FINAL PROJECT

EVALUATION OF SOIL IMPROVEMENT
(A CASE STUDY OF VACUUM CONSOLIDATION METHOD AT PALEMBANG – INDRALAYA TRANS SUMATERA TOLL ROAD CONSTRUCTION ZONE 21 SECTION 1 STA 6+650 – STA 6+950, SOUTH SUMATERA)

Submitted to Universitas Islam Indonesia Yogyakarta to Fulfil the Requirements for a Bachelor of Engineering degree

Daud Azizul Arif
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CIVIL ENGINEERING STUDY PROGRAM
FACULTY OF CIVIL ENGINEERING AND PLANNING
UNIVERSITAS ISLAM INDONESIA
YOGYAKARTA

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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 Universitas 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 source will be listed along with its source properly according to the rule, principle, and ethics of 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 August 2022

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Daud Azizul Arif

(17511202)

PREFACE

All praise from the author to almighty Allah.swt, whom has bestowed his grace, knowledge, and guidance, through his blessing the author could finish this final project report to the best of his abilities. This final project report is one of the academic requirements in completing undergraduate studies at Civil Engineering Study Program, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia.

During the preparation and process of this final project report there were many obstacles faced by the author, however thanks to suggestions, criticisms, and encouragement from various parties, this final project report can be written to the end. Finally, the author would like to express his deepest gratitude towards:

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4. Deepest gratitude towards both of the author's parents whom have sacrificed so much, both materially and spiritually so that this final project report can be finished,
5. Civil engineering class of 2017 for being such a friendly companion during the time of the author undergraduate studies,
6. Civil engineering class of 2017 international program students for being such a great classmate during the time of the author undergraduate studies.

The author is fully aware that this final project report is far from perfect, due to the author lack of experience and knowledge. The author hope that this final project report can benefit and help other academic writer and serve as reliable reference for the sake of knowledge.

Yogyakarta, 13 August 2022

Daud Azizul Arif

(17511202)

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B	= Width of the loaded area	(m/mm)
Cα	= Secondary consolidation coefficient	(-)
Cc	= Compressibility index	(-)
Ch	= Horizontal consolidation coefficient	(-)
Cr	= Radial pore water (Horizontal) consolidation coefficient	(-)
Cs	= Swelling index	(-)
Cv	= Vertical consolidation coefficient	(-)
D	= PVD's influence zone circle equivalent diameter	(m/mm)
dw	= Vertical drain equivalent diameter	(m/mm)
e_0	= Pore number	(-)
ep	= Void ratio during primary consolidation	(-)
Eu	= Elasticity modulus	(-)
Fn	= Resistance factor caused by PVD's distance	(-)
Fr	= Flow resistance factor	(-)
Fs	= Smear factor	(-)
h	= (Soil) layer depth	(m/mm)
H	= PVD length	(m/mm)
Hdr	= Pore water travelled average flow length	(m/mm)
Iv	= Embankment geometry influence factor	(-)
kv	= Soil permeability coefficient	(m/day)
Kh	= Permeability of undisturbed zone	(-)
Ks	= Permeability of disturbed zone (smear zone)	(-)
mv	= Volume coefficient of compressibility	(-)
q	= Stress / load acting on the soil surface	(t/m^2)
R	= Correlation coefficient	(%)
R^2	= Coefficient of determination	(%)
Si	= Immediate Settlement	(m/mm)

Ss	= Secondary consolidation Settlement	(m/mm)
St	= Total Settlement	(m/mm)
t	= Embankment service life	(day(s))
t	= Time	(day(s))
tp	= Primary consolidation duration	(day(s))
Th	= Time factor (horizontal)	(day(s))
Tv	= Time factor (vertical)	(day(s))
U	= Consolidation degree	(%)
Uh	= Horizontal consolidation degree (in decimal)	(-)
Upp	= Consolidation degree (piezometer)	(%)
Uv	= Vertical consolidation degree (in decimal)	(%)
β	= Asaoka graph projected line slope of ρn vs ρn+1	(-)
γ_{sat}	= Specific gravity (saturated)	(kN/m^3)
γ_w	= Specific gravity (water)	(kN/m^3)
σ_0’	= Effective stress	(t/m^2)
σ_c’	= Pre consolidated stress	(t/m^2)
$\Delta\sigma$	= Surcharge / vacuum pressure	(t/m^2)

ABSTRACT

The Palembang – Indralaya Toll Road is one of the sections of the Trans Sumatera Toll Road. This specific section of Trans Sumatera Toll Road knowingly has a very problematic existing soil conditions namely soft silty clay soil from the soil surface up until 15 m deep. The goal of this study is to find out whether or not the method used in the project which is the monitoring of settlement using Settlement Plate is accurate in defining the value of the consolidation by comparing the data obtained by the settlement plate used in the project (consolidation settlement, consolidation degree, and soil parameters) with several theoretical analysis namely the analysis of settlement using Terzaghi's approach, final soil settlement prediction using Asaoka, as well as soil properties recalculation using back analysis. Other than that, this study can be used as reference regarding the implementation of Vacuum Consolidation System literature wise.

In performing all of the analysis of this study regarding the Palembang-Indralaya Toll road, secondary data is collected from PT. Hutama Karya Infrastruktur. In this research, the consolidation settlement and consolidation degree analysis is performed using Terzaghi's approach, Asaoka method, and back analysis to recalculate the soil parameter and the standards used are based off of Kementrian Pekerjaan Umum dan Perumahan Rakyat, Badan Pengatur Jalan Tol 2017) in order to conduct the Vacuum Consolidation Method.

Palembang – Indralaya Toll Road from STA 6+650 – 6+950 has an average actual settlement of 604 mm, consolidation degree of >90%, and soil parameters pre vacuum consolidation with Gs of 2.528, sat of 15.14, dry of 8.945, e of1.9835, Cc of 0.53, Cv of 0.0265 m2/day, and Cs of 0.085. After several other analysis namely using Terzaghi's approach, Asaoka, and back analysis The results obtained from this research are several comparisons of average actual and theoretical settlement estimated at around 0.915 m. As for estimation of final soil settlement using Asaoka observational final soil settlement an average of 0.63 m is obtained, while an average consolidation degree of settlement plate reading obtained at around 94.4% is obtained while consolidation degree obtained from vibrating wire piezometer as big as 100% is obtained. While results of back analysis shows average value of m_v as big as 0.00061925, k_v of 0.00016125, C_h of 0.016225, C_h/C_v of 0.612, and value of C_c at around 0.062215. With that said it can be safely assumed that throughout the whole analysis the soil could settle even more for about several milimeters according to Asaoka results.

Keywords: Vacuum Consolidation System, Terzaghi, Asaoka, Back Analysis.

CHAPTER I
PRELIMINARY

1.1 Background

More often than not when an infrastructure is going to be constructed anywhere in the world, the existing soil at the site of the construction will not be at its ideal state, bear in mind that it depends on the type of infrastructure that will be built as well. Out of all the factors that contributes an infrastructure usability, comfortability, and safety, soil is definitely one of the most important factors that can guarantee whether or not the infrastructure can be operated safely, as soil is the foundation where every infrastructure will essentially stand on. With that in mind the ideal soil characteristics and parameters must be reached depending on the type of infrastructure itself.

The Palembang – Indralaya road segment is located in Southern Sumatera where it is a segment of Trans-Sumatera toll road. This road section spans across 21,9 km in length which connects the city of Palembang and Indralaya. However, there are some problems regarding the existing soil that this road segment will be constructed on, the majority of the existing soil available particularly in this section of southern part of Sumatera are soft soils which are problematic for construction and are very prone to settlement. Therefore PT. Hutama Karya Infrastruktur whom are tasked to carry out the construction of this road segment needed a fast, cheap, and ideal soil improvement method that can provide a countermeasure for the potential soil settlement. Top view of the Palembang – Indralaya toll road can be seen on **Figure 1.1** below.

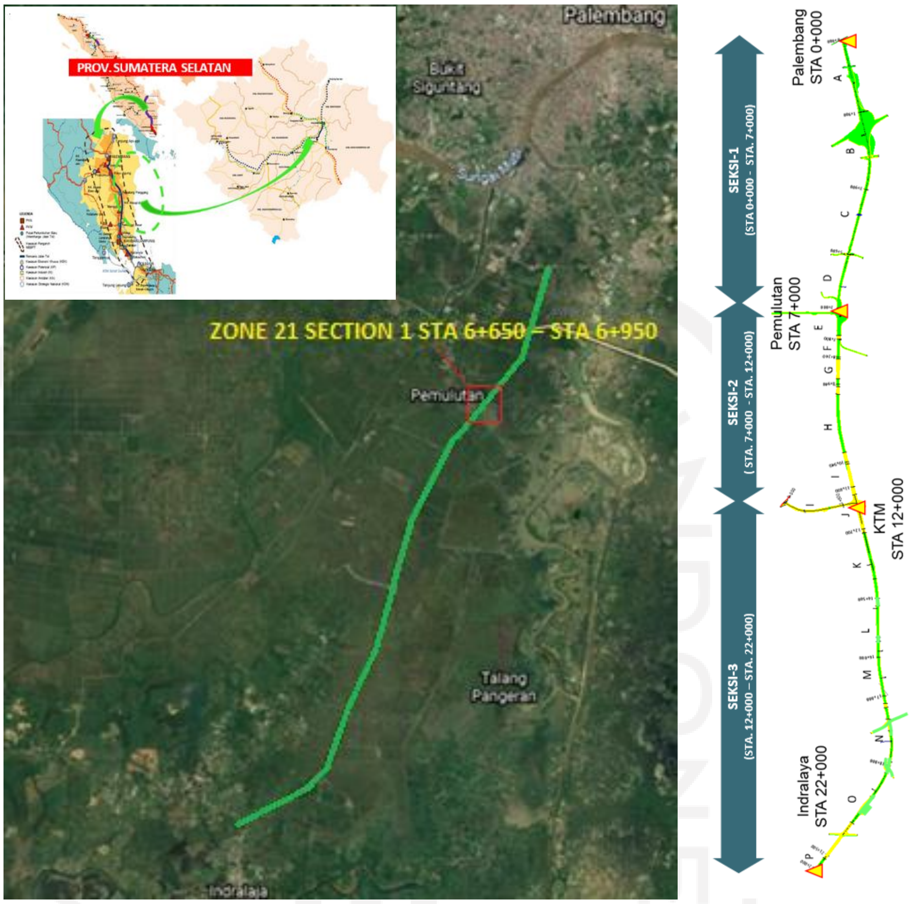


Figure 1.1 Palembang – Indralaya Toll Road Top View

Source: (PT. Hutama Karya Infrastruktur 2017)

Vacuum Consolidation System was first introduced in Sweden by Kjellman in 1952. This method is an alternative method that can be considered for countermeasures of soil settlement caused by consolidation, especially in a location where a procurement of soil embankment materials is relatively hard to procure. Part of the reason why the Vacuum Consolidation System is more beneficial is because it is cheaper and more efficient to do compared to other soil consolidation method, to name one such as the Preloading method with Prefabricated Vertical Drain, as this method requires massive amount of soil material to act as an embankment where the Vacuum Consolidation System replaces the soil embankment material using vacuum pressure.

Wardana (2019) conducted case study research of Vacuum Consolidation System on Pematang Panggang – Kayu Agung road segment located in Southern Sumatera where he compared soil settlement that occurs at the field with theoretical calculation and predicted the amount of final soil settlement using Asaoka method which resulted in a small difference of soil settlement between the actual soil settlement on the field and the theoretical settlement calculation as well as unsignificant difference on the amount of actual final soil settlement and final soil settlement predicted using Asaoka method.

Other settlement analysis needed to be performed regarding the soil settlement in Palembang – Indralaya Toll Road in order to validate the results of the actual settlement found using the settlement plate, since the actual / more practical way needs to be supported by other theoretical analysis to make sure that the soil really is safe to use as an operating Toll road.

1.2 Problem Statement

Based on the aforementioned background, it can be concluded that the problem statement of this research are as follows.

1. How are the comparison between actual soil settlement that happened on the field compared to the theoretical soil settlement on Zone 21 Section 1 STA 6+650 – STA+950?
2. How are the final settlement prediction using Asaoka method compared to the actual final settlement monitored by the settlement on Zone 21 Section 1 STA 6+650 – STA 6+950?
3. How are the consolidation degree at one section of Palembang – Indralaya road segment on Zone 21 Section 1 STA 6+650 – STA 6+950?
4. How are the results of soil parameters obtained from the back analysis method on Zone 21 Section 1 STA 6+650 – STA 6+950?

1.3 Objective

The objective of this research are as follows.

1. To compare actual soil settlement at the field with theoretical settlement using Terzaghi's approach
2. To compare the final settlement predicted using Asaoka method with the actual final soil settlement monitored using the settlement plate data.
3. To obtain information regarding the value of consolidation degree used in the project.
4. To obtain information regarding the soil parameters using back analysis method.

1.4 Benefits

The expected benefits of this research are as follows.

1. To add and contribute towards literature work regarding Vacuum Consolidation method in Indonesia and prediction of soil settlements by consolidation using Asaoka observational method.
2. Give Insights and real example on how soft soil should be handled during road construction.
3. Provide important information about soil as one of the most important variables in civil engineering and how it could be fatal if not handled properly.

1.5 Limitations

The limitations of this research are as follows.

1. Layout and research location is only at one of the sections on Palembang – Indralaya road segment.
2. Data used are primary data obtained from PT. Hutama Karya Infrastruktur and secondary data obtained from literature research.
3. Soil Improvement method used is Vacuum Consolidation method with Prefabricated Vertical Drain.

4. Geotechnical Instrument used are Settlement Plate, Vibrating Wire Piezometer, and Vacuum Gauge.
5. Prediction of final soil settlement methods used is Asaoka Observational method using the data obtained from Settlement plate reading.
6. Incomplete DED (Detailed Engineering Drawing) documentation to show the layout of every single geotechnical monitoring device

CHAPTER II

LITERATURE REVIEW

2.1 General Review

Soft soils are soils that if not recognized and investigated carefully, can cause long term problems of instability and irreversible settlement that cannot be tolerated, soft soil has low shear strength and a high amount of compressibility. Soft soil is a cohesive soil consisting of mostly very small grains of soil particles, an example would be clay or silt. Other than that majority of soft soils have small amount of shearing forces, large amount of compressibility, a small amount of permeability coefficient and a lower bearing capacity compared to other soils.

If a layer of soil experiences outside force or loads, those same layers of soil will experience straining which then leads to settlement. This straining that occurs on the soil is caused by the shift in the fine soil grain arrangement, reduction of pores in soil, or even water inside those same soil layers. These settlements caused by outside forces or loads is a combination of Immediate Settlement and Consolidation Settlement. In permeable sandy soil, water can flow quickly thus the pores of water inside the soil caused by the increase in pore water pressure can finish faster. The discharge of water from the pores is always accompanied by a decrease in soil volume. The reduction in the volume of the soil can lead to settlement of the soil layer due to pores of water in sandy soil that drains out in a quick manner, and thus immediate settlement and consolidation settlement occur simultaneously (DAS,1985).

Regardless of whether or not a process of Vacuum Consolidation System is applied or not, there are several ways to consolidate a soft soil before construction of infrastructure begins. Methods such as the Pre-Loading with Prefabricated Vertical Drain is most similar to the Vacuum Consolidation System, both methods use a Prefabricated Vertical Drain to drain all of the moisture and water out of the soils on a certain depth, the difference of these two methods lies on the pressure or forces that is used to drain the water content on the soils. What the Pre-Loading method uses as massive amount of embankment materials is replaced by Vacuum Pressure by the Vacuum Consolidation System. While both methods have its advantages and disadvantages, the method of Vacuum Consolidation benefits outweighs the performance of Pre-Loading whether in cost or in the speed of the process.

2.2 Previous Study Results

Fadhillah (2018) conducted a study regarding the use of Vacuum Consolidation System with Prefabricated Vertical Drain (PVD) on Cluster D Summarecon City Bandung. The research states that the method that they used to improve the soil is the Vacuum Consolidation System with a Prefabricated Vertical Drain (PVD). The main principle of this method is by removing the atmospheric pressure on the soil which then will be consolidated and stays on vacuum condition until the determined time. The type of soil compatible with this method generally are soils with a very soft consistency, with an N-SPT value of 0 – 4. From the data obtained it is shown that Cluster D area has the average compressible soil depth of 20 m. In laboratory data, the value of C_c is very low which allows a lower settlement from the original state in the field. Correlation of C_c value is needed. To get the planned load, atmospheric pressure correction needs to be done to match the effectiveness of the vacuum pump. Furthermore, the calculation of natural consolidation time followed by the design of PVD and the foundation's carrying capacity is planned. The duration needed until the soil reached 90% consolidation without the help of soil improvement is 194 years, but with the help of soil improvement that have been done it only took 22 weeks. For the foundation design, shallow foundation is used with a rectangular shape. The length and width of it are both 150 cm while the depth of it is 50 cm. The shallow foundation carrying capacity before soil improvement is 0,396 kg/cm2 while after soil improvement being 0,567 kg/cm^2

Wardana (2019) conducted research on Pematang Panggang – Kayu Agung road segment, South Sumatera. The analysis conducted in this research uses theoretical method namely the Terzaghi method in order to obtain soil settlement value while also predicting the final soil settlement using Asaoka. This study shows the comparison between the theoretical soil settlement calculation and the actual soil settlement that happened on Pematang Panggang – Kayu Agung road segment to give the reader an idea of just how accurate these theoretical methods that are available for us to use and for us to have the ability to pick and choose by ourselves the method that we would want to use and apply on real world problems related to soil settlement. This research shows that the comparison between the actual and theoretical calculation for soil settlement averages on 0.743, the prediction of final soil settlement caused by vacuum pressure using Asaoka method averages at around 912.97 mm, average consolidation degree based on settlement plate readings at 91.86%, consolidation degree from vibrating wire piezometer at 84.36%. With an effective vacuum pressure of 81 kPa the vacuum pump reached VG SP 11 reading at 165th day, VG SP 12 reading at 148^{th} day. While back analysis calculation shows an average value of mv= 0,000616 m^2/kN, kv of 0,000034 m/day, C_h of 0,002097 m^2 /day, and C_c of 0,371.

Nawir, Apoji, et all (2012) conducted research predicting the value of final soil settlement using observational method namely the Asaoka method. The purpose of this research is to predict the final soil settlement value using observational method and comparing the result with the actual final settlement that happened in the field. This research also shows soil consolidation theoretical calculations such as the Terzaghi method, even though the soil settlement value resulted using this method tends to have a significantly higher value than the actual settlement, and also by using a method called finite element analysis. This research shows that the estimated soil consolidation value obtained by using Terzaghi method have a significantly higher value compared to the Asaoka method, to be specific by using the Terzaghi method the value of final soil settlement at BV–2 & SP 8 resulted at around 1030 (mm), BV–6 & SP 18 at 565 mm, while using the asaoka method the value of final soil settlement at BV–2 & SP 8 resulted at around

658 (mm),BV–6 & SP 18 at 172 mm. Based solely on the results of the research conducted it can be concluded that even though the purpose of both methods namely the Terzaghi method and Asaoka method both has its own plus and minus, Terzaghi method generally needed a fairly complete soil parameter data with a result of significantly higher than the actual soil settlement, while the Asaoka method generally could predict the value of actual final soil settlement without using parameters that are needed for other theoretical consolidation analysis while still having a fairly accurate or more accurate results.

Ekamargarezki (2018) also conducted research regarding the prediction and evaluation of final soil settlement using Asaoka method and the analysis of actual consolidation degree. This research uses several geotechnical instruments that are essential to Vacuum Consolidation System, just to name a few are the settlement plate, wire vibrating piezometer, and inclinometer. This study also discusses soil design parameters in actual condition using back analysis method. The results obtained in this study are the comparison of actual and theoretical settlement with an average of 1,04. As for the prediction of final soil settlement a value of 1546,36 mm is obtained. The actual consolidation degree from Vibrating Wire Piezometer reading shows 79,1% and from the Settlement Plate reading shows 87,62% with a difference of 8,52%. From the Inclinometer readings there is a lateral shift that occurs underground however it does not cause indications of sliding. The vacuum pump reached its effective pressure of 74 kPa consecutively at the 91st reading (day 45), the 63th reading (day 31), the 70th reading (day 35) and the 91th reading (day 45). While the result of back analysis is a new C_h value of 3,55 C_v.

2.3 Comparison with Previous Study

From the collection of research found during the literature review that somewhat relates and have some kind of similarities to the topic of this study, similarities and differences can be seen on Table 2.1 below.

Table 2.1 Summary of Previous Study

	Previous Studies			**Studies Conducted**
Author	**Wardana (2019)**	**Ekamargarezki (2019)**	**Lilabsari (2018)**	**Arif (2022)**
Title	Evaluasi Perbaikan Tanah Lunak Menggunakan Metode Observasional	Evaluasi Kinerja Perbaikan Tanah Lunak Menggunakan Instrumen Geoteknik	Evaluasi Kinerja Perbaikan Tanah Lunak Menggunakan Instrumen Geoteknik	Evaluation of Soil Improvement
Sub Title	Evaluation of Soil Improvement (Vacuum Consolidation System) using Terzaghi's approach, asaoka, and back analysis	Evaluation of Soil Improvement (Vacuum Consolidation System) using Terzaghi's approach, asaoka, and back analysis	Evaluation of Soil Improvement (Preloading with vertical drains) using Terzaghi's approach, asaoka, and back analysis	Evaluation of Soil Improvement (Vacuum Consolidation System) using Terzaghi's approach, asaoka, and back analysis

Continuation of Table 2.1 Summary of Previous Study

	Previous Studies			Studies Conducted
Author	**Wardana (2019)**	**Ekamargarezki (2018)**	**Lilabsari (2018)**	**Arif (2022)**
Location	Pematang Panggang – Kayu Agung Toll Road, South Sumatera	Summarecon Bandung Cluster D Area	Summarecon Bandung Cluster Amanda and Btari	Palembang – Indralaya Toll Road STA 6+650 – STA 6+950
Objective	To find Consolidation Settlement and Consolidation Degree using Several Methods such as Asaoka, and Terzaghi's approach as well as soil parameters recalculation using back analysis	To compare soil settlement that occurs theoretically using Terzaghi's approach and Asaoka, to find the value of consolidation degree as well as the embankment stability approach as well as soil parameters recalculation using back analysis	To compare soil settlement that occurs theoretically using Terzaghi's approach and Asaoka, to find the value of consolidation degree as well as the embankment stability approach as well as soil parameters recalculation using back analysis	To compare soil settlement that occurs theoretically using Terzaghi's approach and Asaoka, to find the value of consolidation degree as well as soil properties recalculation using back analysis

Continuation of Table 2.1 Summary of Previous Study

	Previous Studies			Studies Conducted
Author	**Wardana (2019)**	**Ekamargarezki (2018)**	**Lilabsari (2018)**	**Arif (2020)**
Research Results	Actual and theoretical settlement averages on 0.743 which shows that actual settlement has not reached theoretical settlement Based on asaoka results, the actual soils settlement has not yet reached 100%, meaning the soil will likely to settle even more in the future	Actual settlement and theoretical settlement averages on 1.04 which shows that actual settlement has exceeded the theoretical settlement conducted Consolidation degree from settlement plate is slightly larger than consolidation degree obtained using Vibrating Wire Piezometer No indication of landslides	Actual settlement and theoretical settlement averages on 0.862 which shows that the actual settlement has not reached the theoretical settlement Based on asaoka results, consolidation will likely to occur even more up to 6 – 43 days Inclinometer shows no indication of landslides	Results of average theoretical settlement is 0,064 lower than actual settlement Based on asaoka settlement the soil will likely to settle for a few more days until it reaches 100% consolidation degree Back analysis shows the soil parameter changes

Continuation of Table 2.1 Previous Study Results

	Previous Studies			Studies Conducted
Author	**Rivanga, Hamdan (2019)**	**Wimpie, Eka, et all (2017)**	**Puspita, Capri (2017)**	**Arif (2022)**
Title	Analisis Vacuum Consolidation Dengan Model Axisymmetric	Perhitungan Kembali Nilai Koefisien Konsolidasi Pada Perbaikan Tanah Lunak	Analisa Penurunan Tanah Lunak Dengan Beberapa Metode Konsolidasi Pada Proyek Jalan Tol Palindra.	Evaluation of Soil Improvement
Sub Title	Analysis of Vacuum Consolidation System using Plaxis 2D and Mohr Coulomb	Analysis of Consolidation Coefficient Value Using Asaoka	Analysis of Soil Consolidation with Rectangular PVD, Recatangular VCM, Triangular PVD, and Triangular VCM	Evaluation of Soil Improvement (Vacuum Consolidation System) using Terzaghi’s approach, asaoka, and back analysis
Location	Not Given	Riau’s Steam Power Plant	Palembang – Indralaya Toll Road Construction Project	Palindra Toll Road Section 1 Zone 9 STA 1+850

Continuation of Table 2.1 Previous Study Results

Previous Studies				Studies Conducted
Author	**Rivanga, Hamdan (2019)**	**Wimpie, Eka, et all (2017)**	**Puspita, Capri (2017)**	**Arif (2022)**
Research Result	The effect of single drainage and double drainage conditions was not significantly different. In the Soft Soil model, the settlement and time between single drainage and double drainage produces almost the same value	Duration required to achieve a degree of consolidation 90% is for approximately 6 (six) months If the soft clay quality is not improved, then the consolidation process will occur over 26.2 years with and never achieve the 90% degree of consolidation degree	Based on the results of this research analysis can be concluded that the function of the PVD method is to speed up the consolidation time of 17.34 years to 105 days. PVD with triangular installation pattern is proven to be most effective as it requires the shortest time to fully consolidate the soil	Results of average theoretical settlement is 0,064 lower than actual settlement Based on asaoka settlement the soil will likely to settle for a few more days until it reaches 100% consolidation degree Back analysis shows the soil parameter changes

Based on **Table 2.1** several similarities and differences between the research mentioned above and the research conducted can be concluded as follows.

