
43												
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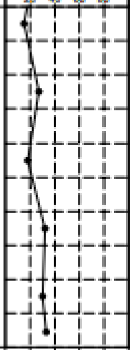
60												



promisco
sinergi indonesia

- Sample
- Pressuremeter Test (PRM)
- Vane Shear Test (VST)
- SPT N Value
- Attempt TW/PM/MZ/U
- P - Piston Sample
- TW - Thin Wall Push
- U - Thick Wall Open Drive
- C - Core Run

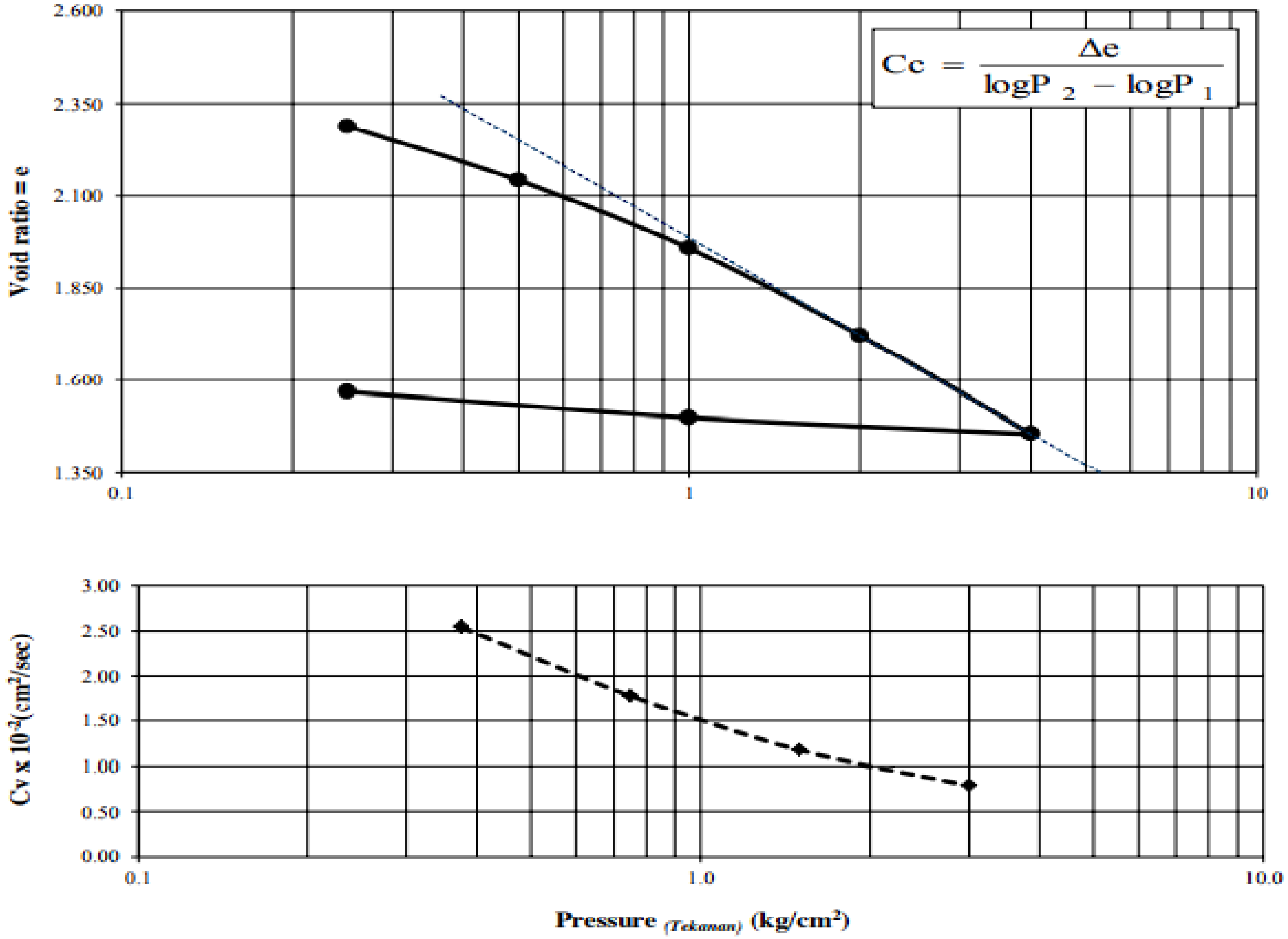
REMARKS:

DATA QUALITY RATING
A

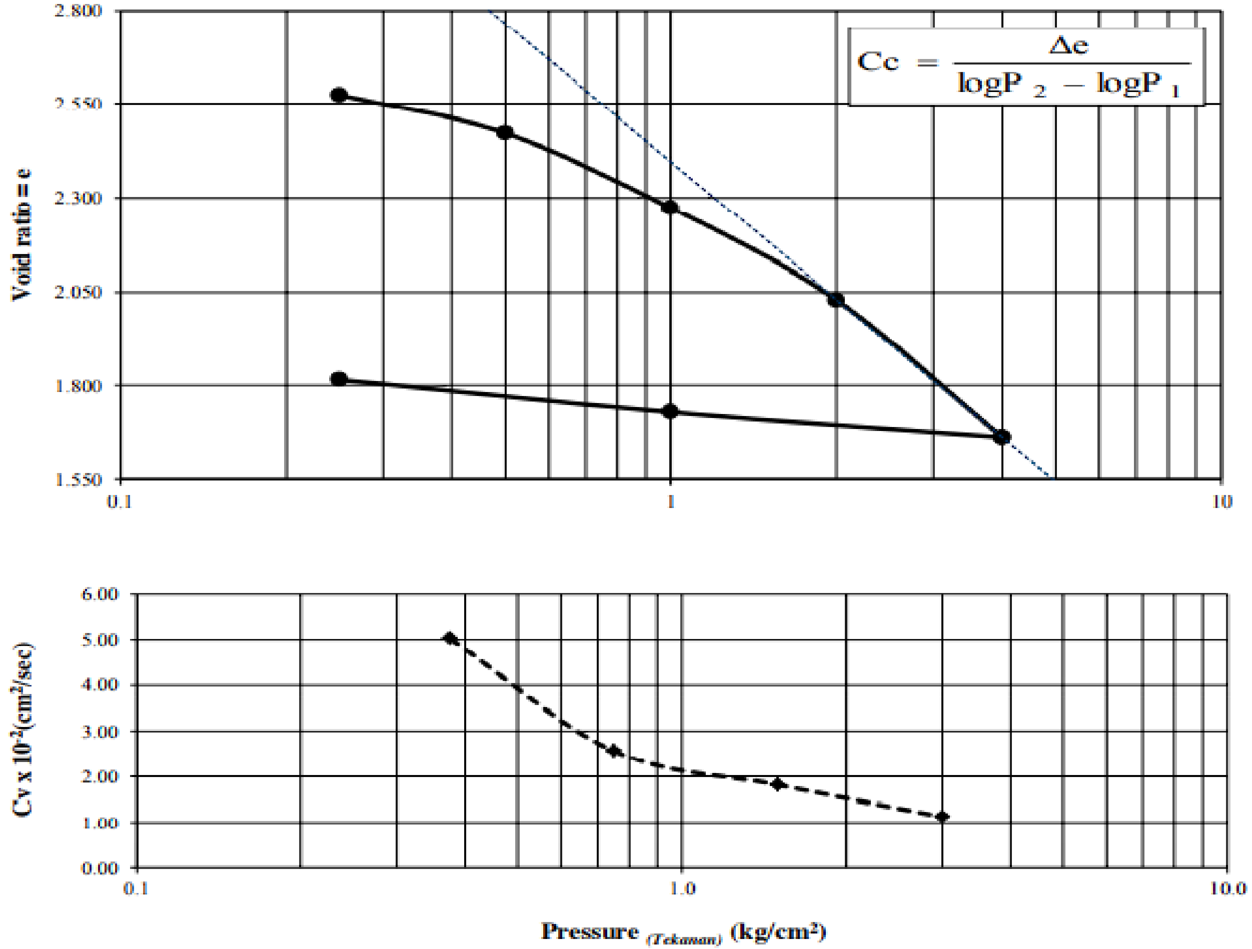
Attachment 2 BH-1 Soil Parameter Data

Sample no. (nomor contoh)	Depth (Kedalaman) (m)	Water Content (kadar air) Wn (%)	Unit Weight (Berat isi) γ_m (gr/cm³)	Dry Density (Berat isi Kering) γ_d (gr/cm³)	Specific Gravity (berat Jenis) G_s (gr/cm³)	Saturability (Kejenuhan) Sr (%)	Void Ratio (Angka Pori) e -	Porosity (Kelengasan) n (%)	Soil Type (Jenis Tanah)	Color (Warna)	Grain Size Analysis (analisis ukuran butir) gravel (Kerikil) (%)	sand (Pasir) (%)	silt (Lanau) (%)	clay (Lempung) (%)	Atterberg Limit (batas-batas Atterberg) W_L (%)	W_P (%)	I_P (%)	Classification (klasifikasi)
BH-1	1.00 - 1.50	107.71	1.307	0.629	2.5576	89.8916	3.065	75.397	SILTY CLAY	BROWN	0.00	0.28	21.22	78.50	100.21	37.26	62.95	CH
	4.00 - 4.50	84.62	1.450	0.785	2.5446	96.1315	2.240	69.135	SILTY CLAY	Dark GREY	0.00	1.91	27.79	70.30	99.05	38.10	60.95	CH
	10.00 - 10.50	40.62	1.809	1.286	2.5807	100.0000	1.006	50.151	CLAY	BLACK	0.00	7.48	3.02	89.50	54.21	24.61	29.60	CH
	14.00 - 14.50	40.03	1.721	1.229	2.5773	94.0440	1.097	52.314	SILTY CLAY	Light GREYISH BROWN	0.00	16.69	24.81	58.50	50.00	27.53	22.47	CL
	18.00 - 18.50	23.05	2.052	1.668	2.6560	100.0000	0.593	37.213	CLAYEY SAND	BROWN	0.00	63.65	16.85	19.50	-	-	-	SC