1. The similarities between this study and research conducted by Fadhillah (2018) is that both construction project under study uses the same method of soil improvement which is the Vacuum Consolidation System and both project uses similar geotechnical instrument. While the difference between the two are the location of the research, different soil characteristics, different analysis methods, and the research conducted by the author are more focused on the settlement analysis, prediction of the final settlement and comparing the theoretical analysis with the actual results in the field, while the research conducted previously by Fadhillah (2018) are more focused on comparison between natural consolidation time and the consolidation using the Vacuum Consolidation System, while also comparing between 2 soil bearing capacity results namely before and after soil improvement using a shallow rectangular shaped foundation design.
2. The similarities between this study and research conducted by Wardana (2018) are that both project uses the same method of soil improvement which is the Vacuum Consolidation System, both study focuses on analysing the soil settlement and prediction of final soil settlement, both studies also uses similar geotechnical instrument and analysing methods namely the Terzaghi and Asaoka method. While the difference between both research is the location where the project under study is located, both research uses a different soil sample and parameters, and both research does not have the same object of study.
3. The similarities between this study and research conducted by Nawir, Apoji, et all (2012) are that both study aims to predict final soil settlement that happened in the construction project by using the same observational method namely the Asaoka method. While the difference being soil improvement method is not the same, the location of study is not the same, and the soil parameter and characteristics under study are not the same.

4. The similarities between this study and research conducted by Ekamargarezki (2018) is that both project uses the same method of soil improvement which is the Vacuum Consolidation System, both uses similar geotechnical instrument that are essential for Vacuum Consolidation System. While the differences are the location under study, and the soils that are investigated which includes all of the soil characteristics and parameters.
5. The similarities between this study and journals written by Rivanga and Hamdan (2018) is that both project uses the same method of soil improvement namely the Vacuum Consolidation System, both study uses the similar geotechnical instrument that are essential for Vacuum Consolidation System. While the differences are the location studied, the soils under study including all of the soil characteristics and parameters, research method where journals written focuses more using Plaxis 2D and all of the methods supporting Plaxis 2D.
6. The similarities between this study and the journal written by Wimpie, Eka, Andri and Arthono (2017) is that both project uses the same analysis method to predict the final soil settlement using the Asaoka method. While the differences are the location under study, the soil consolidation method used because the journal uses the Pre-loading with PVD and also the journal focuses more towards the recalculation of consolidation coefficient after soil consolidation have been conducted.
7. The similarities between this study and the journal written by Puspita and Capri (2017) are that both project uses similar consolidation method namely the Vacuum Consolidation System even though the preloading method is also included in their journal. While the difference can be found on the research method where on the journal of Puspita and Capri (2017) tends to focus more on comparing both the Pre-loading and Vacuum Consolidation System with different PVD configuration (triangle and rectangular).

8. The similarities between this study and the journal written by Nurtjahjaningtyas and Wicaksono (2019) is that both study uses the same research methods namely using the Asaoka method in order to predict the final soil settlement that will occur on the project site, the journal also tends to compare between different methods of analysis similar to the ones the author will conduct. While the difference of both studies can be seen on one of the research methods where the author did not use hyperbolic method, location of research also is not the same which also means soil investigated will not have any similarities whatsoever.

9. The similarities between this study and the journal written by Metri, Mutiara, Sukarman and Ika is that it uses the Vacuum Consolidation System as one of its important elements, the project is also the same which is the Palembang – Indralaya Toll Road however the area under study will be a different location of Palembang – Indralaya Toll Road. While the difference of both study lies on the location (different station, section, and zone), also the research methods are not the same with the journal aims to compare both consolidation methods namely the Vacuum Consolidation System and the Pre-Loading method.

CHAPTER III

THEORETICAL BASIS

3.1 Soil

According to Verhoef (1994) soil is generally defined as a collection of parts that are solid and not bound to one another (some of which may be material organic matter) the void between the material contains air and water.

Soil is defined as a material that consists of solid minerals aggregate (particle) that are not cemented (bound chemically) between one another and form weathered organic materials (with solid particles) paired with liquid substance and oxide that have sedimented in between the material particles. The room in between the particles can be water, air, or any other material (Hardiyatmo, 1992).

According to DAS (1995), soil is a material consisting of solid minerals that are not chemically bound to each other. Soil is formed from organic matter that has weathered and is accompanied by liquids and gases that fill the void between the particles

With all the references above, it can be concluded that soil is a collection of mineral particles that are formed by the process of rock that have weathered either naturally or unnaturally. The weathering of solid rock process caused it to shrink overtime and eventually became smaller in size. The pore in between those smaller sized grain of soil is filled by either substance of water or gas. Depending on the characteristics and parameter soil can be classified generally as sand, silt, clay, or a combination of either of them.

3.2 Soft Soil

Soft soil is a type of soil where if it is not identified and investigated thoroughly and carefully could cause instability problem and long terms settlement that are intolerable, soft soil have a low shearing capacity and high compressibility. Example of this type of soil would be the clay and fine silt.

Soft soil is a cohesive soil that consists mostly of very fine particles or generally referred to as clay or silt. Some characteristics of soft soil are small amount of shearing capacity, highly compressible, low coefficient of permeability, and has a low bearing capacity compared to other soil. Generally soft soil has the following properties as follows.

1. Low shearing capacity,
2. If water content increases, shear capacity decreases,
3. If soil structure is disturbed, shear capacity decreases,
4. Plastic if wet and easily become compressed,
5. Shrinks when dry and expands when wet,
6. High compressibility.

3.3 Soil Settlement

Whenever a layer of soil saturated by water is given an additional load, the value of water pressure will eventually rose. On sandy soil that are very permeable water can flow very quickly, making the flow of water on the soil pores go outwards or upwards as a result of an increase in pore water pressure. The discharge of water from oil pores is always accompanied by a decrease in soil volume, the decrease of volume in sandy soil can cause settlement for that soil layer. Because pore water on a sandy soil is able to discharge very fast, thus an immediate settlement and consolidation settlement could occur at the same time.

3.3.1 Immediate Settlement (S_i)

Immediate Settlement (S_i) is a settlement of soil caused by elastic distortion of the soil particles, usually occurs rapidly typically during construction. Immediate Settlement (S_i) in general is the primary cause of settlement for Coarse Grained Soil (i.e. Gravel and Sand).

To calculate the amount of Immediate Settlement, equation based off of elasticity theory with Poisson Ratio = 0,5 and Elasticity Modulus that can be seen on Equation (3.1) below

$$Si = \frac{Iv\ qB}{\mathrm{Eu}} \tag{3.1}$$

With:

I_v = embankment geometry influence factor

q = stress / load acting on the soil surface

B = the width of the loaded area

E_u = elasticity modulus

Iv factor can be calculated with elasticity theory analysis that can be seen on Equation (3.2)

$$Iv = (1 - v^2)f1 + (1 - v - 2v^2)f2 \tag{3.2}$$

For a case of undrain loading Equation (3.2) can be simplified into Equation 3.3 and Equation 3.4 below

$$Iv = \frac{3}{4}f1 \tag{3.3}$$

$$Eu = \frac{215cu\ ln\ F}{lp} \tag{3.4}$$

Coefficient of f1 and f2 can be seen on **Figure 3.1** below.

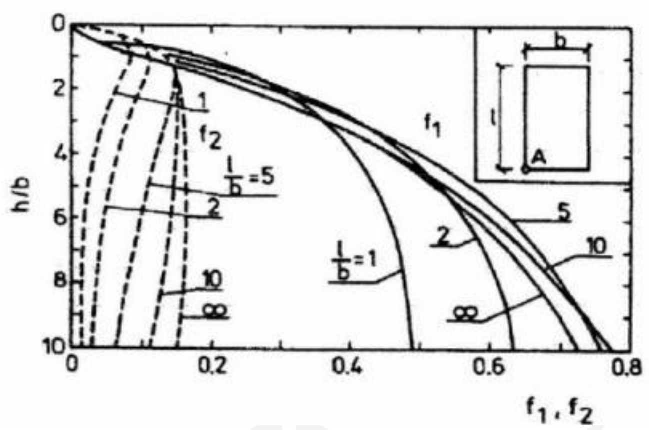


Figure 3.1 f1 and f2 Coefficient Graph

Source: (Lilabsari 2018)

3.3.2 Consolidation Settlement

DAS (1985) defines consolidation as a process of the removal of the water or air from the soil pores, deformation of soil particles, relocation of particles that are caused by load or stresses acting on a soil.

Relationships of time and compressibility during consolidation can be seen on **Figure 3.2** below

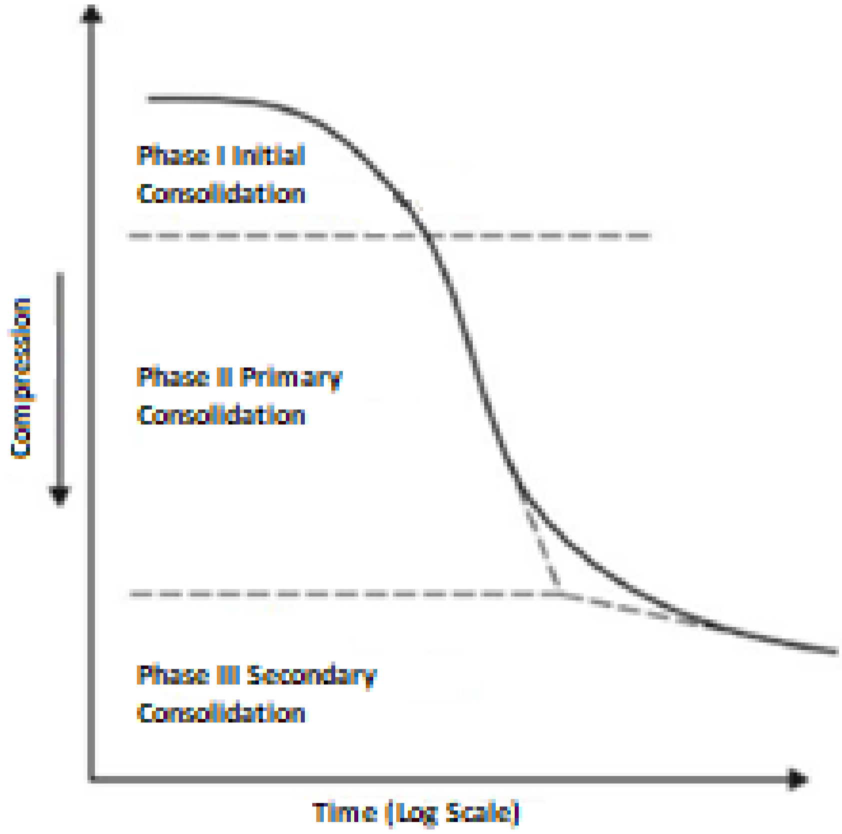


Figure 3.2 Relationship of Time (Log Scale) vs Compressibility During Consolidation for Additional Loads Given

Source: (DAS 1994)

Based on **Figure 3.2** it can be concluded that there are three different stages of consolidation that occur on a soil.

Phase I	:	Initial compression (Immediate Settlement), generally occur during initial Preloading.
Phase II	:	Primary Consolidation, which is the period when Pore Water Pressure slowly transferred into Effective Stress
Phase III	:	Secondary Consolidation, where consolidation occur after pore water pressure had been drained completely, Compression that occurs is caused by the plastic adjustment of the soil grains after primary consolidation

3.3.2.1 Primary Consolidation Settlement (S_c)

Consolidation Settlement is a settlement that occurs due to the dissipation of pore water pressure in undrained soil into a drained soil. According to Weasley (1977), if a layer of soil experiences additional load or stress, then over time the pore water will exits the pores of the soil which then leads to a decrease in the total volume of the soil. In general, consolidation acted on one direction vertically. This happens because the load acting on the soil does not move in a horizontal manner because it is held in place by soil particles surrounding around it.

In order to calculate the amount of consolidation that occurs, Braja M. Das gives several equations based on the soil condition, namely Normally Consolidated Soil and Overly Consolidated Soil.

Normally Consolidated Soil occurs when the current Overburden Effective Stress is the maximum stress that has ever occur on the soil. For soils with a low to medium sensitivity as well as pore number (e_0) and overburden stress (σ_0'), changes on pore number can be seen on Curve 1 of **Figure 3.3** while "Curve 2" shows consolidation test results for soil sample that are Undisturbed. If soil sample is tampered and then remolded, thus the position of pore number (e_0) and overburden stress (σ_0') can be seen on Curve 3. The equation of Normally Consolidated Soil where pore number (e_0) and overburden stress (σ_0') if the Curve were to be a straight line can be seen on Equation 3.5 below

$$Sc = \frac{Cc\ H}{1+e0} log(\frac{\sigma 0' + \Delta\sigma'}{\sigma 0'}) \tag{3.5}$$

While Overly Consolidated Soil occurs if the current effective overburden stress is smaller than past stresses that that particular soil has experienced in the past, that maximum effective overburden stress is called pre-consolidation stress. Braja M. Das expresses Overly Consolidated Soil with low to medium sensitivity and has experienced pre-consolidation stress as well as pore number (e_0) and overburden stress (σ_0'), curve of consolidation is represented by line c-b-d on **Figure 3.4**. Where line b-d represents the real compressibility curve. Soil sample that aren't too tampered is represented by line c-b which is a real on-site recompression, which almost have the same slope as the rebound curve f-g from laboratory consolidation test. With that in mind, the Overly Consolidated Soil can be seen on Equation (3.6) and Equation (3.7) below

If $\sigma0' + \Delta\sigma \leq \sigma'c$, thus

$$Sc = \frac{Cs\ h}{1+e0}\ x\ log(1 + \frac{\Delta\sigma}{\sigma'0}) \tag{3.6}$$

If $\sigma0' + \Delta\sigma > \sigma'c$, *thus*

$$Sc = \frac{Cs\ h}{1+e0}\ x\ log\left(\frac{\sigma'c}{\sigma'0}\right) + \frac{Cc\ h}{1+e0}\ x\ log\left(\frac{\sigma'0+\Delta\sigma}{\sigma'c}\right) \tag{3.7}$$

h = (soil) layer depth

e0 = initial void ratio

C_c = compressibility index

C_s = swelling index

Δ_σ = surcharge

σ'_o = effective overburden stress

σ'_c = effective pre-consolidated stress

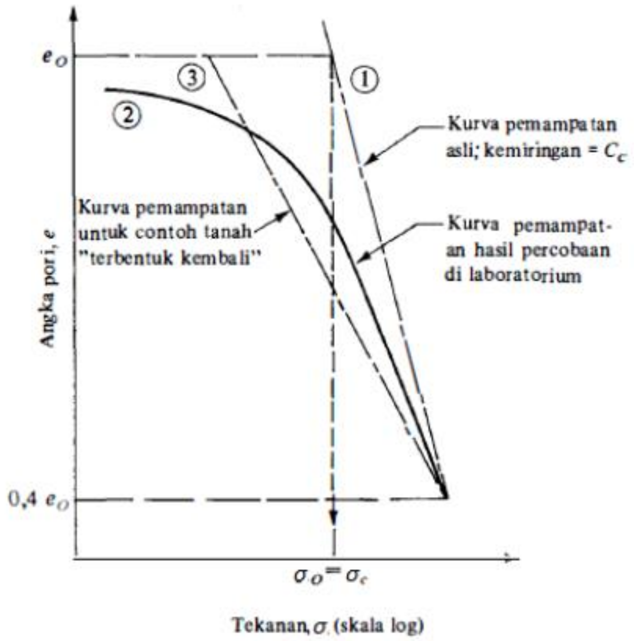


Figure 3.3 Characteristic of Normally Consolidated Clay With Low to Medium Sensitivity

Source: (DAS 1985)

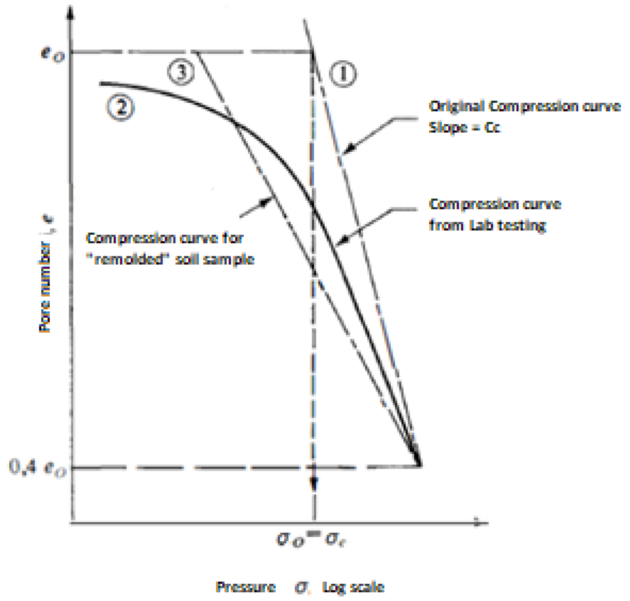


Figure 3.4 Characteristic of Overly Consolidated Clay with Low to Medium Sensitivity

Source: (DAS 1985)

3.3.2.2 Secondary Consolidation Settlement (S_s)

Secondary settlement occur after primary consolidation is fully completed This settlement occurs due to the adjustment of soil grains in the soil after the excess pore water pressure is completely dissipated (u=0). During the process of secondary settlement there is no change in effective soil stress, thus generally secondary consolidation takes place for a very long time. Secondary Settlement can be expressed with Equation (3.8) below

$$Ss = \frac{C\alpha\ H}{1+ep} log \frac{t}{tp} \quad (3.8)$$

$$\frac{C\alpha}{Cc} = 0{,}05 \ \pm 0{,}01 \text{ for clay and fine silt}$$

$$\frac{C\alpha}{Cc} = 0{,}06 \ \pm 0{,}01 \text{ for peat}$$

With:

Cα = secondary consolidation coefficient

tp = primary consolidation duration

t = embankment service life

ep = void ratio during primary consolidation

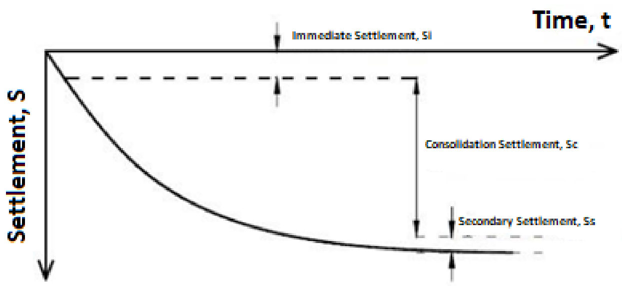


Figure 3.5 Stages of Soil Settlement

Source: (Gouw 2010)

Total settlement that occur on **Figure 3.5** can be calculated from the summation of all three settlement type. The amount of total soil settlement according to Das (1985) can be seen on Equation (3.9) below

$$St = Si + Sc + Ss \tag{3.9}$$

With:

St = total settlement

Si = immediate settlement

Sc = settlement caused by primary consolidation

Ss = settlement caused by secondary consolidation

3.4 Improvement of Soft Soil

Generally, Primary Consolidation can take years to finish naturally if the Fine-grained Soil has a very high compressibility. With that in mind, a solution to accelerate the pore water from exiting the soil is needed.

3.4.1 Soil Improvement with Preloading

One of the most common solutions to accelerate the discharge of pore water from soil is by using an embankment that acts as initial stress that will be applied above the area that will be consolidated.

The Preloading method is a soil improvement method by placing a soil embankment on the soil improvement location with an amount as minimum as the same stress that the structure that will be built will apply, and that same embankment will be removed if the desired amount of consolidation is achieved (Pedoman Konstruksi dan Bangunan, 2004) as can be seen on **Figure 3.6** below.

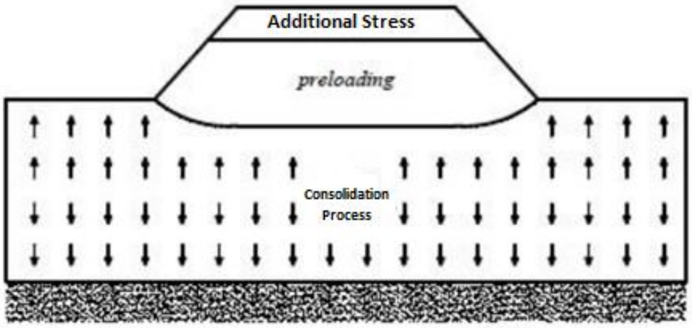


Figure 3.6 Preloading Method Scheme

Source: (Yunias, Lishia 2010)

On a saturated soft soil, the stress applied by Preloading will be resisted by the pore water on the soil, over time the pore water pressure will be dissipated and eventually the stress of the Preloading will be resisted by the soil itself (primary consolidation finished).

Soil improvement using Preloading method can be determined using consolidation degree equation (U), where the consolidation degree for Preloading can be seen on Equation 3.10 below.

$$U = \frac{Sc\ (p)}{Sc(p+f)} \tag{3.10}$$

$S_{c(p)}$ and $S_{c(p+f)}$ can be obtained by using Equation 3.11 and Equation 3.12

$$Sc(p) = \frac{Cc\ (H)}{1+e0} log \frac{\sigma'0+\Delta\sigma'(p)}{\sigma'0} \tag{3.11}$$

$$Sc(p+f) = \frac{Cc\ (H)}{1+e0} log \frac{\sigma'0+(\Delta\sigma'(p)+\Delta\sigma'(f))}{\sigma'0} \tag{3.12}$$

Thus a final equation for consolidation degree using *Preloading* can be seen on Equation 3.13 below.

$$U = \frac{\log\ (1+\frac{\Delta\sigma'(p)}{\sigma'_0})}{\log\ (1+\frac{\Delta\sigma'(p)}{\sigma'_0}\left(1+\frac{\Delta\sigma'(f)}{\Delta\sigma'(p)}\right))} \tag{3.13}$$

Problems that are often encountered during *Preloading* are as follows

a. If the value of $\Delta_{\sigma'(f)}$ is known to be $\frac{\Delta\sigma'(f)}{\Delta\sigma'(p)}$ but the value of t_2 (time after *Preloading* stress application) need to be determined. Value of σ′0, $\Delta\sigma'_{(p)}$, consolidation degree (U) and value of T_v, thus the value of t_2 is considered as the time of on-site consolidation which can be expressed using Equation 2.14 below.

$$t = \frac{Tv\,(H^2dr)}{Cv} \tag{3.14}$$

With:

H_{dr} = pore water travelled average flow length

T_v = time factor

t = time

C_v = vertical consolidation coefficient

The relationship between time factor (T_v) and consolidation degree (U) as well as the relationship between Δσ′(f) dan Δσ′(p) with consolidation degree (U) can be seen on **Figure 3.7** and **Figure 3.8** below.

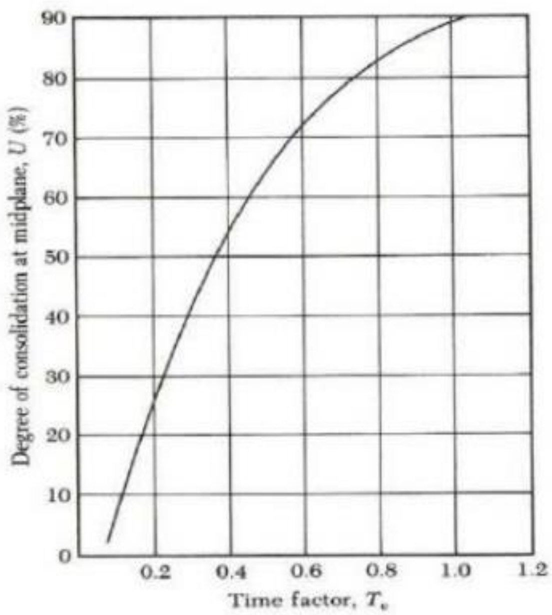


Figure 3.7 Relationship Between Time Factor (Tv) and Consolidation Degree (U)

Source: (Lilabsari 2018)

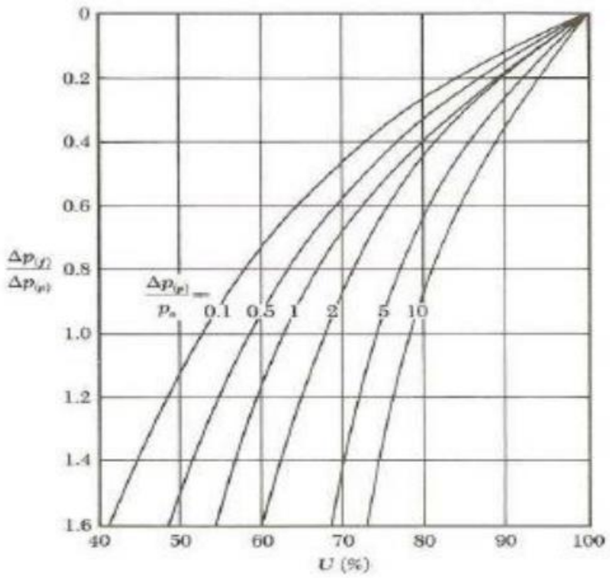


Figure 3.8 Relationship Between ∆σ′(f) dan ∆σ′(p) With Consolidation Degree (U)

Source: (Lilabsari 2018)

b. If during planning a specific value of t_2 is known and value of $\Delta\sigma'_{(f)}$ need to be determined. In this case, the value of Time Factor (Tv) need to be determined first. Value of Tv is plotted onto the graph on **Figure 3.8** in order to find Consolidation Degree (U) value. After Consolidation Degree (U) is known, it is then plotted onto the graph on **Figure 3.9**.

However, during construction it is often found that by only using this Preloading method the consolidation duration still use up years of time in order to fully consolidate the soil. Because of that, Preloading is usually combined with Vertical Drains, this Vertical Drains are installed on the soil where the soil compressibility value is high.

3.4.2 Soil Improvement Using Vacuum Consolidation System

Vacuum Consolidation System is a system that accelerates the process of consolidation on soft soils by using vacuum pressure. Essentially it is a technique that applies vacuum suction on an isolated soil in order to reduce atmospheric pressure inside of it, by reducing pore water pressure on a soil effective stress can increase without changing the total stresses.

This method was first introduced in Sweden by Kjellman (1952). This type of loading system aims to reach a faster consolidation process without increasing the amount of embankment used to consolidate the soil to avoid shearing failure.

The concept of Vacuum Consolidation System is similar to Preloading method, both methods use Prefabricated Vertical Drain to help drain the pore water out of the soil. The difference being the Vacuum Consolidation System replaces the additional embankment materials used in Preloading with vacuum pressure.

1. effective stress increases along with vacuum suction pressure and soil lateral shift can be sustained. That way probability of shear failure can be as minimum as possible,
2. vacuum pressure can be distributed until the depth far below soil layer by using Prefabricated vertical drain (PVD),
3. volume of soil embankment can be massively reduced and will still reach the same settlement value.

The typical vacuum loading can be seen on **Figure 3.9** where Prefabricated Vertical Drain (PVD) and Prefabricated Horizontal Drain are used to distribute vacuum pressure and dissipation of pore water inside the soil

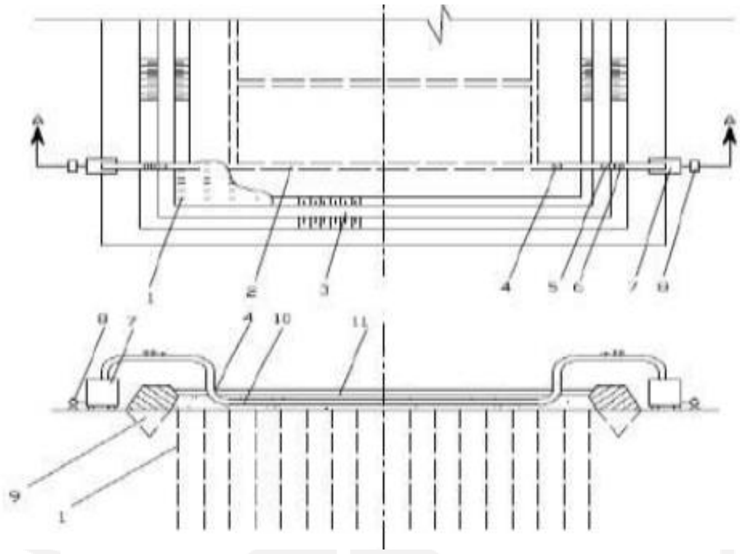


Figure 3.9 Vacuum Loading System Scheme

Source: (J.Chu S.Yan, B.Indraratna 2014)

With:

1. Prefabricated vertical drain (PVD)
2. Prefabricated horizontal drain (PHD)
3. Revetment
4. Water outlet
5. Valve
6. Vacuum gauge

7. Jet pump
8. Centrifugal pump
9.Ditch channel
10. Vacuum main pipe
11. Wrapping membrane

3.4.3 Prefabricated Vertical Drain (PVD)

Soil Improvement by Preloading the duration of consolidation still takes a very long time, and by Vacuum Consolidation System it is a requirement to use Prefabricated Vertical Drain. Because it takes a long time for water to dissipate and flows through soil only, a vertical channel that have a high permeability that gives pore water inside the soil to dissipate. That vertical channel is called Vertical Drains, Vertical Drains back then used to be just a column of sand that can allow water to dissipate called Sand Drains. As technology advances, a product called Prefabricated Vertical Drain (PVD) was made

3.4.4 Prefabricated Horizontal Drain (PHD)

Prefabricated Horizontal Drain is an underground drainage system that is used to drain water horizontally from the vertical drain, usually during the application of soft soil improvement using the Preloading method and Vacuum Consolidation method. Horizontal drains generally use 2 types of geosynthetic materials consisting of a Core (core made of HDPE) and a filter (filter made of geotextile/PET)

3.5 Soil Parameter

In order to estimate the time it took for consolidation to occur, several soil parameters will be needed namely:

3.5.1 Vertical Coefficient of Consolidation (C_v)

Vertical coefficient of consolidation expresses the time of consolidation process on soil vertically. The equation of vertical coefficient can be seen on Equation 3.5 below.

$$Cv = \frac{k}{\gamma w \ x \ mv} \tag{3.15}$$

Where:

C_v = Vertical coefficient of consolidation

k = Soil permeability coefficient

γ_w = Specific gravity of water

3.5.2 Horizontal Coefficient of Consolidation (C_h)

Horizontal coefficient of consolidation can be determined using the value of vertical coefficient of consolidation (C_v) which can be seen on Equation 3.6 below.

$$Ch = \frac{Kh}{Ks} Cv \tag{3.16}$$

Where:

C_v = Vertical coefficient of consolidation

C_h = Horizontal coefficient of consolidation

k_h = Permeability of undisturbed zone

k_s = Permeability of disturbed zone (*smear zone*)

3.5.3 Compressibility Index (C_c)

Compressibility Index used to compute the amount of settlement at construction field caused by consolidation can be determined by curve that shows the relationship between pore water and pressure that can be obtained from laboratory test (DAS,1985).

According to Holtz and Kovacs (1981) the value of compressibility index of several clay soils classified by Unified Soil Classification System (USCS) are as can be seen on **Table 3.1** below.

Table 3.1 Compressibility Index Value (Cc) of Various Clayey Soil

Soil Type	Compressibility Index (Cc)
Normally consolidated medium sensitive clay	0,2 – 0,5
Chicago silty clay (CL)	0,1 – 0,3
Boston Blue clay (CL)	1 – 3
Swedish medium sensitive clay (CL – CH)	1 – 4
Canadian Leds clay (CL – CH)	7 – 10
Mexico City clay (MH)	7 – 10
Organic clays (OH)	> 4
Peats (Pt)	10 – 15
Organic silt and clays (OH)	1,5 – 4
San Francisco Bay Mod (CL)	0,4 – 1,2
San Francisco Old Bay Clays (CH)	0,7 – 0,9
Bangkok clays (CH)	0,4

Source: Holtz and Kovacs (1981)

3.5.4 Swelling Index (C_s)

The value of swelling index is greater than compressibility index with the expression as can be seen on Equation 3.7 below.

$$Cs \approx \frac{1}{5} \text{ to } \frac{1}{10} Cc \tag{3.17}$$

3.5.5 Volume Coefficient of Compressibility (m_v)

Volume coefficient of compressibility is every increase in stress which resulted on volumetric strain in a clayey soil, mv can be expressed as on Equation 3.18 below.

$$Sc = mv \; x \; \Delta\sigma \; x \; Ho$$

$$mv = \frac{Sc}{\Delta\sigma \text{ x } Ho} \tag{3.18}$$

Where:

S_c = Primary consolidation settlement

mv = Volume coefficient of compressibility

Δ_σ = Additional vertical stress

3.5.6 PVD affected zone

the installation of Prefabricated Vertical Drain (PVD) generally is installed with 2 methods. Both methods have a different way to determine the distance of PVD (S) which can be expressed as can be seen on Equation 3.19 and 3.20 below.

D = *1.128 x S*, for rectangular pattern (3.19)

D = *1.05 x S*, for triangular pattern (3.20)

3.5.7 Equivalent Diameter (d_w)

Consolidation theory with radial drainage only applies with the assumption that the soil has experienced drainage process with circular shaped in cross section, with radial consolidation equation consisting of PVD diameter (*d*). With that said, rectangular PVD must be equivalized with equivalent diameter (d_w), as a circular drain diameter that acts as a drain performance theoretically. Design of equivalent diameter can be calculated with Equation 3.21 below.

$$dw = \frac{D(2(a+b)}{\pi} \quad (3.21)$$

Where:

a = PVD cross sectional area (m)

b = PVD cross sectional thickness (m)

Equation (3.22) can be applied in general if part of the area of the PVD circumference which allows the inflow of water (not restrained by the PVD core) exceeds 10 to 20 % of the total circumference. For this type of PVD in general this is easy to obtain. Seepage in the layer between the openings to the drainage channel, theoretically will reduce the effect of PVD core resistance. Thus Equation 3.21 is modified into Equation 3.22 below. While illustration of equivalent diameter can be seen on **Figure 3.10** below.

$$dw = \frac{(a+b)}{2} \quad (3.22)$$

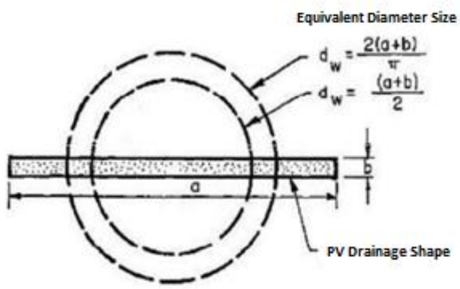


Figure 3.10 Equivalent Diameter

Source: (Pedoman Perencanaan PVD Kementrian PUPR 2021)

3.5.9 Resistance Factor

Resistance factor affects the value of consolidation on vertical drains application.

3.5.9.1 Resistance Factor Caused by Distance Between PVD (*Fn*)

Calculation of resistance factor caused by distance between PVD is defined by Hansbo (1979) as can be seen on Equation 3.23 below.

$$Fn = \frac{n^2}{\mathrm{n}-1} ln(n) - \frac{3n^2-1}{4n^2}$$

$$Fn = \frac{1}{1-\frac{1}{n^2}} ln(n) - \frac{3-\frac{1}{n^2}}{4}, if\ value\ of \frac{1}{n^2} \approx 0$$

Hence

$$Fn = ln(n) - \frac{3}{4}\ or\ Fn = \ln\frac{D}{dw} - \frac{3}{4} \quad (3.23)$$

3.5.9.2 Resistance Factor Caused by Smear Effect (*Fs*)

During installation of vertical drain, it is often assumed that vertical drain does not affect the soil parameter around it, however in reality during the penetration process the mandrel that made contact with the soil will affect the soil around it. The soil that made contact with the mandrel will have a reduced permeability thus slowing down the consolidation process. This is also known as the smear effect.

The smear effect will increase as the drain diameter increases, other factors such as installation method, mandrel size, and anchor plate size also contribute to smear effect. Permeability and compressibility of soil in the smear zone are different from undisturbed soils, with that in mind smear factor needed to be calculated using Equation 3.24 below.

$$Fs = (\frac{Kh}{Ks} - 1) \ln\frac{ds}{dw} \quad (3.24)$$

With:

Fs = Smear factor effect

Kh = Undisturbed horizontal permeability

Ks = Disturbed horizontal permeability (smear zone)

dw = Vertical drain diameter

ds = Disturbed zone diameter (minimum 2,5 times mandrel diameter)

3.5.9.3 Flow Resistance Factor (Fr)

The flow resistance factor is calculated as a limit factor for the drain ability to work effectively, namely the ability of the drains to drain water before buckling/squeezing of the soil around the drain due to the active lateral soil stress. If the drain capacity has reached its limit during the consolidation process so overall the consolidation process is halted. The value of the flow resistance factor can be found by using Equation 3.25 below.

$$Fr = \frac{\pi}{6}\frac{Kh\, L^2}{qw} \tag{3.25}$$

With:

Kh = Undisturbed horizontal permeability

L = The entire length of the PVD when water can only flow through one end of the PVD, and is equal to half the length of the PVD when water can flow out through both ends of PVD

qw = The PVD equivalent well flow capacity at a hydraulic gradient of one

3.5.10 Consolidation Degree Determination Using PVD

Consolidation degree is one of the criteria to evaluate the effectivity of soil improvement by using additional stress and PVD. This is often used as a design specification. Consolidation degree used is calculated as a ratio between current settlement of soil and the final soil settlement.

With vertical drainage on soil layer, excess pore water pressure will be dissipated in 2 directions, namely vertical and horizontal. Total consolidation degree (U) can be calculated using Equation 3.26 below.

$$U = 1 - (1 - Uh)\,(1 - Uv) \tag{3.26}$$

With:

Uv = Vertical consolidation degree

Uh = Horizontal consolidation degree

Vertical consolidation degree can be determined using Equation 3.27 for Uv value between 0 – 60% and Equation 3.28 for Uv value greater than 60%.

$$Uv = \left(2\sqrt{\frac{Tv}{\pi}}\right).100\% \quad (3.27)$$

$$Uv = (100 - 10a) . 100\% \quad (3.28)$$

With:

$$a = \frac{1{,}781 - Tv)}{0{,}933}$$

Tv = Vertical time factor

Value of horizontal consolidation degree is expressed by Barron (1948) on Equation (3.29) and Equation (3.30) below.

$$Uh = 1 - \exp\left(\frac{-8Th}{\mathrm{F(n)}}\right) \quad (3.29)$$

$$Th = \frac{Ch.t}{D^2} \quad (3.30)$$

With:

Th = Horizontal time factor

Ch = Horizontal consolidation coefficient

3.6 Vacuum Consolidation System Implementation in Construction

In order for the Vacuum Consolidation System to work optimally a series of construction implementation method must be followed, construction implementation method for Vacuum Consolidation System are as follows:

3.6.1 Measurement of Row and Embankment

This consists of measurement of existing elevation (long section), measurement of Row with an average width of 60 m (L/R), and measurement of embankment of road which is 45 m (adjusted to finish grade elevation) and temporary road 7.5 m (L/R). Measurement of row and embankment process can be seen on **Figure 3.11** below

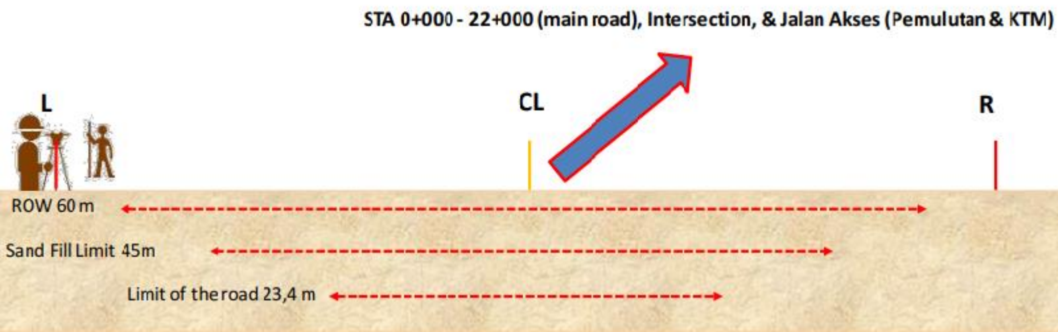


Figure 3.11 Measurement of Row and Embankment

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.2 Embankment Filler and Horizontal Sand Drainage

First the existing soft soil is coated with geotextile woven which acts as a separator between the existing soft soil and the embankment soil. After the existing soft soil is coated with geotextile woven an embankment made of soil is then spread all over the area above it. The length of geotextile woven installation on main road is 65 m wide. While the length of geotextile woven is about 200 – 500 m. Embankment filler and horizontal sand drainage process can be seen on **Figure 3.12** below.

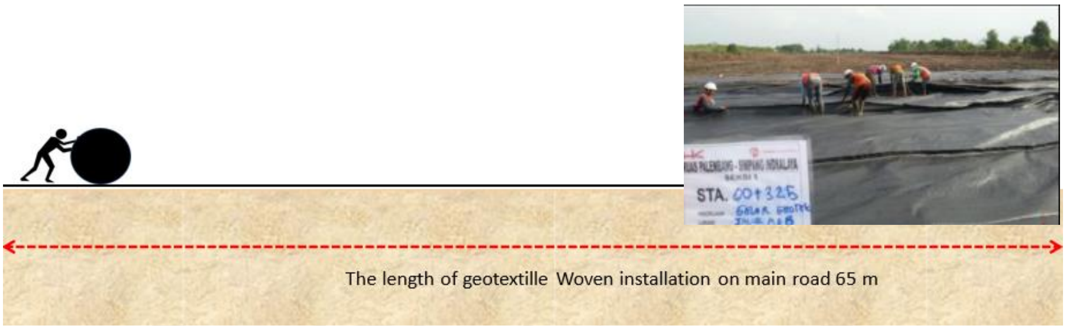


Figure 3.12 Geotextile Woven Coating

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.3 Pre boring

In order to install the Prefabricated vertical drain (PVD), several holes are made with 5 m depth and distance between each hole are 1 x 1 m. This task is done with a drilling machinery adjusted to drill holes for installation of PVD. Pre boring process can be seen on **Figure 3.13** below

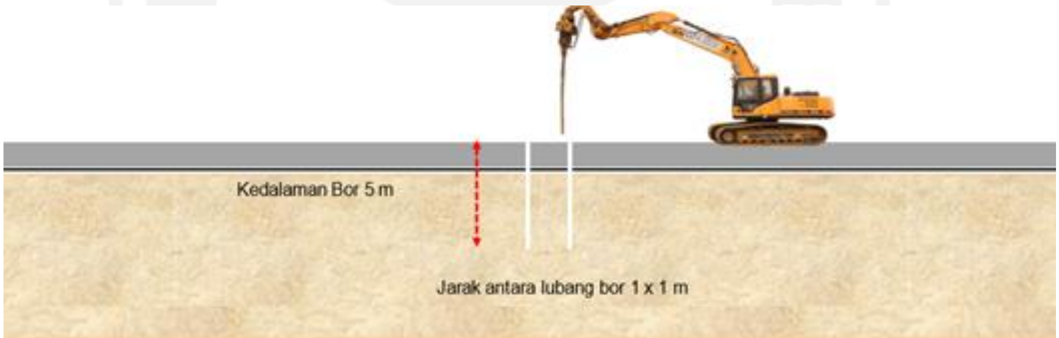


Figure 3.13 Pre boring

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.4 Installation of Prefabricated Vertical Drain (PVD)

Installation of PVD is done on the hole made by the drilling machinery (1 x 1 m), each and every hole made is inserted with PVD by using PVD rig (Excavator Modified) with planned depth referring to the Cone Penetration Test (CPT) result and is given an extra 50 cm, this is done so that the water sucked by the PVD are able to reach the Prefabricated Horizontal Drain (PHD) faster, and then are relocated outside the vacuum area. Installation of PVD process can be seen on **Figure 3.14** below

Figure 3.14 Installation of PVD

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.5 Installation of Prefabricated Horizontal Drain (PHD)

PHD consists of 2 types of pipes, namely filter pipe and main pipe. Installation of PHD is done on horizontal sand drainage, the maximum distance between PHD is 6 m if permeability of sandy soil is good, and 3 m if permeability of soil is bad. Installation of PHD can be seen on **Figure 3.15** and **Figure 3.16** below

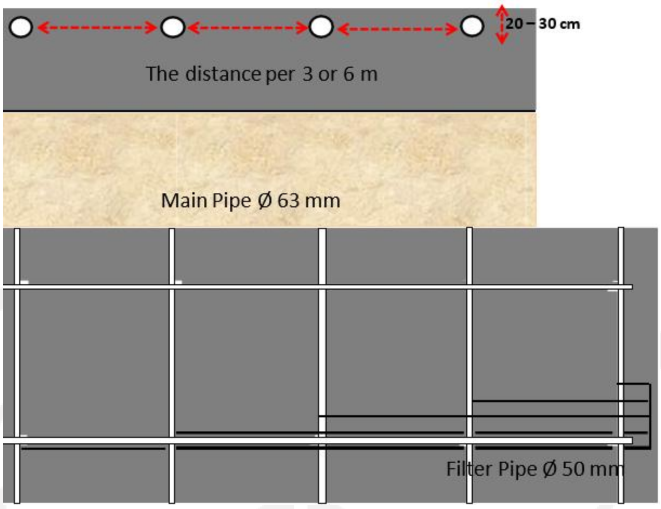


Figure 3.15 PHD Installation Layout

Source: (PT. Hutama Karya Infrastruktur 2017)

Figure 3.16 Installation of PHD

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.6 Sealing Ditch

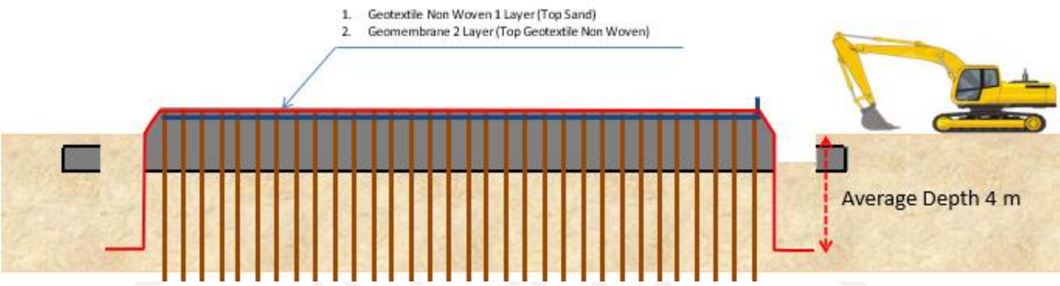


Figure 3.17 Sealing Ditch Layout

Source: (PT. Hutama Karya Infrastruktur 2017)

The first geotextile nonwoven is installed above the horizontal sand drainage, then *geomembrane* is installed and planted covering the whole vacuum area with about 4 – 5 m depth. Installation of sealing ditch can be seen on **Figure 3.17 and Figure 3.18**

Figure 3.18 Sealing Ditch Installation

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.7 Vacuum System Installation

One vacuum pump can cover up to more than 1000 m^2 of vacuum area, thus the need for vacuum pump can be calculated based on the area where vacuum process will occur, while the need for power generator powering the vacuum pump can be calculated based on how big the equivalent of load to pump that will be done. Installation of Vacuum system can be seen on **Figure 3.19** and **Figure 3.20** below

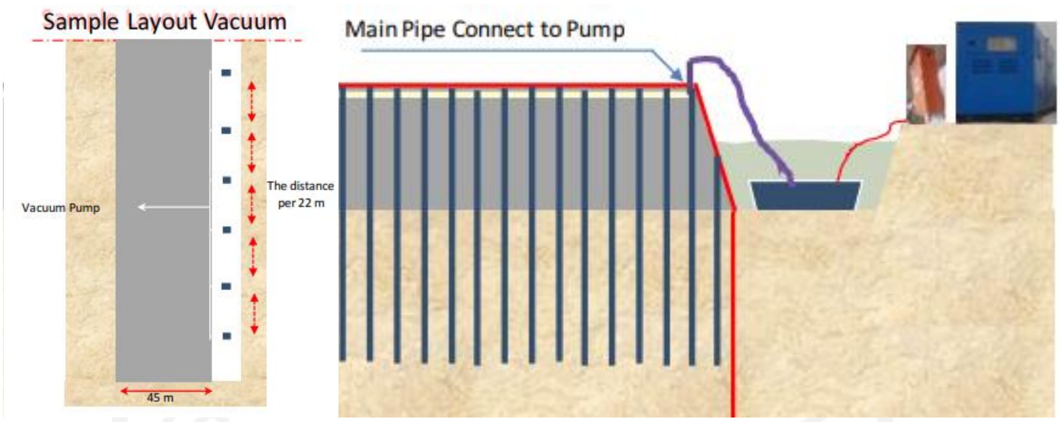


Figure 3.19 Vacuum System Layout

Source: (PT. Hutama Karya Infrastruktur 2017)

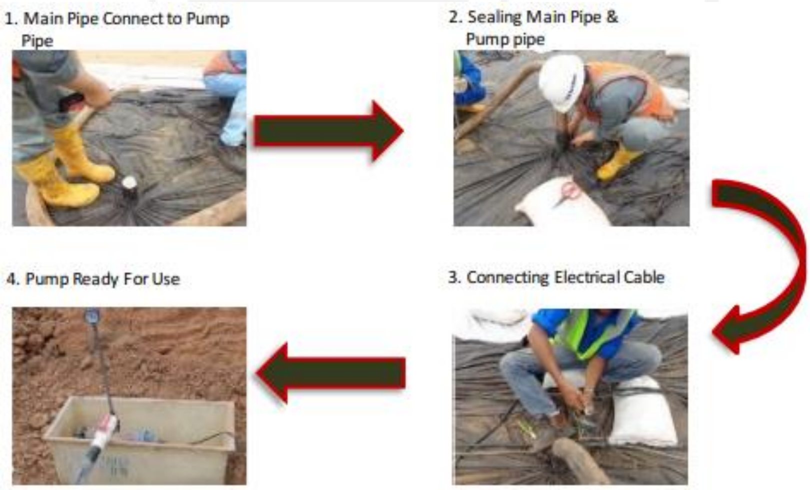


Figure 3.20 Vacuum System Installation

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.8 Monitoring Instrument (Surface Settlement & Pressure Gauge)

Surface settlement is installed at centre line above the geomembrane with 100 m distance, this is done to give information about surface settlement caused by vacuum. While vacuum gauge is an instrument used in order to give information regarding the pressure on vacuum area caused by the vacuum, vacuum gauge installed with 50 m distance in radius on the centre line. Surface settlement and Pressure gauge process can be seen on **Figure 3.21** below

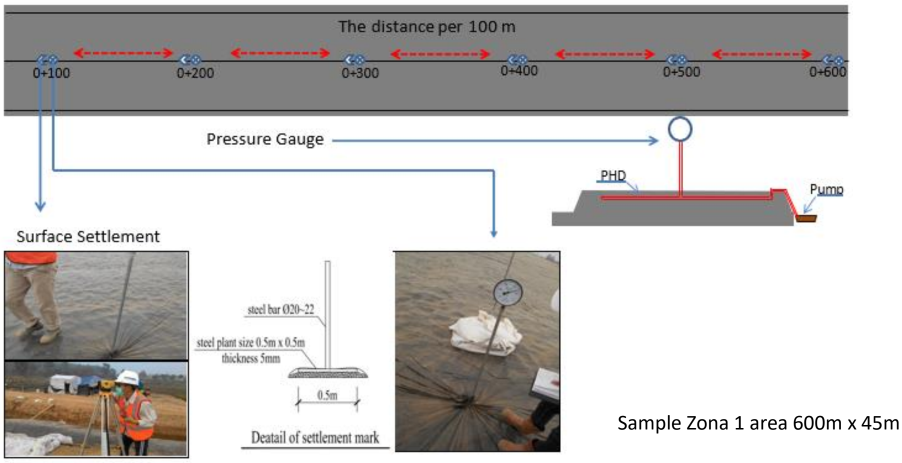


Figure 3.21 Surface Settlement and Pressure Gauge Layout

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.9 Monitoring Instrument (Piezometer & Extensometer)

Piezometer functions as measuring instrument for pore water pressure during the vacuuming process. Piezometer is installed at the centre line with a distance of 200 m in radius with 5, 10, and 15 m depth (depends on PVD depth). While extensometer functions as measuring instrument to give information about layer to layer movement or settlement caused by vacuum. Extensometer is installed on the centre line with 5, 10, and 15 m depth (depends on PVD depth). Piezometer Installation details can be seen on **Figure 3.22** below

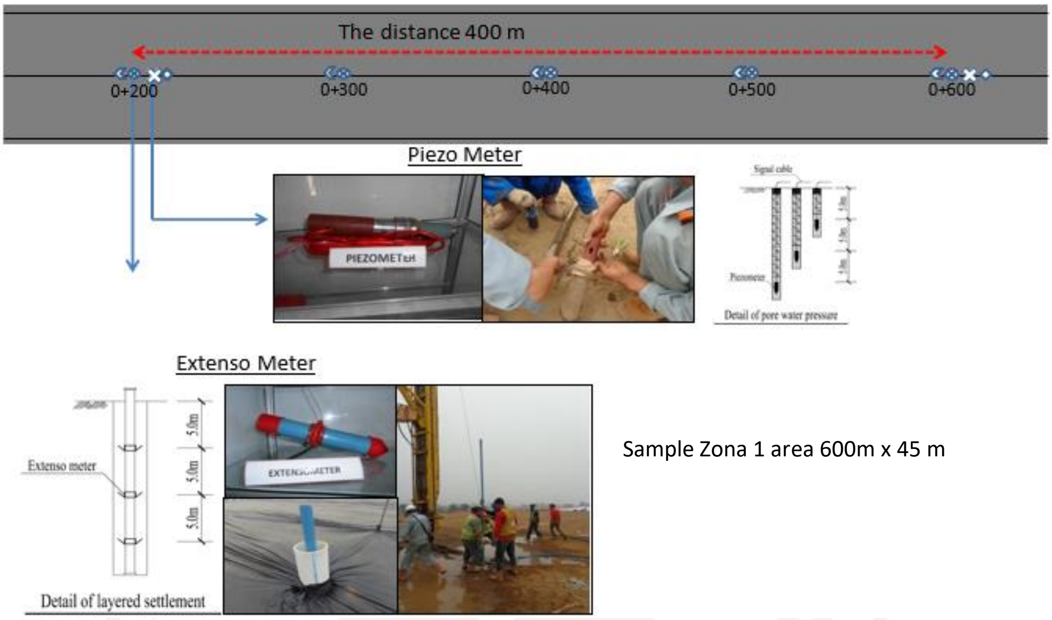


Figure 3.22 Piezometer and Extensometer Layout

Source: (PT. Hutama Karya Infrastruktur 2017)

3.6.10 Monitoring Instrument (Inclinometer)

Inclinometer functions as a monitoring instrument to give information about changes or shift on soil layer outside the vacuum area caused by the vacuum. While Inclinometer is installed outside the vacuum area with the same depth as the PVD depth, one inclinometer is installed for an area of 1800 m^2. Installation of Inclinometer can be seen on **Figure 3.23** below

Figure 3.23 Inclinometer Layout

Source: (PT. Hutama Karya Infrastruktur 2017)

3.7 Soil Settlement Prediction Using Asaoka Method

Asaoka (1978) is one of the methods commonly used in Indonesia to predict the amount of final settlement. This method one of the more popular one directional consolidation observation method, it can predict the value of final settlement as well giving information about a more accurate consolidation parameter. With Asaoka method the value of actual soil settlement can be predicted without the need of parameters such as laboratory soil investigation data, but the data needed for this method are the field monitoring results. Field monitoring results in question are the likes of pore water pressure, drainage length, soil maximum strain, and consolidation coefficient. Asaoka method also functions as to predict soil settlement using curve fitting. However according to past records with Asaoka method, even without the need of laboratory test result the information obtained is reliable and accurate with a relatively small margin of error.