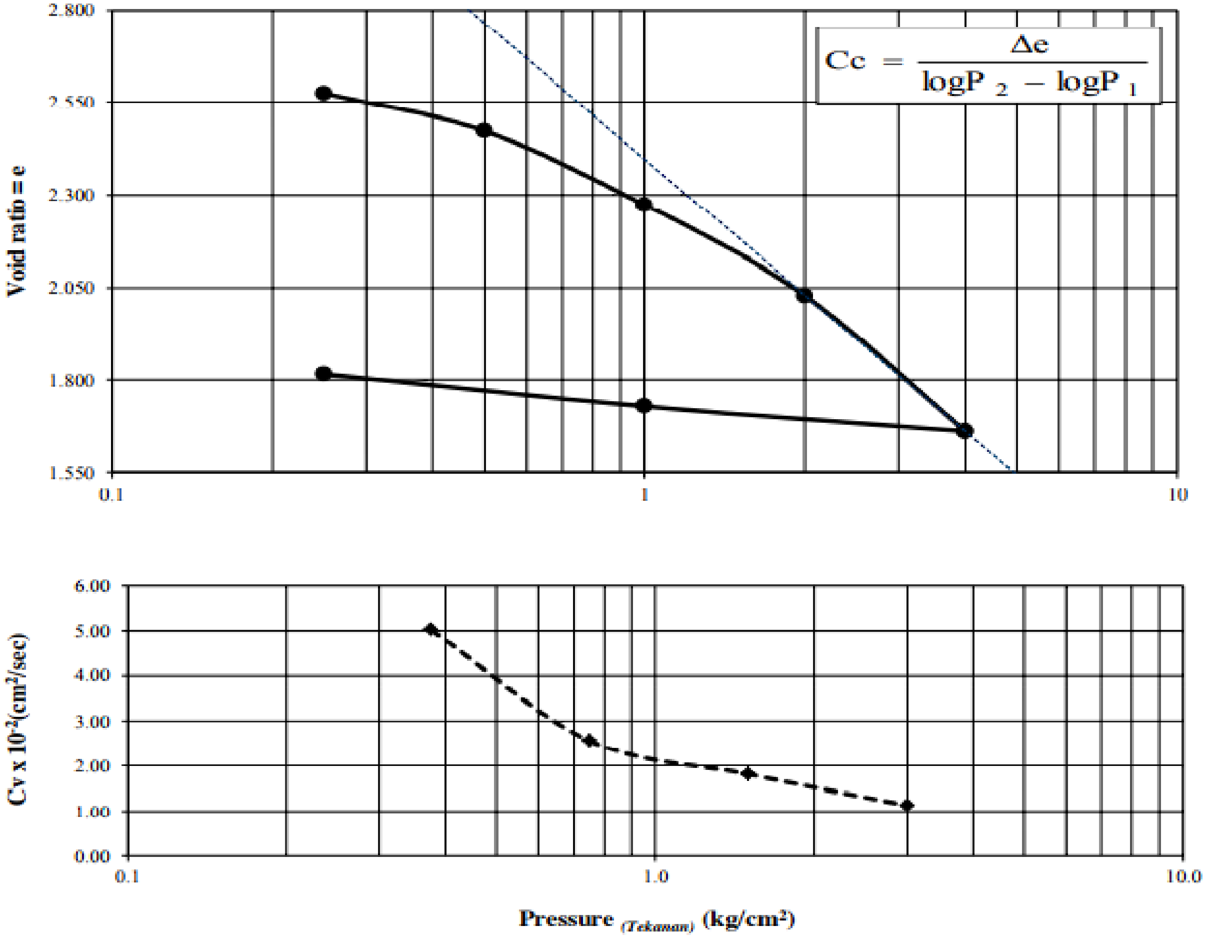
Attachment 3 Result of Consolidation for BH-1 1.00 m – 1.50 m



Attachment 4 Result of Consolidation for BH-1 4.00 m - 4.50 m



Attachment 5 Result of Consolidation for BH-1 10.00 m – 10.50 m



Attachment 6 Result of Consolidation for BH-1 14.00 m – 14.50 m