This basic consolidation expression chosen by Asaoka (1978) to be derived into linear differential equation because it is simpler than Terzaghi. The final equation to determine value of settlement at the time of (-j) can be expressed as can be seen on Equation 3.12 below.

$$\rho j = \frac{\beta 0}{1-\beta 1} - \{\frac{\beta 0}{1-\beta 1} - \rho 0\}(\beta 1)^{j} \quad (3.31)$$

Where ρj is the amount of soil settlement at the time of t = tj as well as the coefficient β0 and βs (s= 1,2 …, n) are an unknown parameter.

Based on final settlement result, the horizontal coefficient from soil at the field can be known. In his book Grouw (2008), the equation to compute the value of horizontal coefficient based on graph of Asaoka are as can be seen on Equation 3.13 below.

$$\frac{n^2 Cv}{8H^2} + \frac{8Ch}{D^2 Fn} = -\frac{\ln\beta}{\sigma t} \quad (3.32)$$

Where:

σ_t = asaoka graph time interval

β = asaoka graph projected line slope of ρ_n vs ρ_n+1

H = PVD length

F_n = resistance factor caused by PVD's distance

C_r = radial pore water (horizontal) consolidation coefficient

C_v = vertical consolidation coefficient

D = PVD's influence zone circle equivalent diameter

While Graph related to Asaoka can be seen on **Figure 3.24** and **Figure 3.25** below

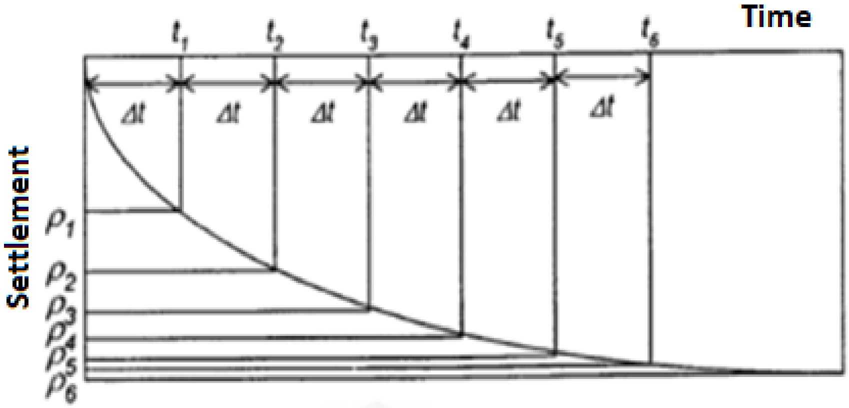


Figure 3.24 Analysis of Settlement Monitoring with Constant Time Interval

Source: (Asaoka,1978)

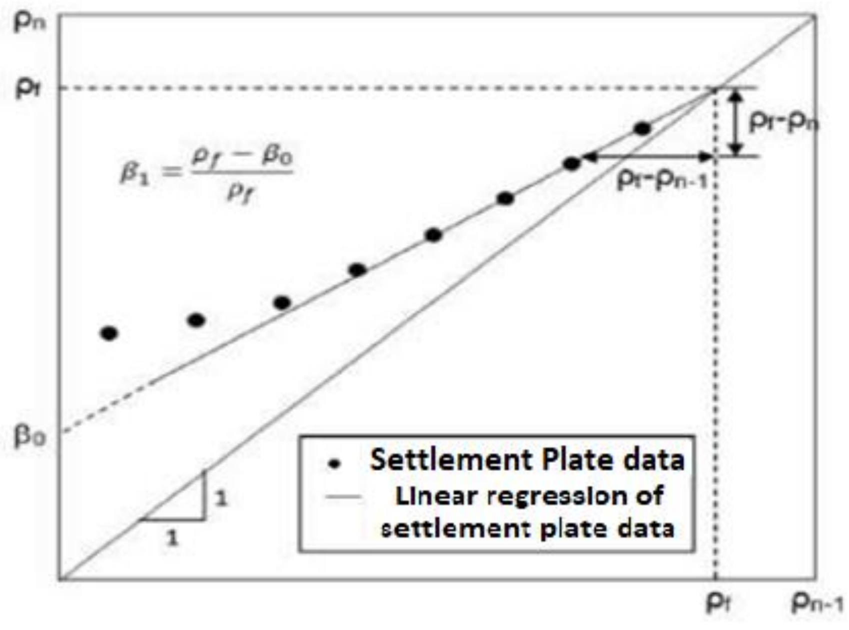


Figure 3.25 Prediction of Final Settlement with Asaoka Method

Source: (Asaoka,1978)

CHAPTER IV

RESEARCH METHOD

4.1 Research Method

This study uses a case study method where in this study the author wanted to comprehensively understand in depth regarding the object of study. A case study is a detailed examination of one background or one subject in an intensive and detailed manner so that later the researcher will achieve a deep understanding and not only to explain what the object under study are like, but to explain how the existence and why the case can occur. In other words, case study research is not just answering research questions about what the object under study is, but also about how and why the object of study can occur and is formed as and can be viewed as a case.

4.2 Data Collection

One of the more important parts of a research is reliable data, without a reliable source of data then the problem we are trying to overcome and theory that we would like to prove would be meaningless. There are two types of data, namely Primary data and Secondary data. Primary data is a data that we can only obtain from the original or main source, while secondary data is data that is already available and are ready to collect and use. In this study the type of data used is mainly secondary data.

Stages of research regarding this study includes the stage of determining the problem, determining the objectives and study environment, collecting secondary data, organizing the secondary data obtained, analysing, as well as determining results and conclusions. In the analysis of this research, the data used is secondary data obtained from PT. Hutama Karya Infrastruktur. The data obtained from PT. Hutama Karya Infrastruktur are as follows.

1. Research Location

Project Location is at Palembang – Indralaya road segment, South Sumatera. On a more detailed level the data obtained is on *Vacuum Consolidation System* area on whereas is also an area where the road segment will be constructed. Research location layout can be seen on **Figure 4.1** below

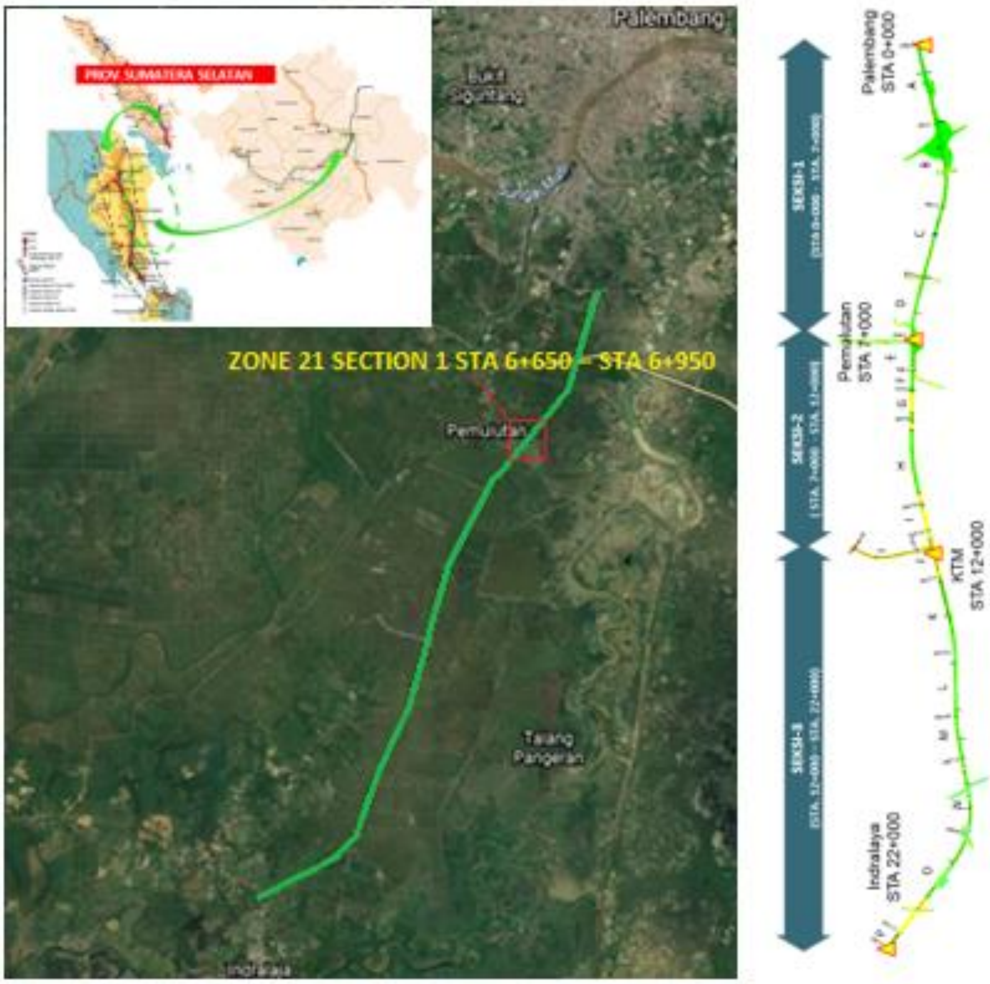


Figure 4.1 Research Location Layout

Source:(PT. Hutama Karya Infrastruktur 2017)

2. Soil Parameter Data

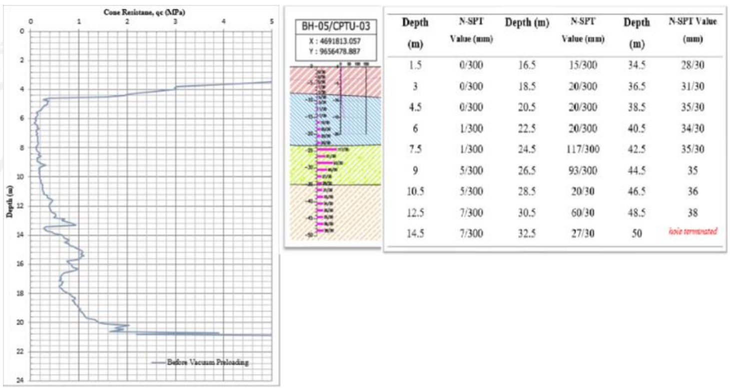
Several soil parameter data obtained as an example are laboratory test data such as Specific Gravity (γ), Water Content (ω), Pore Number (e), Compression Index (C_c), Vertical Consolidation Coefficient (C_v), and Horizontal Consolidation Coefficient (C_h). Soil parameter data can be seen on **Table 4.1** below.

Table 4.1 Soil Parameter Data BH-05

Depth (m)	G_s	Density (kN/m^3)		n	e	C_c	C_v (m^2/day)	C_s
		γ_{sat}	γ_d					
0 – 5	2.5329	13.38	6.57	0.73	2.78	0.81	0.038	0.135
6 -15	2.5239	16.64	11.32	0.54	1.187	0.25	0.015	0.042
Average	**2.5284**	**15.14**	**8.945**	**0.635**	**1.9835**	**0.53**	**0.0265**	**0.0885**

3. Soil Investigation Data

Soil Investigation data obtained are the existing soil testing results with several testing instruments on the field namely the Cone Penetration Test (CPTu), and the Standard Penetration Test (SPT). Example of CPTu and NSPT data can be seen on **Figure 4.2** below



Depth (m)	N-SPT Value (mm)	Depth (m)	N-SPT Value (mm)	Depth (m)	N-SPT Value (mm)
1.5	0/300	16.5	15/300	34.5	28/30
3	0/300	18.5	20/300	36.5	31/30
4.5	0/300	20.5	20/300	38.5	35/30
6	1/300	22.5	20/300	40.5	34/30
7.5	1/300	24.5	117/300	42.5	35/30
9	5/300	26.5	93/300	44.5	35
10.5	5/300	28.5	20/30	46.5	36
12.5	7/300	30.5	60/30	48.5	38
14.5	7/300	32.5	27/30	50	hole terminated

Figure 4.2 SPT and CPTu Data for STA 6+650

Source: (PT.Hutama Karya Infrastruktur 2017)

4. Geotechnical Instrument Monitoring Data

Monitoring data obtained such as the Settlement Plate data, Vibrating Wire Piezometer data, and Vacuum Gauge data. The example of monitoring data can be seen on **Figure 4.3**, **Figure 4.4** and **Figure 4.5** below

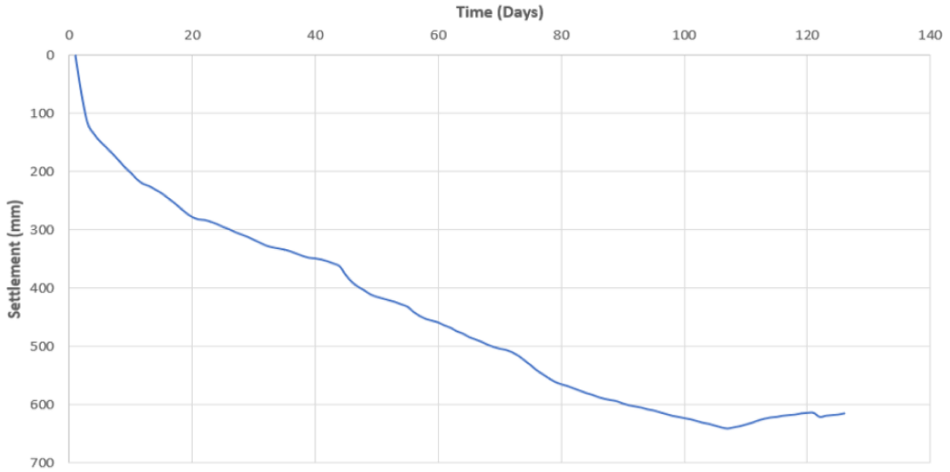


Figure 4.3 Settlement Plate Monitoring Data STA 6+650

Source: (PT.Hutama Karya Infrastruktur 2017)

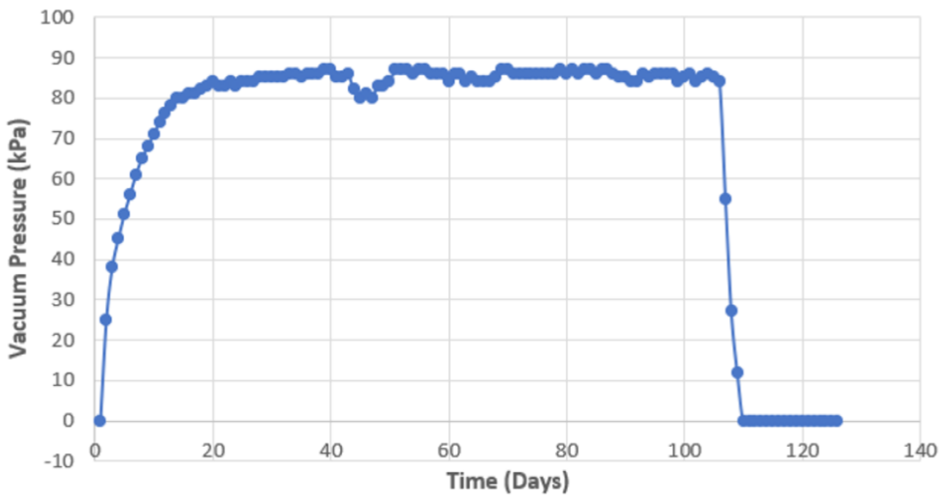


Figure 4.4 Vacuum Gauge Monitoring Data STA 6+650

Source: (PT.Hutama Karya Infrastruktur 2017)

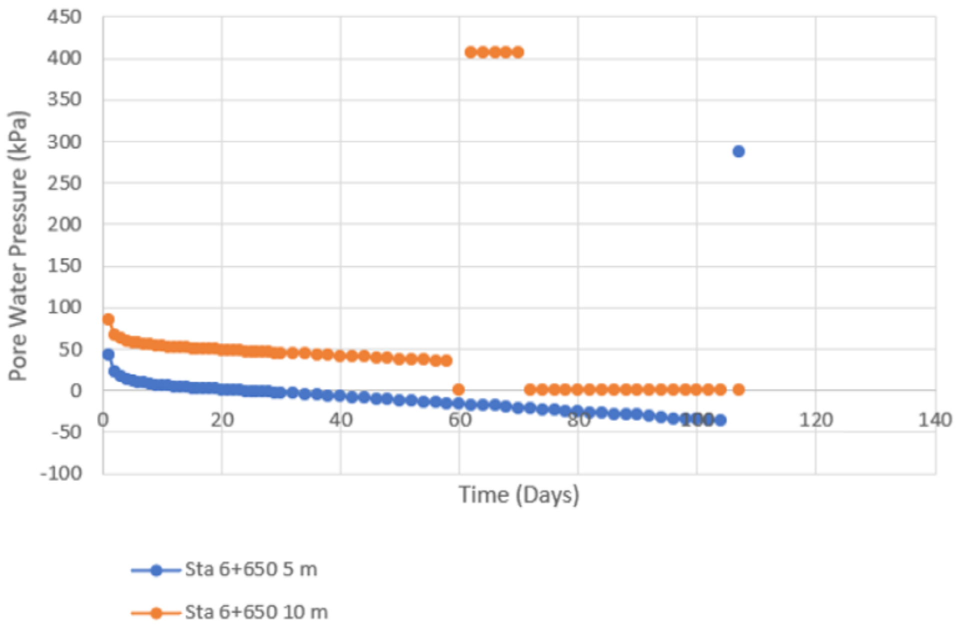


Figure 4.5 Piezometer Monitoring Data STA 6+650

Source: (PT.Hutama Karya Infrastruktur 2017)

5. Complementary Data (Photographs, Illustrations, etc)

Complementary data obtained consists of data that complements the writing of this study, thus making it easier to understand. To name a few are photographs and illustrations of instruments, methodology, field conditions, heavy machinery, etc.

4.3 Analysis Procedure

Analysis procedure for this study includes the determination of problem namely that the existing soil condition available in Palembang – Indralaya Trans Sumatera Toll Road Construction Zone 21 Section 1 STA 6+650 – STA 6+950 consist in majority of soft soils which can be seen according to the CPT Test result conducted that can be seen on CPT Test Result Before Vacuum Preloading. CPT testing results can be seen on **Figure 4.6** below

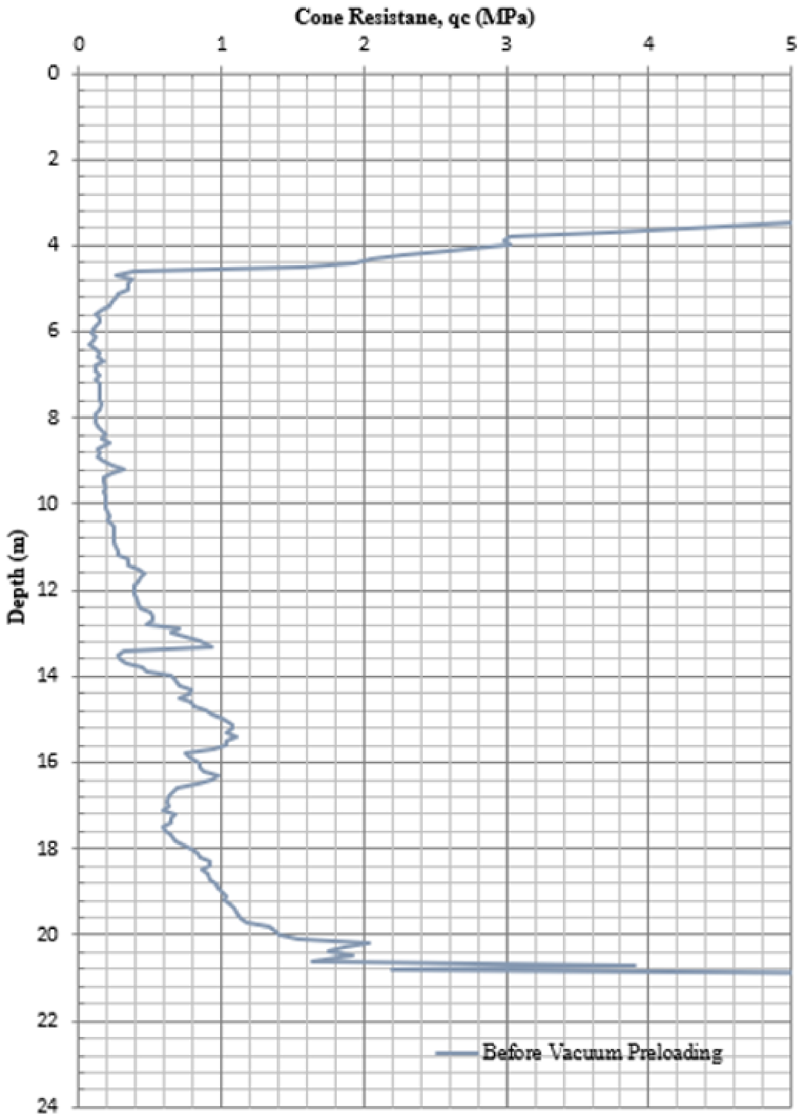


Figure 4.6 CPT Test Before Vacuum Preloading

Source: (PT. Hutama Karya Infrastruktur 2017)

Based on the data monitored from the CPT test namely the Cone resistance (Mpa) per depth (m) obtained it can be concluded that the surface of the soil investigated starts out as soft on the surface then gradually turns even softer up until around 12 meter deep and then after that gradually starts to harden a considerable amount when it reaches deeper than 20 meters.

After existing soil condition is confirmed to be soft soil and needed a countermeasure the vacuum consolidation method is conducted. During the vacuum process several geotechnical instruments are installed throughout Zone 21 Section 1 STA 6+650 – STA 6+950 namely the settlement plate, piezometer, and vacuum gauge. The Analysis on this research will be separated onto three different data that will be processed based on each geotechnical instrument.

4.3.1 Settlement Plate

The settlement plate on zone 21 section 1 installed in total are 4 settlement plate located on STA 6+650, STA 6+750, STA 6+850, and STA 6+950 where the detailed drawing of each individual settlement plate can be seen on **Figure 4.7** below.

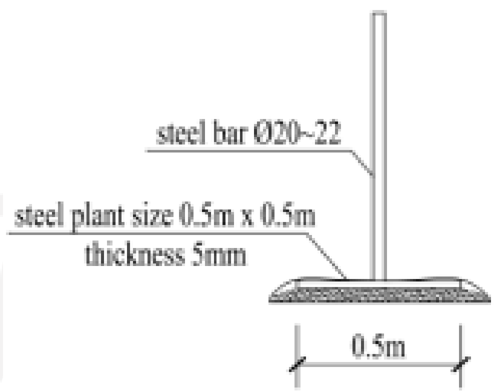


Figure 4.7 Settlement Plate Detail

Source: (PT. Hutama Karya Infrastruktur 2017)

The data we are looking for by using the settlement plate is the gradual settlement per day up until the settlement per day reaches the standard safety requirement, for this case on STA 6+650 the settlement plate monitoring are conducted for 126 days.

After the monitoring data is obtained and the actual settlement data are obtained, a theoretical settlement calculation will be conducted using Terzaghi method in order to make sure both data are as accurate as possible.

Not only that, the data will be processed further to find out the prediction of possible final settlement that will likely happen using Asaoka method.

Procedure for Asaoka method for final soil settlement prediction are as follows.

1. Draw a time-settlement curve, then divide the curved part into several distances with the same or constant time (Δ_t), thus settlement time are obtained (t1, t2, t3, … tn, tn+1).
2. Draw a perpendicular line from the point in time until it intersects with the existing load-descending curve so that the amount of settlement (S1, S2) is obtained.
3. Value of settlement obtained at S_n is plotted onto S_{n+1} on a graph.
4. Draw a regression line with a 45° angle, S3, this intersecting line indicates the final settlement. (When $S_n = S_{n+1}$ there is no further decrease).

The amount of settlement caused by consolidation theoretically as well as the amount of settlement from settlement plate are plotted into a graph and compared. From that prediction, consolidation degree calculation is conducted by comparing real settlement at the field with the final settlement prediction using Asaoka method.

4.3.2 Vibrating Wire Piezometer

After settlement plate calculation, consolidation degree calculation is conducted using vibrating wire piezometer which functions to validate whether or not the consolidation degree obtained from settlement plate monitoring matches the piezometer.

The *Vibrating wire piezometer* on zone 21 section 1 installed are 2 in total located on STA 6+650 and STA 6+950 where the detailed drawing of each individual *vibrating wire piezometer* can be seen on **Figure 4.8** below.

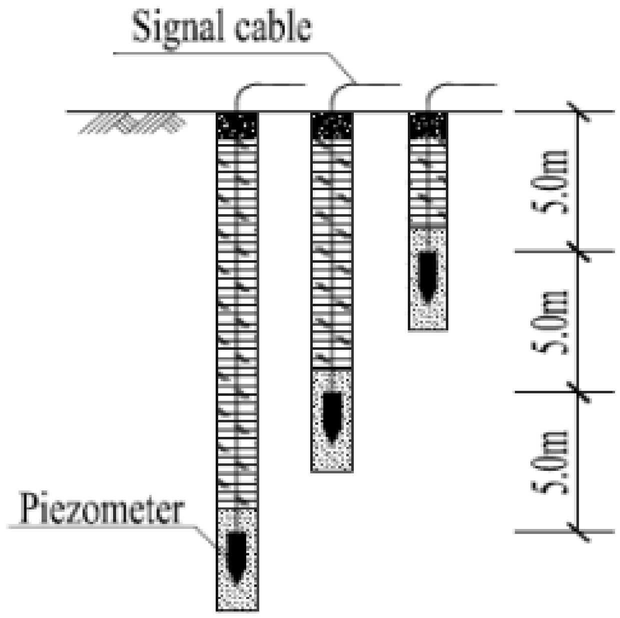


Figure 4.8 Vibrating Wire Piezometer Detail

Source: (PT. Hutama Karya Infrastruktur 2017)

The data we are looking for by using the vibrating wire piezometer is the pore water pressure during the vacuum process, piezometers are installed on the centre line with 200 m distance in radius with the depth of 5m, 10m, and 15m (depends on the PVD depth).

The output of this vibrating wire piezometer will be the consolidation degree where results are then used to validate whether or not the consolidation degree obtained using real settlement and Asaoka method matches the consolidation degree using the Vibrating wire piezometer data.

4.3.3 Vacuum Gauge

The vacuum gauge uses atmospheric correction which is then calculated based on vacuum pump effectivity, the vacuum gauge or pressure gauge functions as an instrument to know the pressure on the vacuum area which is installed on a 5 m radius on the centre line, The schematics of pressure gauge can be seen on **Figure 4.9** below.

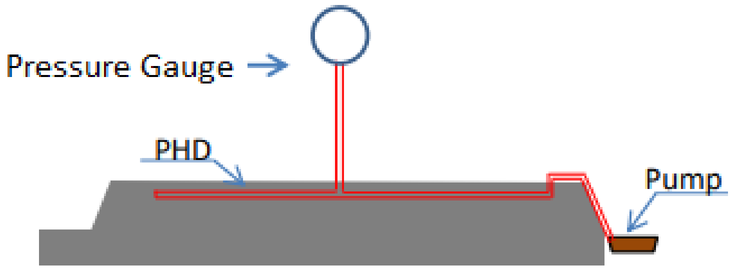
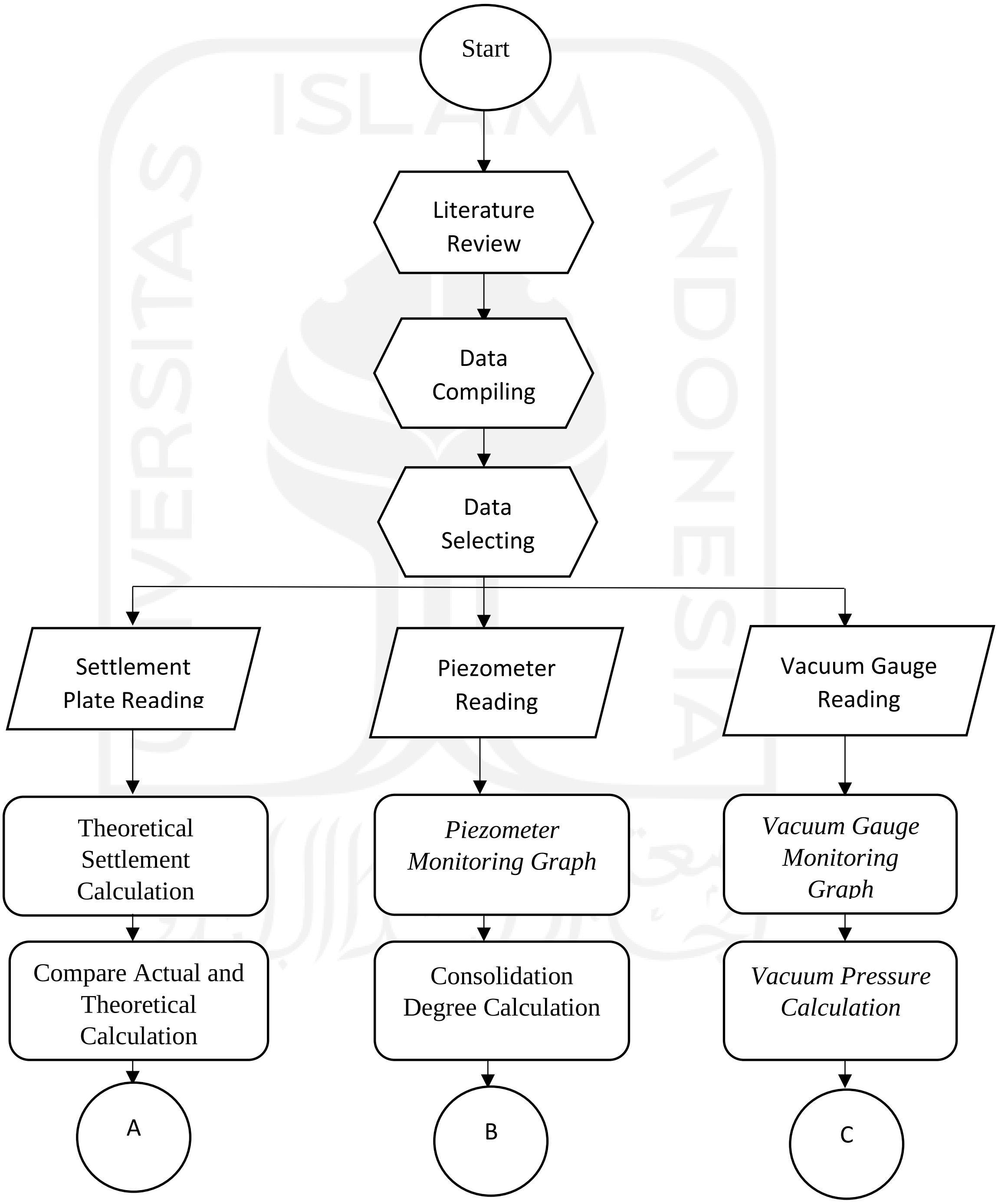


Figure 4.9 Vacuum Gauge Schematics

Source: (PT. Hutama Karya Infrastruktur 2017)

4.4 Research Flowchart

In order to make it easier for the author to conduct this analysis and easier for the reader to understand the procedure, an analysis procedure flowchart was made. The flowcharts regarding this research can be seen on **Figure 4.10**



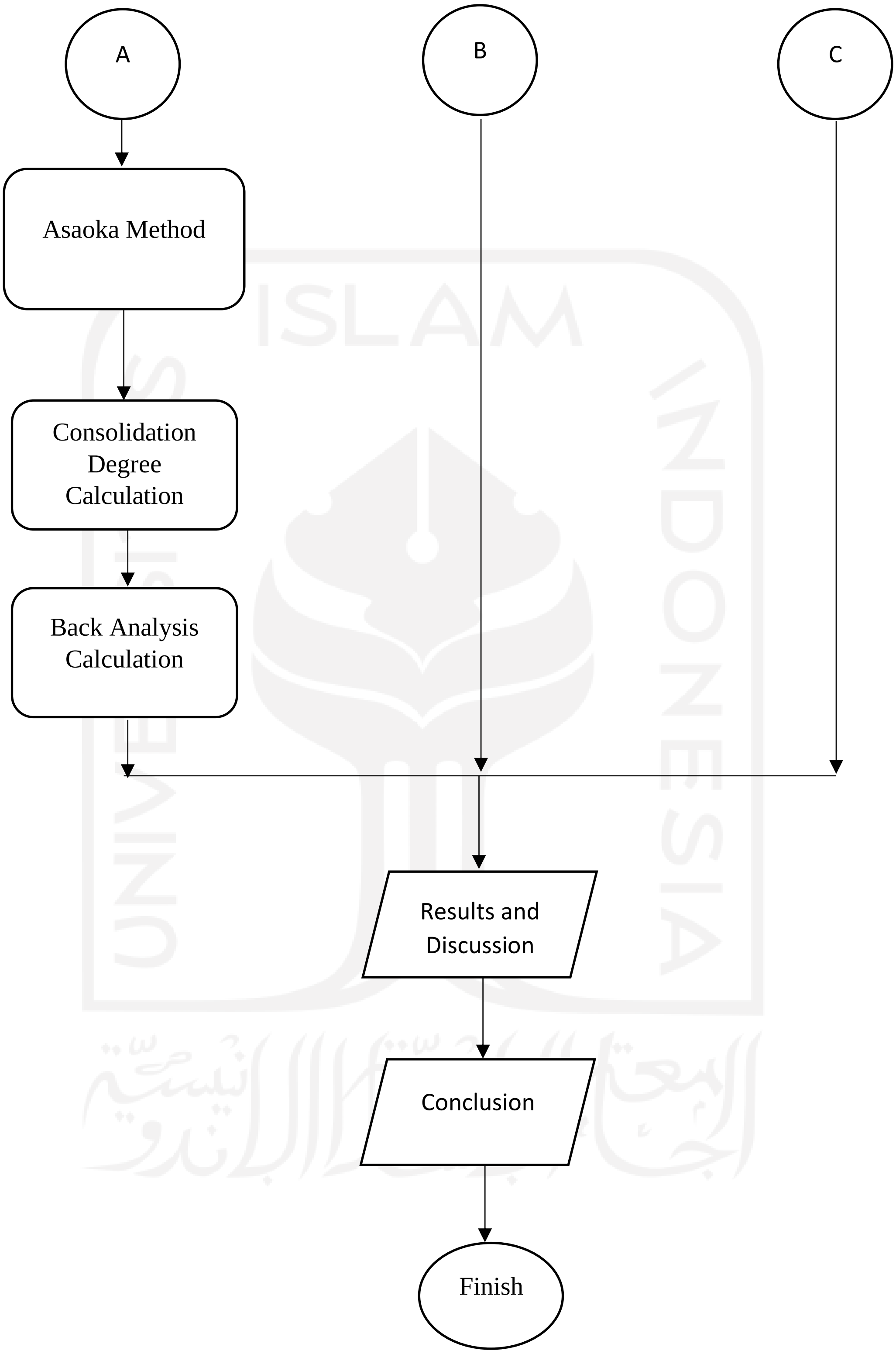


Figure 4.10 Research Flowchart

CHAPTER V

RESULTS AND DISCUSSION

5.1 Data Compiling

Before computation and analysis of data, the data that are available and provided by PT. Hutama Karya Infrastruktur (Pengujian Tanah Tambahan Jalan Tol Ruas Palembang – Indralaya, 2017) are picked out and selected based on what is needed in order to conduct the analysis.

5.1.1 Soil Properties

Soil properties data used is obtained through secondary measures by *Cone Penetration Test* (CPT), *Standard Penetration Test* (N-SPT), and lab results obtained from the studied location soil sample namely BH-05 which represents STA 6+650 – STA 6+950. Layout of the boring area as well as its coordinates can be seen on **Figure 5.1** below. While the cross section of BH-05 can be seen on **Figure 5.2** below.

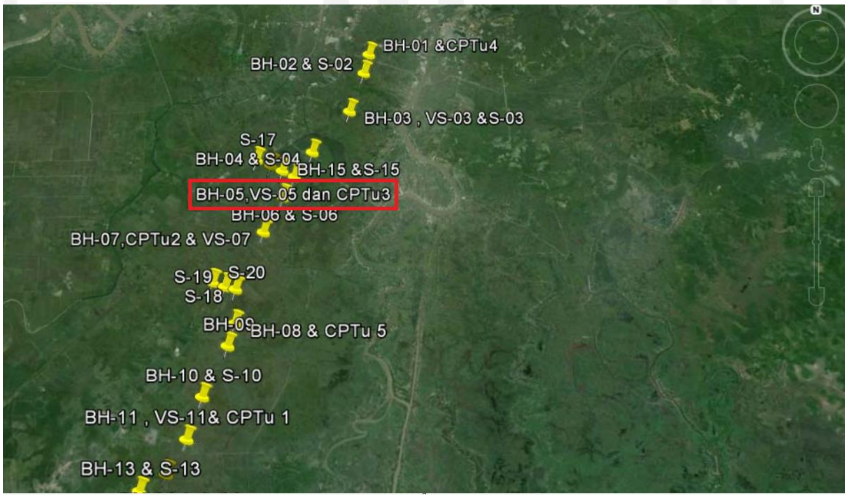


Figure 5.1 Soil Investigation Point Layout

Source: (PT.Hutama Karya Infrastruktur, 2017)

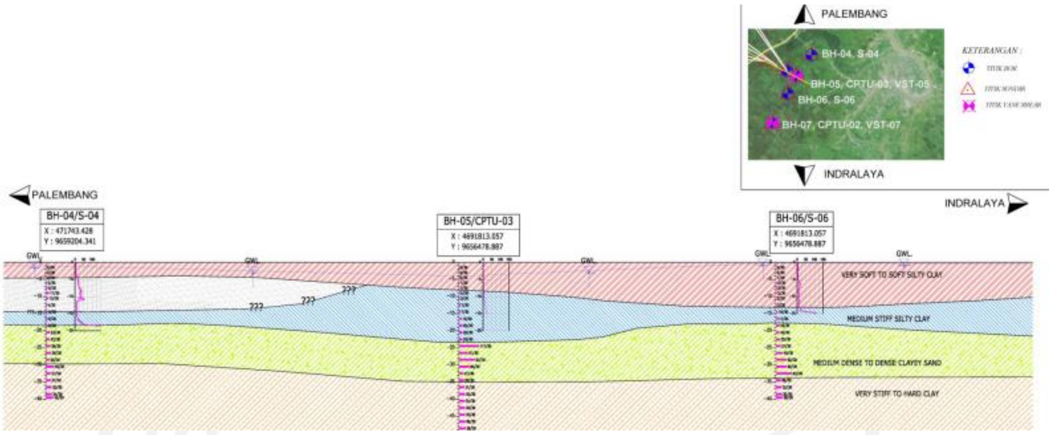


Figure 5.2 BH-05 Cross Section

Source: (PT.Hutama Karya Infrastruktur, 2017)

Boring depth for the purpose of sampling on boring point BH-05 is 50 m deep with Groundwater level of boring point is -0,4 m. Boring log data, Standard Penetration Test (SPT), and lab results specifically can be seen on **Attachment 1.**

5.1.2 Material Data

Prefabricated Vertical Drain (PVD) is installed on the studied area with installation in details as follows:

1. Installation depth : CPT depth + 50 cm
2. Installation Pattern : Rectangular
4. Vertical drains width : 100 mm
5. Vertical drains thickness : 4 mm

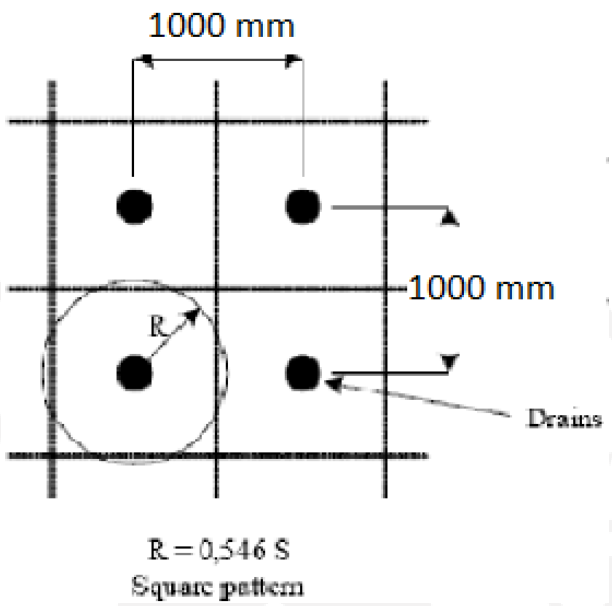


Figure 5.3 PVD Installation Details

Source: (PT. Hutama Karya Infrastruktur 2017)

While the Prefabricated Horizontal Drain (PHD) is installed on the studied area with installation details as follows:

1. Installation Pattern : Rectangular
2. Horizontal Drain width : 63 mm

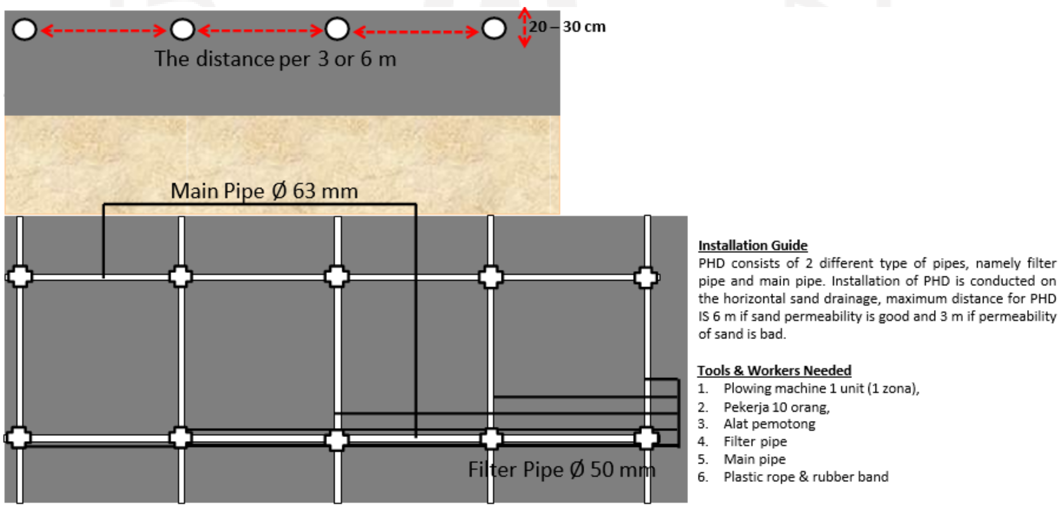


Figure 5.4 PHD Installation Details

Source: (PT. Hutama Karya Infrastruktur 2017)

5.1.3 Settlement Plate Data

In order to monitor the settlement occurring at the project site, a settlement plate is used. This monitoring activity lasted for 126 days for this specific road section, starting on the first day of monitoring until the last day where the settlement plate is allowed to be removed. For this specific road section there are 4 settlement-plate installed namely SP.01, SP.02, SP.03, SP.04. The settlement of SP.01 can be seen on **Figure 5.6** and **Table 5.1**. While the settlement of SP.02, SP.03, SP.04 can be seen on **Attachment 4**, **Attachment 5**, and **Attachment 6**.

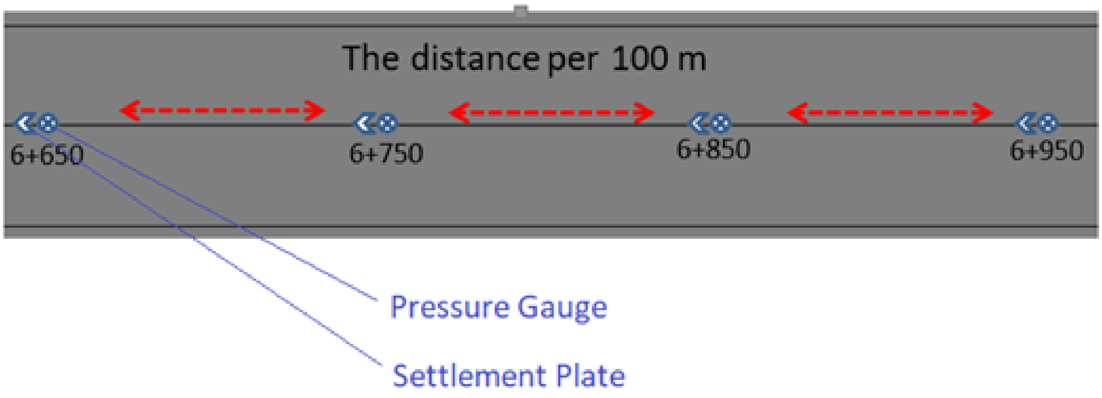


Figure 5.5 Settlement Plate and Vacuum Gauge Layout

Source: (PT.Hutama Karya Infrastruktur,2017)

Table 5.1 126 Day Reading of Settlement Plate SP.01

Day	Settlement (mm)	Settlement Cum. (mm)	Vacuum Gauge (Kpa)
1	0	0	0
2	66	66	25
3	51	117	38
4	18	135	45
5	13	148	51
6	10	158	56
7	11	169	61
8	11	180	65
9	12	192	68
10	10	202	71
11	11	213	74
12	8	221	76
13	4	225	78
14	6	231	80
5	6	237	80
16	8	245	81
17	8	253	81

Continuation of Table 5.1 126 Day Reading of Settlement Plate SP.01

Day	Settlement (mm)	Settlement Cum. (mm)	Vacuum Gauge (Kpa)
18	9	262	82
19	9	271	83
20	7	278	84
21	4	282	83
22	1	283	83
23	3	286	84
24	4	290	83
25	5	295	84
26	4	299	84
27	5	304	84
28	4	308	85
29	4	312	85
30	5	317	85
31	5	322	85
32	5	327	85
33	3	330	86
34	2	332	86
35	2	334	85
36	3	337	86
37	4	341	86
38	4	345	86
39	3	348	87
40	1	349	87
41	2	351	85
42	3	354	85
43	4	358	86

Continuation of Table 5.1 126 Day Reading of Settlement Plate SP.01

Day	Settlement (mm)	Settlement Cum. (mm)	Vacuum Gauge (Kpa)
44	5	363	82
45	15	378	80
46	12	390	81
47	8	398	80
48	6	404	83
49	7	411	83
50	4	415	84
51	3	418	87
52	3	421	87
53	3	424	87
54	4	428	86
55	4	432	87
56	9	441	87
57	7	448	86
58	5	453	86
59	3	456	86
60	3	459	84
61	5	464	86
62	4	468	86
63	6	474	84
64	4	478	85
65	6	484	84
66	4	488	84
67	4	492	84
68	5	497	85
69	4	501	87

Continuation of Table 5.1 126 Day Reading of Settlement Plate SP.01

Day	Settlement (mm)	Settlement Cum. (mm)	Vacuum Gauge (Kpa)
70	3	504	87
71	2	506	86
72	4	510	86
73	6	516	86
74	8	524	86
75	8	532	86
76	9	541	86
77	7	548	86
78	7	555	86
79	6	561	87
80	4	565	86
81	3	568	87
82	4	572	86
83	4	576	87
84	4	580	87
85	3	583	86
86	4	587	87
87	3	590	87
88	2	592	86
89	2	594	85
90	4	598	85
91	3	601	84
92	2	603	84
93	2	605	86
94	3	608	85
95	2	610	86

Continuation of Table 5.1 126 Day Reading of Settlement Plate SP.01

Day	Settlement (mm)	Settlement Cum. (mm)	Vacuum Gauge (Kpa)
96	3	613	86
97	3	616	86
98	3	619	86
99	2	621	84
100	2	623	85
101	2	625	86
102	3	628	84
103	3	631	85
104	2	633	86
105	3	636	85
106	3	639	84
107	2	641	55
108	-2	639	27
109	-2	637	12
110	-3	634	0
111	-3	631	0
112	-4	627	0
113	-3	624	0
114	-2	622	0
115	-1	621	0
116	-2	619	0
117	-1	618	0
118	-1	617	0
119	-2	615	0
120	-1	614	0
121	0	614	0

Continuation of Table 5.1 126 Day Reading of Settlement Plate SP.01

Day	Settlement (mm)	Settlement Cum. (mm)	Vacuum Gauge (Kpa)
122	7	621	0
123	-2	619	0
124	-1	618	0
125	-1	617	0
126	-2	615	0

Source: (PT.Hutama Karya Infrastruktur 2017)

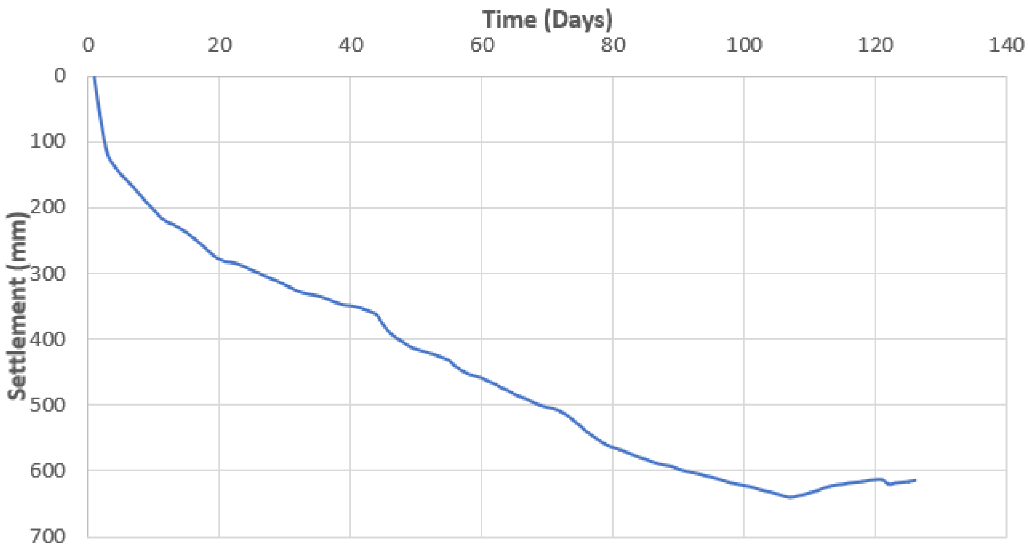


Figure 5.6 126 Day Reading of Soil Settlement, Settlement Plate SP.01

Source: (PT.Hutama Karya Infrastruktur 2017)

5.1.4 Vibrating Wire Piezometer Data

Vibrating wire piezometer data is used to measure the pore water pressure in soil at a certain depth, earth/rock-fill foundations and concrete structures. Monitoring of vibrating wire piezometer VWP.01 is done alongside SP.01. The layout of Vibrating Wire Piezometer can be seen on **Figure 5.7** below

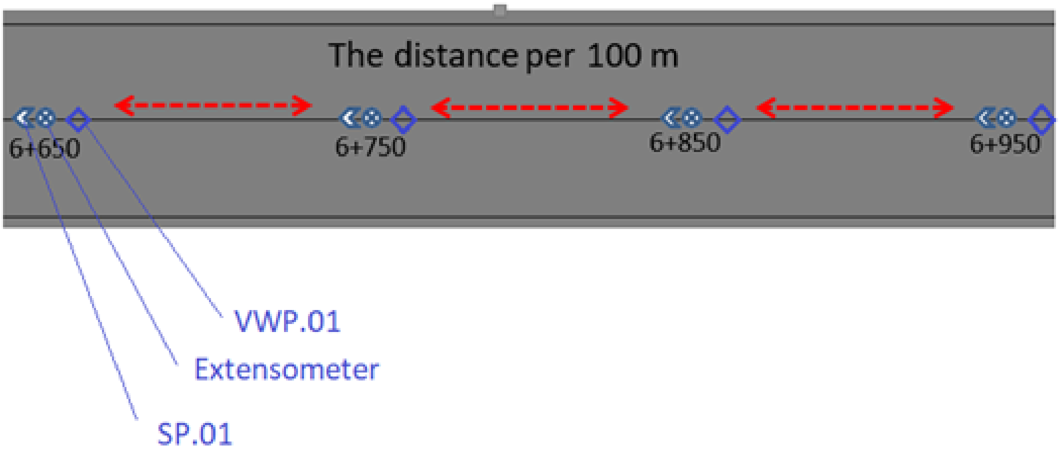


Figure 5.7 SP.01 and VWP.01 Layout

Source: (PT.Hutama Karya Infrastruktur, 2017)

This type of piezometer specifically is monitored consistently every single day. Results of this piezometer reading is then used to measure the consolidation degree that occurs on the project site. Example of piezometer monitoring data VWP.01 from the first day of monitoring until the last day can be seen on **Figure 5.8** and **Table 5.2** below. While the monitoring data of VWP.02 can be seen on **Attachment 12.**

Table 5.2 126 Day Reading of Piezometer VWP.01

Day	Pore Water Pressure (Kpa)		Vacuum Gauge (Kpa)
	L=5m	L=10m	
1	42.58	85.12	0
2	21.78	67.22	25
3	16.55	62.78	38
4	13.35	59.87	45
5	11.28	58.31	51
6	9.95	57.04	56
7	8.86	55.65	61
8	7.87	54.9	65
9	6.83	53.81	68
10	6.03	53.19	71
11	5.09	52.67	74
12	4.54	52.18	76
13	4.04	51.7	78
14	3.59	51.3	80
15	3.2	50.82	80
16	2.75	50.74	81
17	2.3	50.12	81
18	1.9	49.76	82
19	1.45	49.41	83
20	1	48.97	84
21	0.6	48.57	83
22	0.25	48.22	83
23	-0.2	47.78	84
24	-0.65	47.29	83
25	-1.05	46.94	84

Continuation of Table 5.2 126 Day Reading of Piezometer VWP.01

Day	Pore Water Pressure (Kpa)		Vacuum Gauge (Kpa)
	L=5m	L=10m	
26	-1.5	46.58	84
27	-1.9	46.09	84
28	-2	45.7	85
29	-2.71	45.34	85
30	-3.06	44.99	85
31			85
32	-3.86	44.23	85
33			86
34	-4.71	43.92	86
35			85
36	-5.57	43.21	86
37			86
38	-6.38	42.54	86
39			87
40	-7.23	41.83	87
41			85
42	-8.14	41.07	85
43			86
44	-9.05	40.36	82
45			80
46	-9.71	39.55	81
47			80
48	-10.67	38.88	83
49			83
50	-11.97	38.07	84

Continuation of Table 5.2 126 Day Reading of Piezometer VWP.01

Day	Pore Water Pressure (Kpa)		Vacuum Gauge (Kpa)
	L=5m	L=10m	
51			87
52	-12.8	37.4	87
53			87
54	-13.71	36.68	86
55			87
56	-14.58	36.01	87
57			86
58	-15.49	35.29	86
59			86
60	-16.36	0	84
61			86
62	-17.17	407.03	86
63			84
64	-18.09	407.03	85
65			84
66	-18.69	407.03	84
67			84
68	-19.88	407.03	85
69			87
70	-20.75	407.03	87
71			86
72	-21.62	0	86
73			86
74	-22.59	0	86
75			86

Continuation of Table 5.2 126 Day Reading of Piezometer VWP.01

Day	Pore Water Pressure (Kpa)		Vacuum Gauge (Kpa)
	L=5m	L=10m	
76	-23.52	0	86
77			86
78	-24.49	0	86
79			87
80	-25.37	0	86
81			87
82	-26.24	0	86
83			87
84	-27.12	0	87
85			86
86	-28.05	0	87
87			87
88	-28.39	0	86
89			85
90	-29.8	0	85
91			84
92	-30.73	0	84
93			86
94	-31.98	0	85
95			86
96	-34.05	0	86
97			86
98	-34.05	0	86
99			84
100	-34.88	0	85

Continuation of Table 5.2 126 Day Reading of Piezometer VWP.01

Day	Pore Water Pressure (Kpa)		Vacuum Gauge (Kpa)
	L=5m	L=10m	
101			86
102	-35.4	0	84
103			85
104	-36.65	0	86
105			85
106			84
107	288.08	0	55
108			27
109			12
110			0
111			0
112			0
113			0
114			0
115			0
116			0
117			0
118			0
119			0
120			0
121			0
122			0
123			0
124			0
125			0
126			0

Source: (PT.Hutama Karya Infrastruktur 2017)

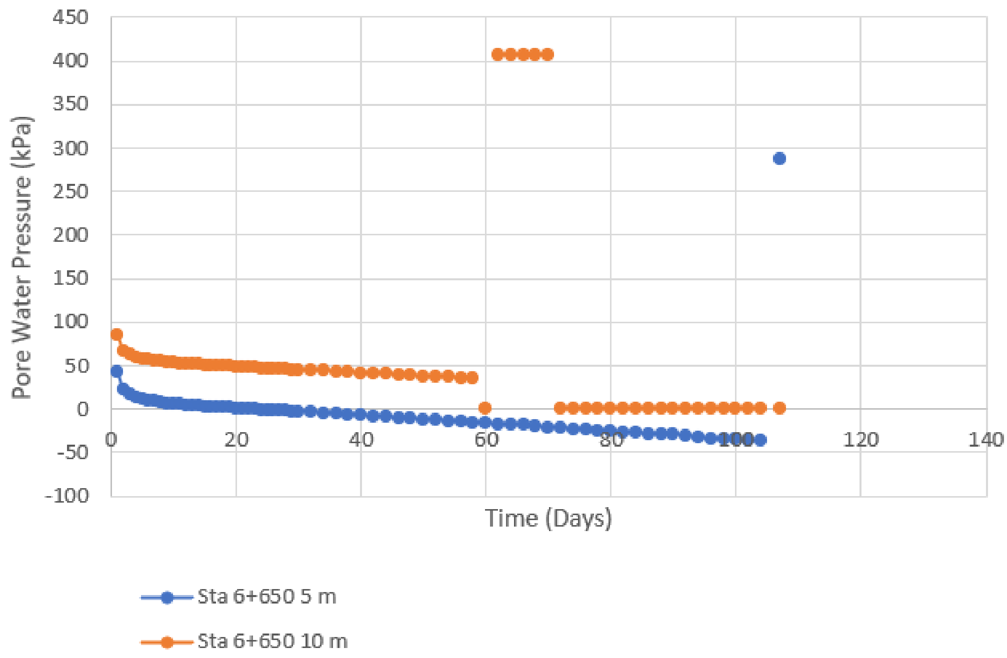


Figure 5.8 126 Day Reading of Piezometer VWP.01

Source: (PT. Hutama Karya Infrastruktur 2017)

5.1.5 Vacuum Gauge Data

In order to find out if the vacuum pressure that occurs on the soil have reached the desired effective value, a vacuum gauge is used. **Table 5.3** and **Figure 5.9** below shows an example of vacuum gauge VG.01 monitoring results that are monitored from the designated start time until the requirements for stopping have been met. As for the reading of VG.02, VG.03, VG.04 can be seen on **Attachment 8**, **Attachment 9**, and **Attachment 10**.

Table 5.3 126 Days Reading of Vacuum Gauge VG.01

Day	Pressure (Kpa)	Day	Pressure (Kpa)	Day	Pressure (Kpa)
1	0	28	85	55	87
2	25	29	85	56	87
3	38	30	85	57	86
4	45	31	85	58	86
5	51	32	85	59	86
6	56	33	86	60	84
7	61	34	86	61	86
8	65	35	85	62	86
9	68	36	86	63	84
10	71	37	86	64	85
11	74	38	86	65	84
12	76	39	87	66	84
13	78	40	87	67	84
14	80	41	85	68	85
15	80	42	85	69	87
16	81	43	86	70	87
17	81	44	82	71	86
18	82	45	80	72	86
19	83	46	81	73	86
20	84	47	80	74	86
21	83	48	83	75	86
22	83	49	83	76	86
23	84	50	84	77	86
24	83	51	87	78	86
25	84	52	87	79	87
26	84	53	87	80	86
27	84	54	86	81	87

Continuation of Table 5.3 126 Days Reading of Vacuum Gauge VG.01

Day	Pressure (Kpa)	Day	Pressure (Kpa)
82	86	**109**	12
83	87	**110**	0
84	87	**111**	0
85	86	**112**	0
86	87	**113**	0
87	87	**114**	0
88	86	**115**	0
89	85	**116**	0
90	85	**117**	0
91	84	**118**	0
92	84	**119**	0
93	86	**120**	0
94	85	**121**	0
95	86	**122**	0
96	86	**123**	0
97	86	**124**	0
98	86	**125**	0
99	84	**126**	0
100	85		
101	86		
102	84		
103	85		
104	86		
105	85		
106	84		
107	55		
108	27		

Source: (PT.Hutama Karya Infrastruktur 2017)

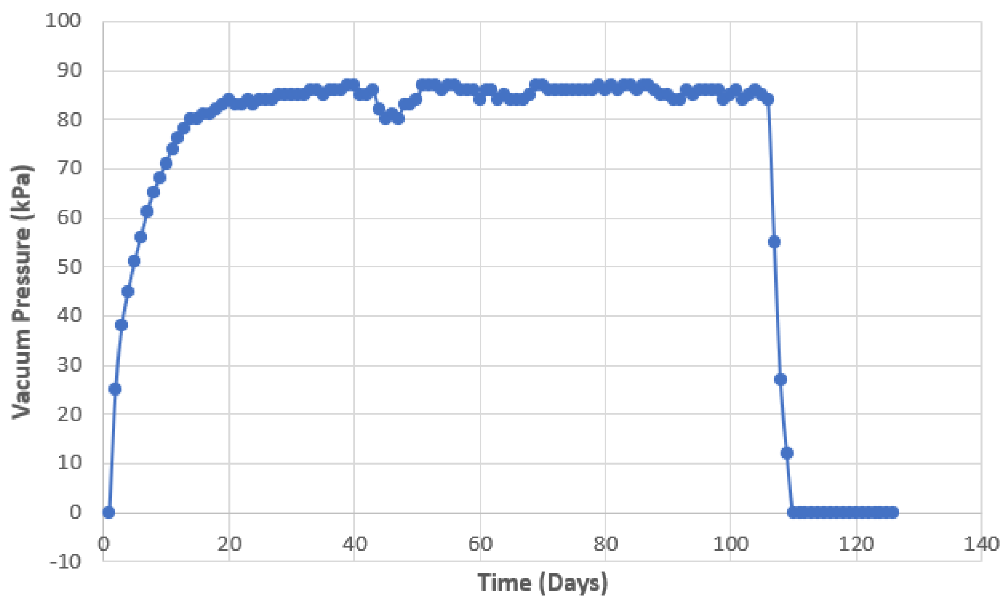


Figure 5.9 126 Days Reading of Vacuum Gauge VG.01

Source: (PT.Hutama Karya Infrastruktur 2017)

5.2 Data Processing

Data that are available is then processed in such a way in order to find Final Settlement, Consolidation Degree, Effective Pressure on soil as well as the actual Soil Parameter.

5.2.1 Identifying Soil Parameter

Soil sample from BH-05 as deep as 50 m are drilled. Based on the soil sample it can be determined that the Ground water level is located on -0.4 m. From 0 m to 8,5 m deep the SPT value is below or equal to 2 meaning that mainly it consists of very soft soil, at 14.5 m deep the SPT value is 7 meaning that it mainly consists of medium stiff soils, and on 16.5 m until 48.5 m the SPT value reaches above 9 with the highest value of 117 where it is located on 24.5 m deep. The SPT value of BH-05 can be seen on **Table 5.4** and **Figure 5.10** below. While boring log of BH-05 can be seen on **Attachment 1**.

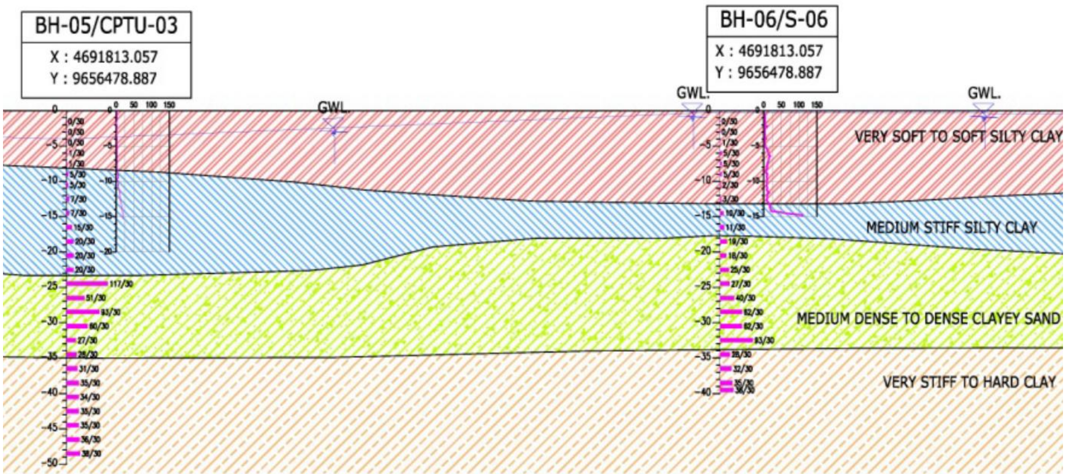


Figure 5.10 BH-05 Soil Profile Cross Section

Source: (PT.Hutama Karya Infrastruktur 2017)

The layout that shows the location of all geotechnical instrument can be seen on **Figure 5.11** below

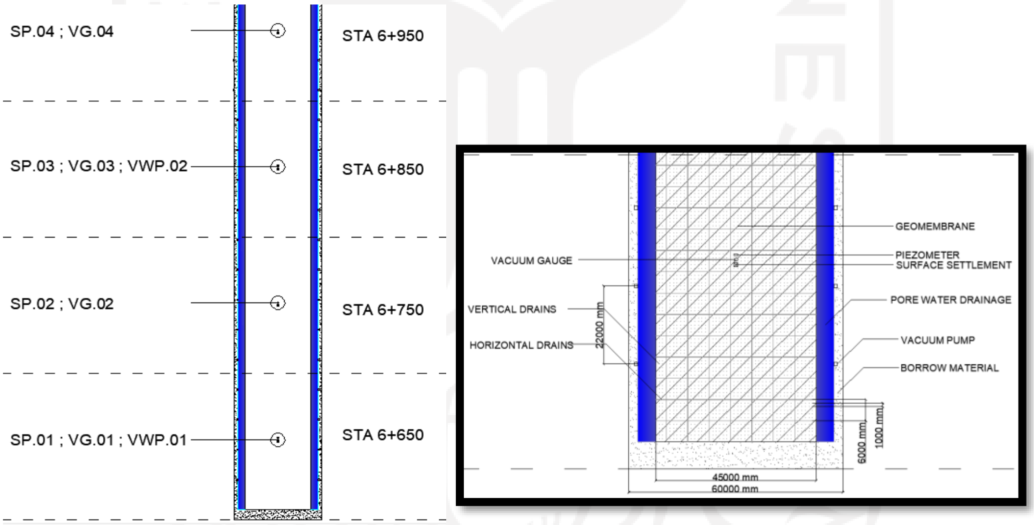


Figure 5.11 Geotechnical Instrument Layout in BH-05

Source: (PT. Hutama Karya Infrastruktur 2017)

Table 5.4 N-SPT Value of BH-05

Depth (m)	N-SPT Value (mm)	Depth (m)	N-SPT Value (mm)	Depth (m)	N-SPT Value (mm)
1.5	0/300	16.5	15/300	34.5	28/30
3	0/300	18.5	20/300	36.5	31/30
4.5	0/300	20.5	20/300	38.5	35/30
6	1/300	22.5	20/300	40.5	34/30
7.5	1/300	24.5	117/300	42.5	35/30
9	5/300	26.5	93/300	44.5	35
10.5	5/300	28.5	20/30	46.5	36
12.5	7/300	30.5	60/30	48.5	38
14.5	7/300	32.5	27/30	50	*Hole terminated*

Source: (PT.Hutama Karya Infrastruktur 2017)

Soil sample that has been tested at the lab are then analysed using specific statistical method by grouping based on its consistency and the same type of soil. The value of those soil parameter is then used in the analysis of initial settlement. Value of C_s *is 1/6* C_c while $C_h = 2C_v$ is assumed. With that said a recapitulation of soil parameters and cross section of SP.01 (6+650) can both be seen on **Table 5.5** and **Figure 5.12** below. While full soil properties of BH-05 can be seen on **Attachment 2**.

Table 5.5 Recapitulation of Soil Parameters BH-05

Depth (m)	G_s	Density (kN/m^3)		n	e	C_c	C_v (m^2/day)	C_s
		γ_{sat}	γ_d					
0 – 5	2.5329	13.38	6.57	0.73	2.78	0.81	0.038	0.135
6 -15	2.5239	16.64	11.32	0.54	1.187	0.25	0.015	0.042
Average	**2.5284**	**15.14**	**8.945**	**0.635**	**1.9835**	**0.53**	**0.0265**	**0.0885**

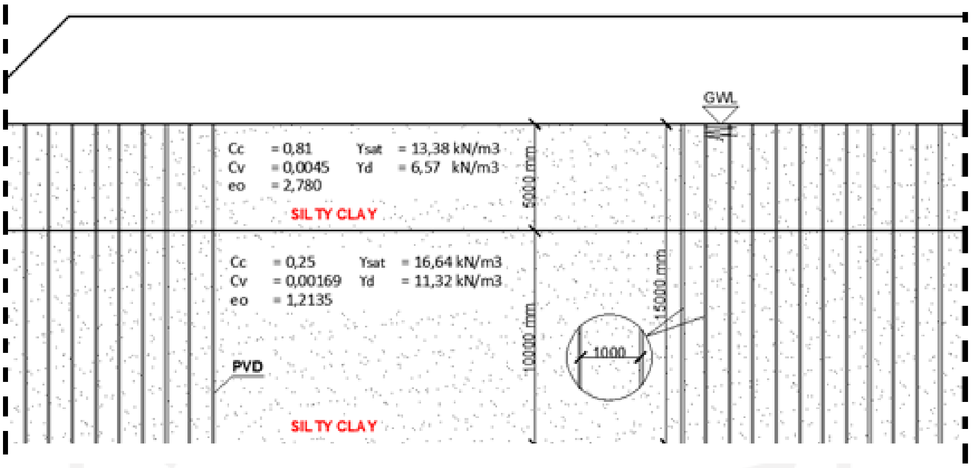


Figure 5.12 SP.01 (6+650) Soil Cross Section

5.2.2 Soil Settlement Theoretical Calculation with Terzaghi Method

Settlement analysis used are based on one way dimension settlement. Soil condition are overly consolidated thus the amount of settlement can be calculated using equation or with soil layer H every 1m until it reaches the determined depth of Prefabricated Vertical Drain on every Preloading or surcharge.

Known:

Table 5.6 Vacuum Gauge 1 Consolidation Settlement Soil Properties SP.01

Depth (m)	**C_c**	**e_0**	**γ_w (t/m^3)**	**γ_{sat} (t/m^3)**	**C_s**
0-5	0.81	2.78	0.981	1.338	0.135
6-15	0.25	1.187	0.981	1.664	0.042
Average	**0.53**	**1.98**	**1.54**	**0.91**	**0.088**

Effective stress, σ0' received by the soil on initial condition can be calculated as follows:

Depth 0 – 5 m (per 1 m)

$\sigma_{o'}$ $= ((\gamma_{sat1} - \gamma_w) \times z)$

$= ((1.338-0.981) \times 0.5)$

$= 0.178$ t/m^2

Depth 6 – 15 m (per 1 m)

$\sigma_{o'}$ $= ((\gamma_{sat1} - \gamma_w) \times z)$

$= ((1.664-0.981) \times 6.5)$

$= 4.44$ t/m^2

Pre consolidated stress caused by load ($\sigma_{c'}$) can be calculated with $2 + \sigma_{o'}$ (2 being the fluctuation of ground water level).

Depth 0 – 6 m (per 1 m)

$\sigma_{c'}$ = 2 + 0.178

= 2.178 t/m^3

Depth 6 – 15 m (per 1 m)

$\sigma_{c'}$ = 2 + 2.662

= 6.440 t/m^2

If said soil is given a vacuum pressure as big as 82 kPa while effective stress and pre consolidated stress as well as its changes have been known, thus the settlement that will occur on 1 m deep into the soil are as follows:

$$Sc = \frac{Cs.H}{1+e0} log\ (1 + \frac{\Delta\sigma'}{\sigma 0'})$$

$$Sc = \frac{0{,}135.1}{1+2.78} log\ (1 + \frac{8.2}{0.178})$$

$$Sc = 0.059\ m$$

Settlement that occurs during phase 1 of consolidation with 15 m depth can be seen on **Table 5.7** Below

Table 5.7 Phase 1 Consolidation Settlement SP.01

No	H (m)	Z (m)	σ'_0	$\sigma'c$	$\sigma'_0 + \Delta\sigma$	$(\sigma'_0 + \Delta\sigma)/\sigma'_0$	Sc (m)
1	1	0.5	0.179	2.179	8.3785	3.845994951	0.05969743
2	1	1.5	0.536	2.536	8.7355	3.445277066	0.043304582
3	1	2.5	0.893	2.893	9.0925	3.143474503	0.036002682
4	1	3.5	1.250	3.250	9.4495	2.907985844	0.031381163
5	1	4.5	1.607	3.607	9.8065	2.719118259	0.028058332
6	1	5.5	1.964	3.964	10.1635	2.564274	0.025500442
7	1	6.5	4.440	6.440	12.6395	1.962807671	0.008726395
8	1	7.5	5.123	7.123	13.3225	1.87048087	0.007971814
9	1	8.5	5.806	7.806	14.0055	1.794311703	0.007344891
10	1	9.5	6.489	8.489	14.6885	1.730399953	0.006814354
11	1	10.5	7.172	9.172	15.3715	1.676007196	0.006358693
12	1	11.5	7.855	9.855	16.0545	1.629154194	0.005962545
13	1	12.5	8.538	10.538	16.7375	1.588374852	0.005614593
14	1	13.5	9.221	11.221	17.4205	1.552560046	0.005306291
15	1	14.5	9.904	11.904	18.1035	1.520855211	0.005031048
Total							**0.283075256**

Hence the total of settlement during phase 1 with vacuum pressure of 82 kPa is around 0.283 m or 283 mm.

Settlement analysis of SP.01 reading is divided into 7 phases. Before phase 2 of the analysis is carried out, Phase 1 of the analysis will be done beforehand where from said vacuum activity an initial settlement of 283 mm is found through analysis using theoretical calculation. Theoretical analysis of settlement during phase 1 - 7 of vacuum process can be seen on **Table 5.8** below.

Table 5.8 Theoretical Settlement SP.01 Calculation

Phase	Duration		Vacuum Gauge (Kpa)	$\Delta\sigma'$ (t/m^2)	Settlement (mm)	
	From (Day)	Until (Day)				
Existing	0	0	0	0	0	0
I	1	18	82	8.2	283	283
II	19	36	85	8.5	94	377
III	37	54	86	8.6	59	436
IV	55	72	86	8.6	43	480
V	73	90	85	8.5	34	514
VI	91	108	27	2.7	26	541
VII	109	126	0	0	0	541
Total						**541**

Thus, the amount of final consolidation settlement obtained from SP.01 reading is 541 mm or 0.541 m.

The same procedure is done for all settlement plate data namely SP.01, SP.02, SP.03, SP.04 until a theoretical final settlement value is obtained which can be seen on **Table 5.9** below**.** As for theoretical settlement on STA 6+750, 6+850, AND 6+950 can be seen on **Attachment 15, 16, and 17**.

Table 5.9 Theoretical Analysis Final Settlements and Consolidation Degree

Settlement Plate	Actual Settlement 126 Days (mm)	Theoretical Settlement (mm)	Actual and Theoretical Sc Ratio
SP.01	615	541	1.136
SP.02	651	542	1.201
SP.03	569	543	1.047
SP.04	581	540	1.075
Average	**604**	**541.5**	**1.078**

While the *Vacuum Gauge* monitoring data and comparison between theoretical analysis and real settlement on SP.01 (6+650) can be seen on **Figure 5.13** and **Figure 5.14** below.

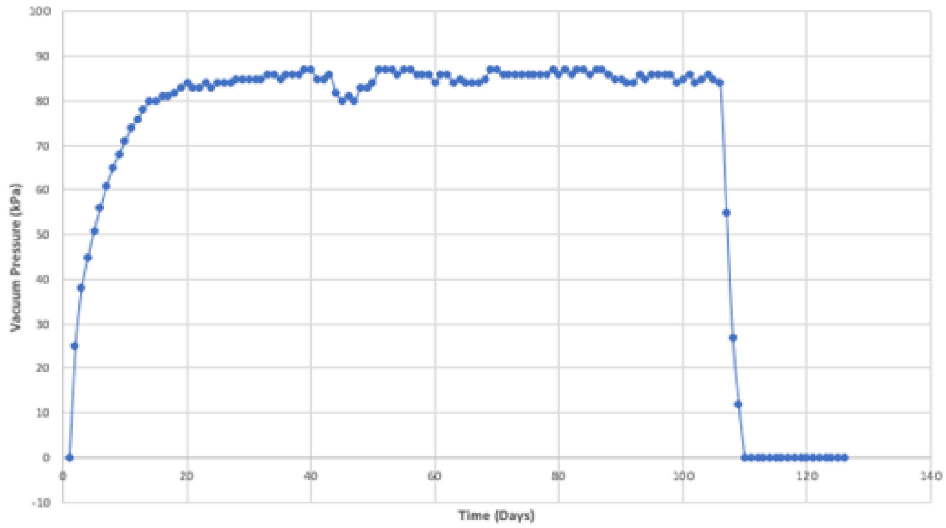


Figure 5.13 VG.01 Vacuum Gauge Monitoring

Source: (PT.Hutama Karya Infrastruktur 2017)

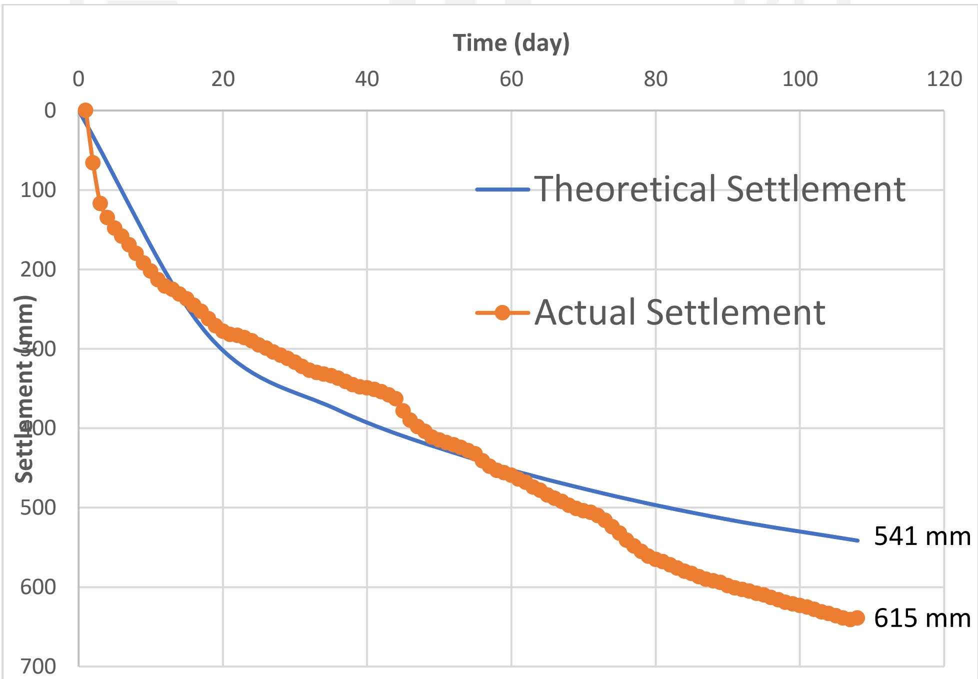


Figure 5.14 Theoretical vs Actual Settlement SP.01

Based off the results above it can be concluded that the results of theoretical settlements is actually significantly lower than the actual settlement that happened, with both settlement have a 47 mm difference or 12.03% lower than the actual settlement

From the results that can be seen on **Figure 5.14** above, Coefficient of determination (R^2 test) analysis is then conducted in order to find out the correlation and relationships between those two variables.

Table 5.10 Theoretical and Actual Settlement Data Recap for R^2 Test

no	x (actual)	y (theoretical)	x^2	y^2	xy
1	262	283	68644	80132	74166
2	75	94	5625	8843	7053
3	91	59	8281	3524	5402
4	82	44	6724	1932	3604
5	88	34	7744	1183	3027
6	43	27	1849	710	1146
Σ	**641**	**541**	**98867**	**96324**	**94398**

The data recapped above is then inserted into regression equation as follows

$$\beta 1 = \frac{n \sum xy - \sum x - \sum y}{n \sum x^2 - (\sum x)^2}$$

$$\beta 1 = \frac{6(94398) - 641 - 541}{6(98867) - (641)^2}$$

$$\beta 1 = 1.20$$

$$\beta 0 = \frac{\sum y}{n} - q(\frac{\sum x}{n})$$

$$\beta 0 = \frac{541}{6} - 1.2(\frac{641}{6})$$

$$\beta 0 = -38.26$$

Hence the model will be

y = -38.26+1,2x

Next is to calculate the correlation between the two settlement results namely the actual (variable x) and theoretical (variable y) settlement.

$$R = \frac{n\sum xy - (\sum x) - (\sum y)}{\sqrt{n\sum x^2 - (\sum x)^2}\ \sqrt{n\sum y^2 - (\sum y)^2}}$$

$$R = \frac{6(94398) - (641) - 541}{\sqrt{6(98867) - (641)^2}\ \sqrt{6(96324) - (541)^2}}$$

$$R = 0.962$$

$$R^2 = 0.926$$

From calculations above it can be concluded that the correlation coefficient between the two settlements namely actual (variable x) and theoretical (variable y) shows a 96.2% correlation coefficient meaning both variables have a very strong and positive correlation relationship, and from the coefficient of determination (R^2) test results it can be concluded that the dependent variable (theoretical settlement) is 92.6% influenced by the independent variable (actual settlement).

Correlation coefficient and coefficient of determination of all stations can be seen on **Table 5.11** below

Table 5.11 Recapitulation of Correlation and Determination Coefficient

	6+650	**6+750**	**6+850**	**6+950**
R (%)	96.2	93.9	87.52	88.71
R^2 (%)	92.6	88.18	76.6	76.7

5.2.3 Initial Consolidation Degree Prediction Calculation

During landfill activity of each station, ertical drains have been installed ahead of time, because of that consolidation degree calculation can be carried out using Equation 3.19.

Installation distance of each vertical drains is 1m with a rectangular pattern using Equation 3.19, and it should be noted that the distance between each vertical drains for the case of this project is (S = 1m), with that in mind the influenced zone diameter caused by the drain can be found using Equation 3.19 as follows.

D = 1.128 x S

D = 1.128 x 1

D = 1.128 m

Hence the influenced zone diameter caused by the drain value is 1.128 m

Vertical drains used have a width of 0.1 m with 0.004 m thickness. Using that information, the equivalent diameter (d_w) and drain distance factor (Fn) can be found using Equation 3.22 and Equation 3.21 respectively as follows

$$dw = \frac{2(a+b)}{\pi}$$

$$dw = \frac{2(0.1+0.004)}{\pi}$$

$$dw = 0.0662\ m$$

$$Fn = \ ln\left(\frac{D}{dw}\right) - \frac{3}{4}$$

$$Fn = \ ln\left(\frac{1.128}{0.0662}\right) - \frac{3}{4}$$

$$Fn = \ 2.085$$

Based on the values obtained from the analysis above, an influence from the existence of *vertical drains* which is the factor and consolidation degree for horizontal and vertical drainage thus a consolidation degree on a certain amount of duration can be known.

Below is an example of calculation during landfilling process have been carried out for 126 days with C_h = 2C_v (C_h = 2(0,0265) = 0.053 m2/day.

Horizontal (radial) consolidation degree can be found using Equation 3.31 as follows

$$Th = \frac{t\,.Ch}{D^2}$$

$$Th = \frac{126\,.\,0{,}053}{1.128^2}$$

$$Th = 5.25$$

On the initial calculation Fs and Fr value are ignored, thus the value of Uh during the first phase of landfilling of 126 days old can be calculated using Equation 3.30 as follows.

$$Uh = 1 - exp\frac{-8Th}{Fn}$$

$$Uh = 1 - exp\frac{-8\,.\,5{,}25}{2.085}$$

$$Uh = 0.998\ \%$$

Vertical consolidation degree can be found using Equation

The soil below the silty soil lies the clayey soil thus it is assumed that vertical drainage only moves towards the soil surface.

Value of C_v = 0.0265 m^2/day, thus

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

$$Tv = \frac{126\ x\ 0.0265}{15^2}$$

$$Tv = 0.01484$$

Value of *Uv* is calculated using Equation 3.27 as follows

$$U\,v \quad = \left(2\sqrt{\frac{Tv}{\pi}}\right).100\%$$

$$Uv \quad = \left(2\sqrt{\frac{0{,}01484}{\pi}}\right).100\%$$

Uv = 0.137 ≈ 0.137%

With that in mind, value of Consolidation degree can be found using Equation 3.26 below

$$U = 1 - (1 - Uh).(1 - Uv)$$

$$U = 1 - (1 - 0{,}998).(1 - 0{,}137)$$

$U = 0.9983$ ≈ 99.83 %

Hence, during t = 126 days consolidation has reached 99,83 %.

5.2.4 Soil Settlement Prediction with Asaoka

Predictions of consolidation settlement can also be done by using observational method such as Asaoka. Soil settlement prediction using Asaoka method is done using data based on the settlement plate monitoring data, it should be noted that only a sample of settlement plate data needed to be used for this method thus the data used will be starting on day 50 and day 60 of the observation. Recapitulation of Asaoka along with its calculation can be seen on **Table 5.12**, **Figure 5.14** and **Figure 5.15**. While results of Asaoka for STA 6+750, STA+850. And STA 6+950 can be seen on **Attachment 19**, **Attachment 20**, and **Attachment 21**.

Table 5.12 Settlement During n (Sn) and Settlement During n+1 (Sn+1)

Day-n	Sn	Sn+1	Day-n	Sn	Sn+1	Day-n	Sn	Sn+1
60	459	464	87	590	592	114	622	621
61	464	468	88	592	594	115	621	619
62	468	474	89	594	598	116	619	618
63	474	478	90	598	601	117	618	617
64	478	484	91	601	603	118	617	615
65	484	488	92	603	605	119	615	614
66	488	492	93	605	608	120	614	614
67	492	497	94	608	610	121	614	621
68	497	501	95	610	613	122	621	619
69	501	504	96	613	616	123	619	618
70	504	506	97	616	619	124	618	617
71	506	510	98	619	621	125	617	615
72	510	516	99	621	623	126	615	
73	516	524	100	623	625			
74	524	532	101	625	628			
75	532	541	102	628	631			
76	541	548	103	631	633			
77	548	555	104	633	636			
78	555	561	105	636	639			
79	561	565	106	639	641			
80	565	568	107	641	639			
81	568	572	108	639	637			
82	572	576	109	637	634			
83	576	580	110	634	631			
84	580	583	111	631	627			
85	583	587	112	627	624			
86	587	590	113	624	622			

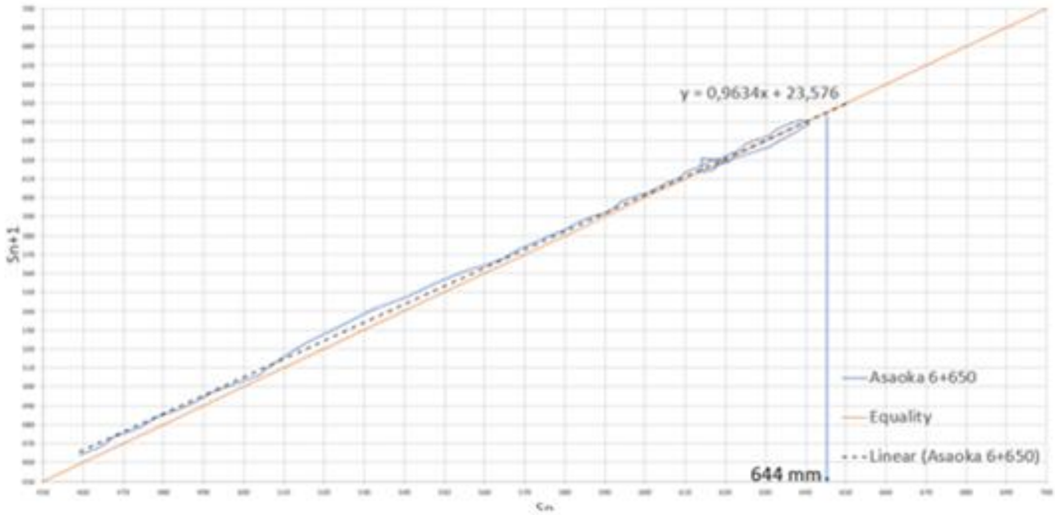


Figure 5.15 Final Settlement Prediction Using Asaoka Method Based on SP.01 (6+650) Data

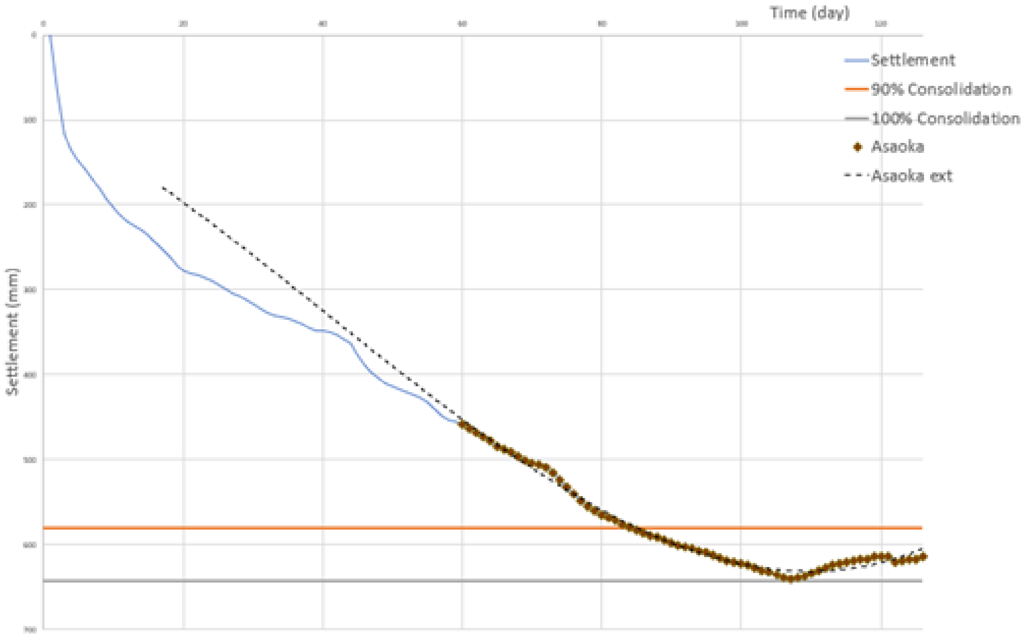


Figure 5.16 Asaoka Method Settlement vs Time Graph SP.01 (6+650) Data

From the settlement plate data, relationship curve between time and settlement can be made. From the curve of settlement plate reading SP.01 as well as SP.02 starting from day 60 on up until day 126 and SP.03 as well as SP.04 starting on day 50 on up until day 126 of monitoring which acts as a sample of the data, future settlements (final) can be predicted.

Based on the results shown on **Figure 5.15** and **Figure 5.16** it can be seen that the Settlement Plate SP.01 reads peak settlement of STA 6+650 is at 641 mm, but through further analysis namely using Asaoka method a final settlement value of 644 mm is found, thus we can safely assume that primary consolidation of STA 6+650 causes a 641 mm soil settlement which and because through asaoka method a final settlement assumption is found, there is a possibility that the soil will settle even further as deep as 0.03 mm in the coming future.

After that, final settlement prediction using Asaoka method with the help of Microsoft excel to find the regression line can be done, which previously can be seen on **Table 5.12**. Based on final settlement prediction using Asaoka method, soil settlement that will occur when consolidation reaches 100% on SP.01 caused by vacuum pressure is 644 mm. Recapitulation of real settlement that occur at the project site and final settlement prediction using asaoka method can be seen on **Table 5.13** Below.

Table 5.13 Estimation of Final Settlements by Asaoka

Settlement Plate	Settlement until day 126 (mm)	Final Settlement Prediction using Asaoka (mm)
SP.01 (6+650)	615	644
SP.02 (6+750)	651	681
SP.03 (6+850)	569	609
SP.04 (6+950)	581	623

5.2.5 Consolidation Degree Based on Settlement Plate and Asaoka

Determining consolidation degree can be done using the settlement plate monitoring data, it is done by comparing the amount of real settlement at a certain time interval (t) towards the final consolidation settlement obtained using asaoka method. Example of consolidation degree calculation mentioned previously can be seen below.

1. Settlement Plate SP.01 (6+650)

$$Uv - sp = \frac{St}{Sc}$$

$$Uv - sp = \frac{615}{644}$$

$$Uv - sp = 0.954 \approx 95.4\%$$

2. Settlement Plate SP.02 (6+750)

$$Uv - sp = \frac{St}{Sc}$$

$$Uv - sp = \frac{651}{681}$$

$$Uv - sp = 0.956 \approx 95.6\%$$

3. Settlement Plate SP.03 (6+850)

$$Uv - sp = \frac{St}{Sc}$$

$$Uv - sp = \frac{569}{609}$$

$$Uv - sp = 0.934 \approx 93.4\%$$

4. Settlement Plate SP.04 (6+950)

$$Uv - sp = \frac{St}{Sc}$$

$$Uv - sp = \frac{581}{623}$$

$$Uv - sp = 0.932 \approx 93.2\%$$

Table 5.14 Consolidation Degree with Asaoka Estimation

Settlement Plate	Settlement Until Day 126 (mm)	Final Settlement Prediction Using Asaoka (mm)	Consolidation Degree (%)
SP.01	615	644	95.4
SP.02	651	681	95.6
SP.03	569	609	93.4
SP.04	581	623	93.2
Average	**604**	**639**	**94.4**

Referencing from calculation results on **Table 5.14** above, it can be seen that all of the station on BH-05 during soil improvement experiences settlement ranging from as low as 569 mm to as big as 651 mm during vacuum consolidation process, however all station in BH-05 also has the potential to settle even further based off of analysis using Asaoka method. Even though after vacuum process and monitoring using settlement plate SP.01 the soil has the potential to settle even further, the consolidation degree requirement of 90% have been reached, and the residual of settlement found using Asaoka method can be safely assumed to be tolerable.

5.2.6 Consolidation degree determination using *Piezometer* monitoring

Consolidation degree can also be determined using piezometer monitoring data where in this case each settlement plate namely SP.01 (6+650), SP.02 (6+750), SP.03 (6+850), SP.04 (6+950) and only station STA 6+650 and STA 6+950 has its own vibrating wire piezometer namely VWP.01 and VWP.02.

From piezometer VWP.01 can be seen that peak excessive of soil pore water pressure from tip 1, and tip 2 in order are 0 kPa and 0 kPa. Through that reading a consolidation degree achieved on day 126 using piezometer VWP.01 are as follows:

$$Upp = \frac{Shaded\ Area}{Parallelogram\ Area}$$

$$Upp = \frac{82.5}{82.5} x100\%$$

$Upp = 100\%$

With that said the consolidation degree that occurs until day 126 is 100% caused by both piezometer tip reads 0 kPa on day 126 (last monitoring day).

Illustrations of consolidation degree analysis can be seen on **Figure 5.17 and Figure 5.18** below.

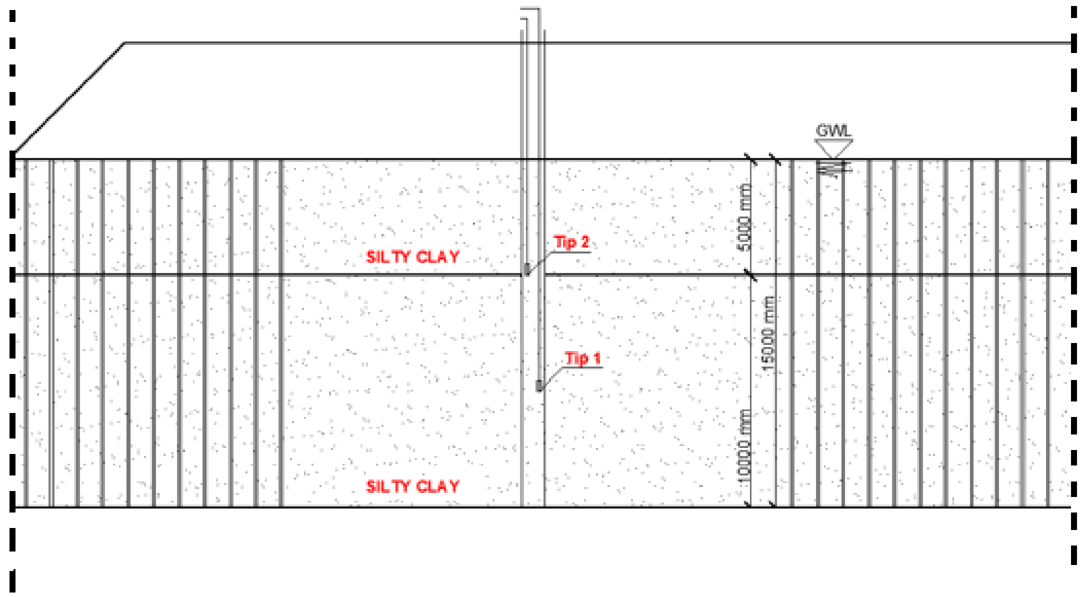


Figure 5.16 Installation of VWP STA 6+650 Illustration

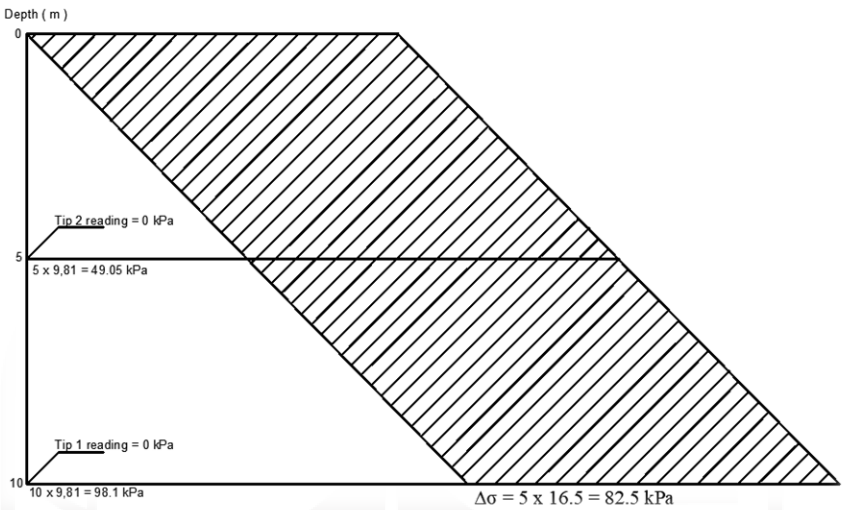


Figure 5.17 Excess Pore Water Pressure on Day 126

From Figure **5.17** we can conclude that at the end of Vibrating wire piezometer process (day 126) consolidation degree achieved is at 100%, this is caused by the value of excess pore water pressure reading form piezometer during day 126 = 0 kPa while according to Settlement plate the average consolidation degree value is 94,4%. However, fortunately both consolidation degree has reached the required standards (>90%).

5.2.7 Soil Parameter Back Analysis for Vacuum Consolidation Design Using Vertical Drains

Calculation of back analysis consists of soil parameter horizontal consolidation coefficient (C_h), volume compressibility coefficient (m_v), vertical soil permeability (k) and compressibility coefficient (C_c) which will be explained in detail below.

5.2.7.1 Horizontal Consolidation Coefficient (C_h) Based on Asaoka Estimation

From **Figure 5.13** it can be determined that the value of β to be inserted into Equation 3.33.

$$\frac{\pi^2 Cv}{8H^2}+\frac{8Ch}{D^2 Fn} = -\frac{\ln \beta}{\delta t}$$

$$\frac{\pi^2 0.0265}{8.15^2}+\frac{8Ch}{1.128^2 \,.\, 2.085} = -\frac{\ln 0.963}{1}$$

C_h = 0.0112

Hence it can be concluded that according to SP.01 data

C_h = $0.423C_v$

5.2.7.2 Volume Coefficient Compressibility Value (m_v)

Based on Equation 3.18. Where S_c were the Asaoka estimated final settlement, thus if H_o and Δσ are known the value of mv can be recalculated. As example recalculation of mv using SP.01 data can be seen using Equation 3.18 as follows:

$$mv = \frac{Sc}{\Delta\sigma \,.\, \mathrm{Ho}}$$

$$mv = \frac{0.644}{69.063 \,.\, 15}$$

$$mv = 0.000622$$

With that said, according to SP.01 data the volume compressibility coefficient is about 0,000622 m^2/kN. Value of compressibility coefficient based on SP.02, SP.03, SP.04 each are also analysed where it can be seen on **Table 5.15**.

5.2.7.3 Soil Vertical Permeability Value (k_v)

Referencing from Equation, if a C_v value is known to be 0,00723 m^2/day, γ_w at 9.81 kN/m^3 and the value of mv which we find previously is at 0.000826 m^2/kN thus the value of k can be determined by using Equation 3.15 as follows:

$$Cv = \frac{k}{\gamma w . mv}$$

$$kv \;=\; Cv\,.\,\gamma w\;.\,mv$$

$$kv \;=\; 0.0265\,.\,9{,}81\,.\,0{,}000622$$

$$kv \;=\; 0.000162\; m/day$$

Thus, the value of soil vertical permeability is 0,000162 m/day. While the value of soil vertical permeability based on SP.02, SP.03, SP.04 each are also analysed where the results can be seen on **Table 5.15.**

5.2.7.4 Compressibility Index Value (C_c)

After soil parameters from back analysis that are based on project site data is obtained, a recalculation of soil settlement using Equation 3.5 will be done.

Based on SP.01 project site data:

Sc	= 0.641 m	$\sigma_o{}'$	= 43.425 kN/m^2
H_o	= 15 m	Δ_σ	= 64.43 kN/m^2
e_o	= 1.984		

By using Equation 3.5 $Sc = \frac{Cc\,.\,H}{1+e0}\log\frac{\sigma0' + \Delta\sigma'}{\sigma0'}$ value of Cc can be found.

$$Cc = \frac{Sc}{\frac{H0}{1+e0}\log\frac{\sigma0' + \Delta\sigma}{\sigma0'}}$$

$$Cc = \frac{0.644}{\frac{15}{1+1.984}\log\frac{43.425 + 64.43}{43.425}}$$

$$Cc = 0.06269$$

According to SP.01 project site data a soil coefficient of compressibility of 1.921 is obtained. While value of soil compressibility index based on SP.02, SP.03, SP.04 can be seen on **Table 5.15** below.

Table 5.15 Soil Parameters Using Back Analysis

Settlement Plate	**C_h (m^2/day)**	**C_h/C_v**	**mv (m^2/kN)**	**kv (m/day)**	**C_c**
SP.01	0.0112	0.423	0.000622	0.000162	0.06269
SP.02	0.0128	0.483	0.000661	0.000172	0.06629
SP.03	0.0107	0.403	0.000584	0.000152	0.05928
SP.04	0.0302	1.139	0.00061	0.000159	0.06062
Average	**0.016225**	**0.612**	**0.00061925**	**0.00016125**	**0.062215**

Based on **Table 5.15** above, the value of soil parameters found using back analysis in each station can be seen where instead of a the tested BH-05 soil parameter result assumes that all station has the same soil properties, The generalization of soil parameters per Boring Hole is done because it will be very inconvenient and time wasting to test the soil in every station (per 100 meters), thus the soil parameters from STA6+650 – STA 6+950 is assumed to be the same.

The test results above also shows that the soil parameters on each station included on BH-05 have similar value, thus making the generalized soil parameters of BH-05 justifiable. Other than that, these soil properties found using per station can be used as reference in case there will be any construction happening in the future near the area.

CHAPTER VI

CONCLUSION AND SUGGESTIONS

6.1 Conclusion

1. According to the theoretical analysis, soil settlement that occurred up until day 126 is as big as 0.541 m for SP.01, 0.543 m for SP.02, 0.544 m for SP.03, and 0.540 m for SP.04 with an average theoretical settlement of 0.542 m in Palembang – Indralaya STA 6+650 – STA 6+950. While the actual settlement plate reading is 0.615 for SP.01, 0.651 for SP.02, 0.569 for SP.03, 0.609 for SP.04 with an average settlement of 0,604 m. Meaning that theoretical analysis is 0.064 mm lower than the actual settlement conducted on site.

2. Based on Asaoka estimation a final settlement prediction value for SP.01, SP.02, SP.03, and SP.04 respectively are 0.644 m, 0.674 m, 0.596 m, and 0.609 m. While the actual settlement plate reading is 0.615 for SP.01, 0.651 for SP.02, 0.569 for SP.03, 0.609 for SP.04 with an average settlement of 0,604 m.Which means that the soil will likely to settle for a few more days considering the reading for settlement plate haven’t reached those numbers just yet. With that in mind the vacuum process can be stopped and have reached the required consolidation degree value of >90%.

3. Consolidation degree value obtained based off of several different methods can be seen below

   Actual settlement vs Theoretical settlement (AVERAGE) = 111.5%

   Actual settlement vs Asaoka (AVERAGE) = 94.4%

   Consolidation degree using PVD properties (AVERAGE) = 99.8%

   Consolidation degree using piezometer (AVERAGE) = 100%

4. From back analysis estimation, new soil parameter average value obtained are as follows:

   C_h = 0.016225

   C_h/C_v = 0.612

   mv = 0.00061925

   kv = 0.00016125

   C_c = 0.062215

   Meaning that the soil properties changes after vacuum consolidation system has been carried out until finish, and soil properties has improved and can be safely assumed that shearing capacity and bearing capacity of the soil has improved after Vacuum Consolidation System

6.2 Suggestions

Based on conclusions that have been made regarding consolidation settlements on Palembang – Indralaya road section STA6+650 – STA6+950, several suggestions for future research can be concluded as follows:

1. Because the consolidation settlement done in Palembang – Indralaya Toll Road uses Vacuum Consolidation System, there needs to be future research analysis using different consolidation settlement design such as Preloading method.
2. Because the consolidation settlement done in Palembang – Indralaya Toll Road uses Vacuum Consolidation System, there needs to be future research analysing the consolidation settlement by natural consolidation and how long it took for natural consolidation to reach 100% consolidation degree.
3. Future researchers can do analysis regarding other areas of Palembang – Indralaya Toll Road by using Preloading method or to calculate the time it took for natural settlement to occur and reach 100%.

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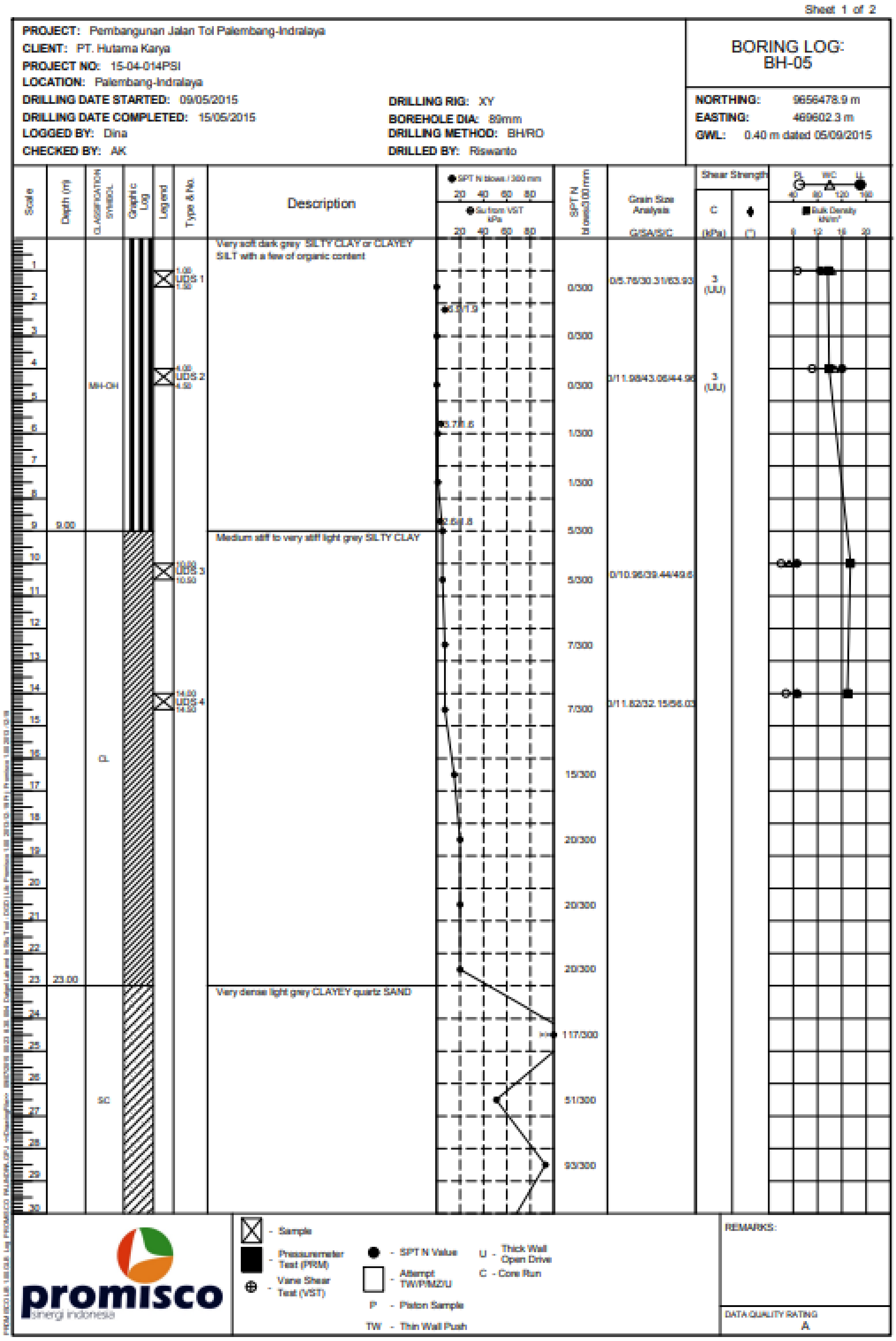
ATTACHMENT

Attachment 1 Boring Log BH-05 Data



Sheet 2 of 2

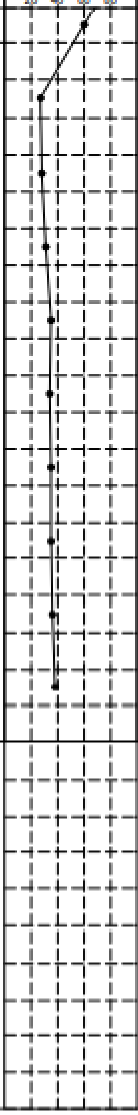
PROJECT: Pembangunan Jalan Tol Palembang-Indralaya
CLIENT: PT. Hutama Karya
PROJECT NO: 15-04-014PSI
LOCATION: Palembang-Indralaya
DRILLING DATE STARTED: 09/05/2015
DRILLING DATE COMPLETED: 15/05/2015
LOGGED BY: Dina
CHECKED BY: AK

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

BORING LOG: BH-05

NORTHING: 9656478.9 m
EASTING: 469602.3 m
GWL: 0.40 m dated 05/09/2015

Scale	Depth (m)	Classification Symbol	Graphic Log	Legend	Type & No.	Description	SPT N blows/300 mm	Grain Size Analysis G/S/A/S/C	Shear Strength C (kPa)	Shear Strength φ (°)
31	31.00	SC				Very dense light grey CLAYEY quartz SAND (continued)	60/300			
32–50	50.00	SW-SC				Very stiff to hard grey SANDY CLAY	27/300, 28/300, 31/300, 35/300, 34/300, 35/300, 35/300, 36/300, 38/300			
51–60						Hole Terminated at 50.00 m				



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

REMARKS:

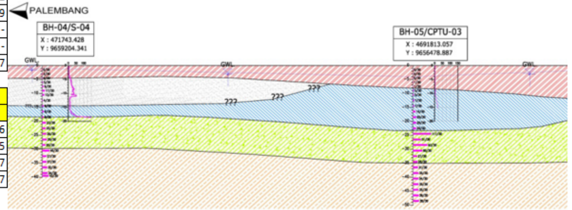
DATA QUALITY RATING: A

Attachment 2 Recapitulation of Soil Properties Data

FORM SUMMARY OF TESTS (FORMULIR RESUME HASIL PENGUJIAN)
Jalan Tol Ruas Palembang - Indralaya

Depth (m)			Kadar air	Berat isi	Berat isi kering	Berat jenis	Derajat kejenuhan	Angka pori	Porosity	Soil Type	Warna	Consolidation			
			Wn (%)	γn (gr/cm3)	γn (gr/cm3)	Gs (gr/cm3)	Sr (%)	e	n (%)			e0	Cc	Cv	k
1	-	1,5	69,57	1,550	0,914	2,5806	98,4723	1,823	64,579	Silty Clay	BROWNISH GREY	1,8235	0,78	0,0206	0,00000442
4	-	4,5	82,8	1,580	0,864	2,5381	100	1,936	65,946	Silty Clay	GREY	1,92361		0,012	0,00000189
10	-	10,5	27,05	1,880	1,480	2,6178	92,0701	0,769	43,474	Clayey Sand	GREY	-	-	-	-
14	-	14,5	122,69	1,388	0,623	2,6008	100	3,173	76,035	Clayey Sand	GREY	-	-	-	-
18	-	18,5	18,82	1,774	1,278	2,5478	99,5308	0,994	49,842	Silty Clay	REDDISH BROWN	0,9936	0,33	0,0301	0,00000367

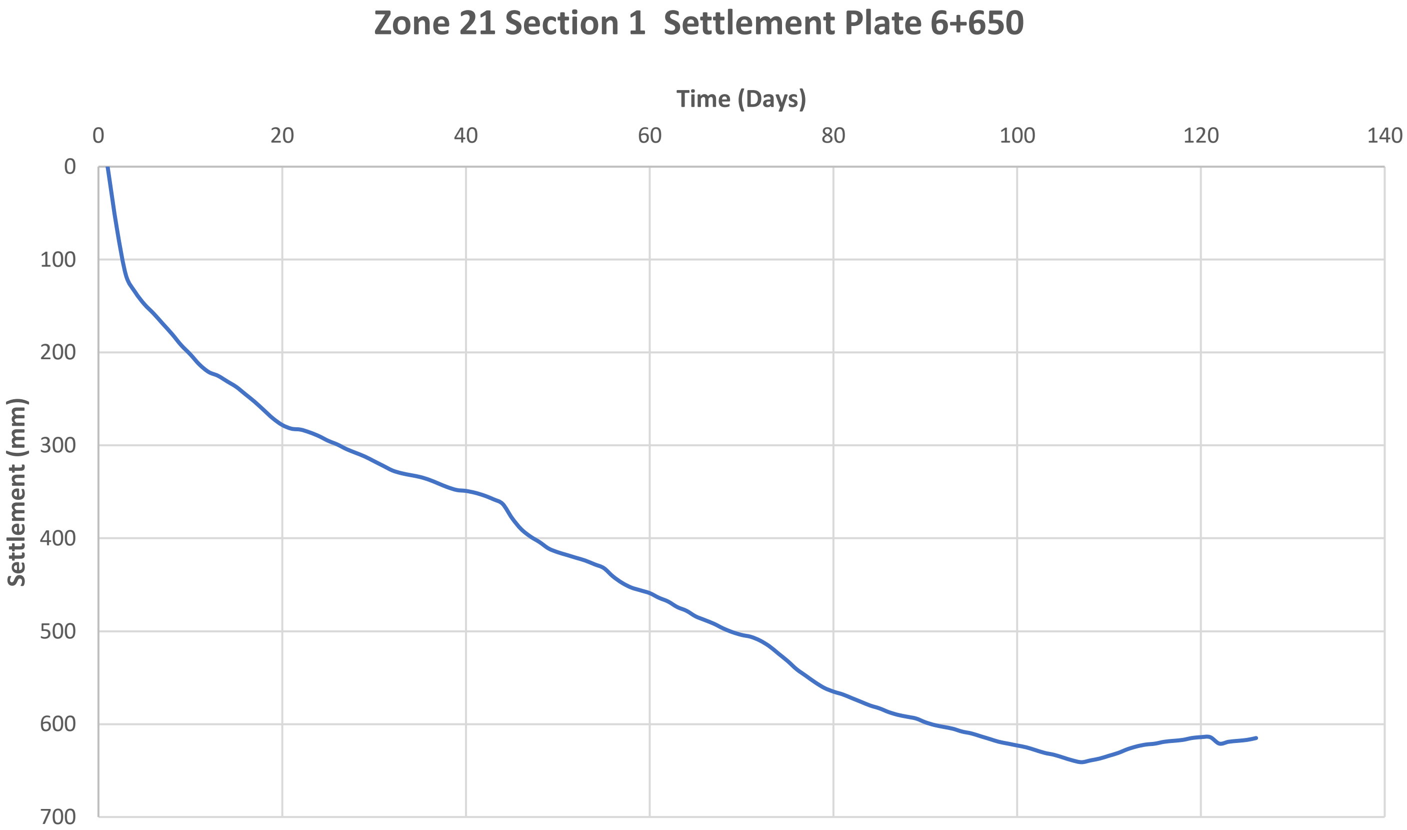
Depth (m)			Kadar air	Berat isi	Berat isi kering	Berat jenis	Derajat kejenuhan	Angka pori	Porosity	Soil Type	Warna	Consolidation			
			Wn (%)	γn (gr/cm3)	γn (gr/cm3)	Gs (gr/cm3)	Sr (%)	e	n (%)			e0	Cc	Cv cm/sec2	k
1	-	1,5	103,9	1,371	0,672	2,4517	96,2612	2,646	72,575	Silty Clay	DARK GREY	2,9009	0,67	0,00356	0,000000636
4	-	4,5	108,01	1,394	0,670	2,5329	98,4257	2,780	73,542	Silty Clay	DARK GREY	2,8077	0,81	0,0045	0,00000115
10	-	10,5	33,25	1,735	1,302	2,5970	86,8255	0,995	49,863	Silty Clay	LIGHT GREY	0,9504	0,24	0,00962	0,0000000587
14	-	14,5	46,8	1,694	1,154	2,5239	99,4949	1,187	52,279	Silty Clay	LIGHT GREY	1,2135	0,25	0,00169	0,00000027



GEOTEKNIKA

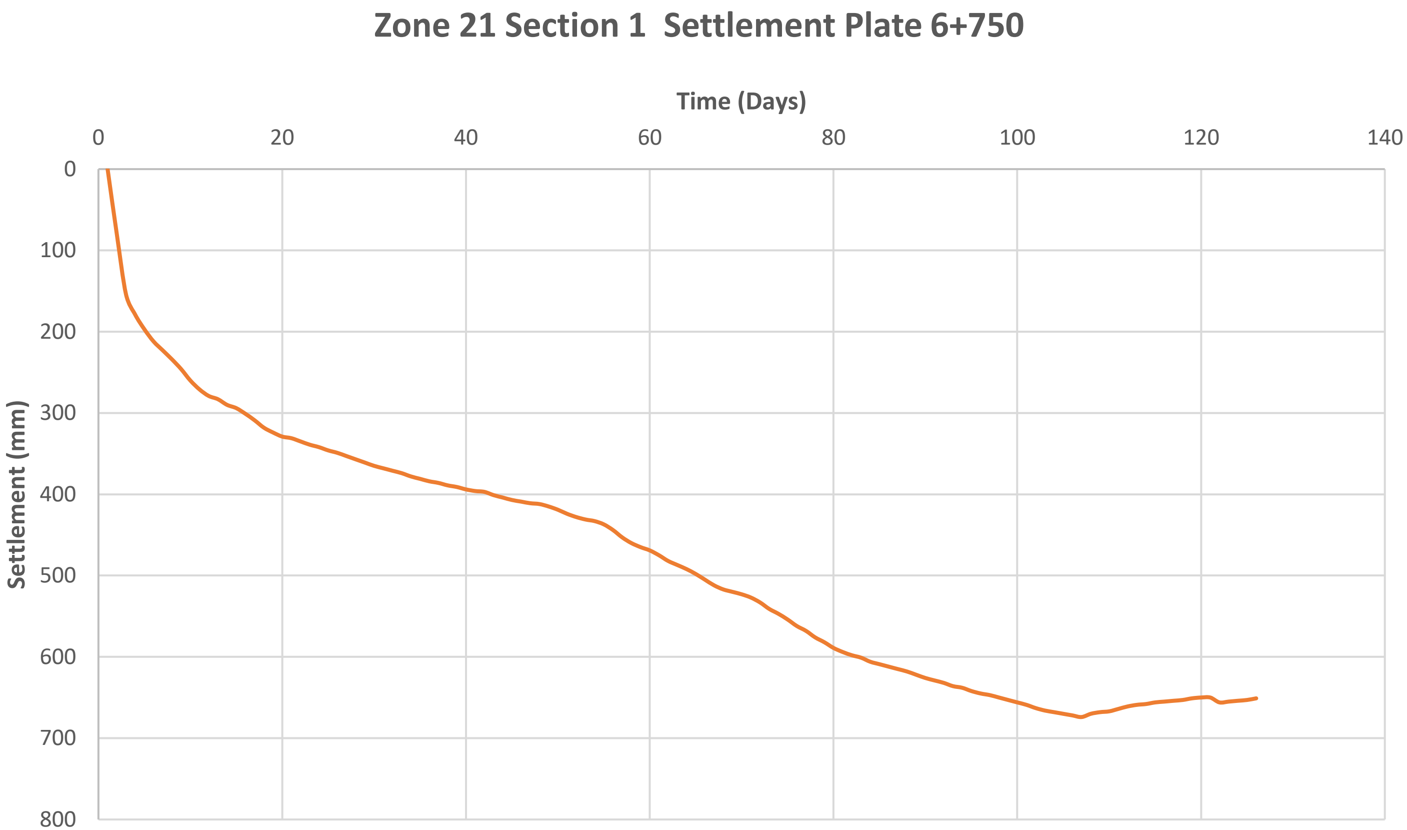
Attachment 3 Settlement Plate SP.01 Monitoring Data

Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement
1	0	24	290	47	398	70	504	93	605	116	619
2	66	25	295	48	404	71	506	94	608	117	618
3	117	26	299	49	411	72	510	95	610	118	617
4	135	27	304	50	415	73	516	96	613	119	615
5	148	28	308	51	418	74	524	97	616	120	614
6	158	29	312	52	421	75	532	98	619	121	614
7	169	30	317	53	424	76	541	99	621	122	621
8	180	31	322	54	428	77	548	100	623	123	619
9	192	32	327	55	432	78	555	101	625	124	618
10	202	33	330	56	441	79	561	102	628	125	617
11	213	34	332	57	448	80	565	103	631	126	615
12	221	35	334	58	453	81	568	104	633		
13	225	36	337	59	456	82	572	105	636		
14	231	37	341	60	459	83	576	106	639		
15	237	38	345	61	464	84	580	107	641		
16	245	39	348	62	468	85	583	108	639		
17	253	40	349	63	474	86	587	109	637		
18	262	41	351	64	478	87	590	110	634		
19	271	42	354	65	484	88	592	111	631		
20	278	43	358	66	488	89	594	112	627		
21	282	44	363	67	492	90	598	113	624		
22	283	45	378	68	497	91	601	114	622		
23	286	46	390	69	501	92	603	115	621		


Zone 21 Section 1 Settlement Plate 6+650
Time (Days)
0
20
40
60
80
100
120
140
Settlement (mm)
0
100
200
300
400
500
600
700

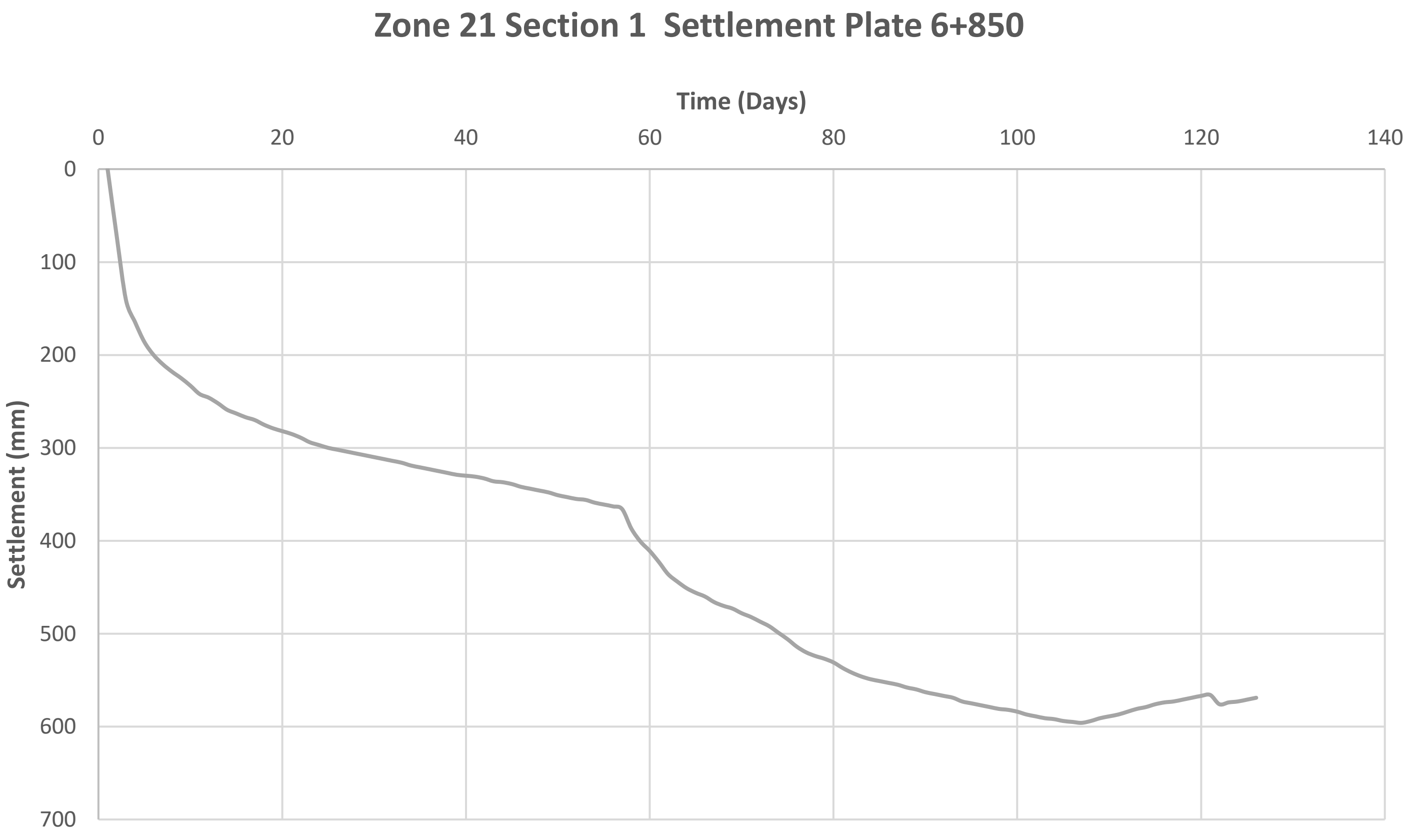
Attachment 4 Settlement Plate SP.02 Monitoring Data

Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement
1	0	24	342	47	411	70	523	93	636	116	655
2	80	25	346	48	412	71	527	94	638	117	654
3	154	26	349	49	415	72	533	95	642	118	653
4	179	27	353	50	419	73	541	96	645	119	651
5	197	28	357	51	424	74	547	97	647	120	650
6	212	29	361	52	428	75	554	98	650	121	650
7	223	30	365	53	431	76	562	99	653	122	656
8	234	31	368	54	433	77	568	100	656	123	655
9	246	32	371	55	437	78	576	101	659	124	654
10	260	33	374	56	444	79	582	102	663	125	653
11	271	34	378	57	453	80	589	103	666	126	651
12	279	35	381	58	460	81	594	104	668		
13	283	36	384	59	465	82	598	105	670		
14	290	37	386	60	469	83	601	106	672		
15	294	38	389	61	475	84	606	107	674		
16	301	39	391	62	482	85	609	108	670		
17	309	40	394	63	487	86	612	109	668		
18	318	41	396	64	492	87	615	110	667		
19	324	42	397	65	498	88	618	111	664		
20	329	43	401	66	505	89	622	112	661		
21	331	44	404	67	512	90	626	113	659		
22	335	45	407	68	517	91	629	114	658		
23	339	46	409	69	520	92	632	115	656		


Zone 21 Section 1 Settlement Plate 6+750
Time (Days)
0
20
40
60
80
100
120
140
Settlement (mm)
0
100
200
300
400
500
600
700
800

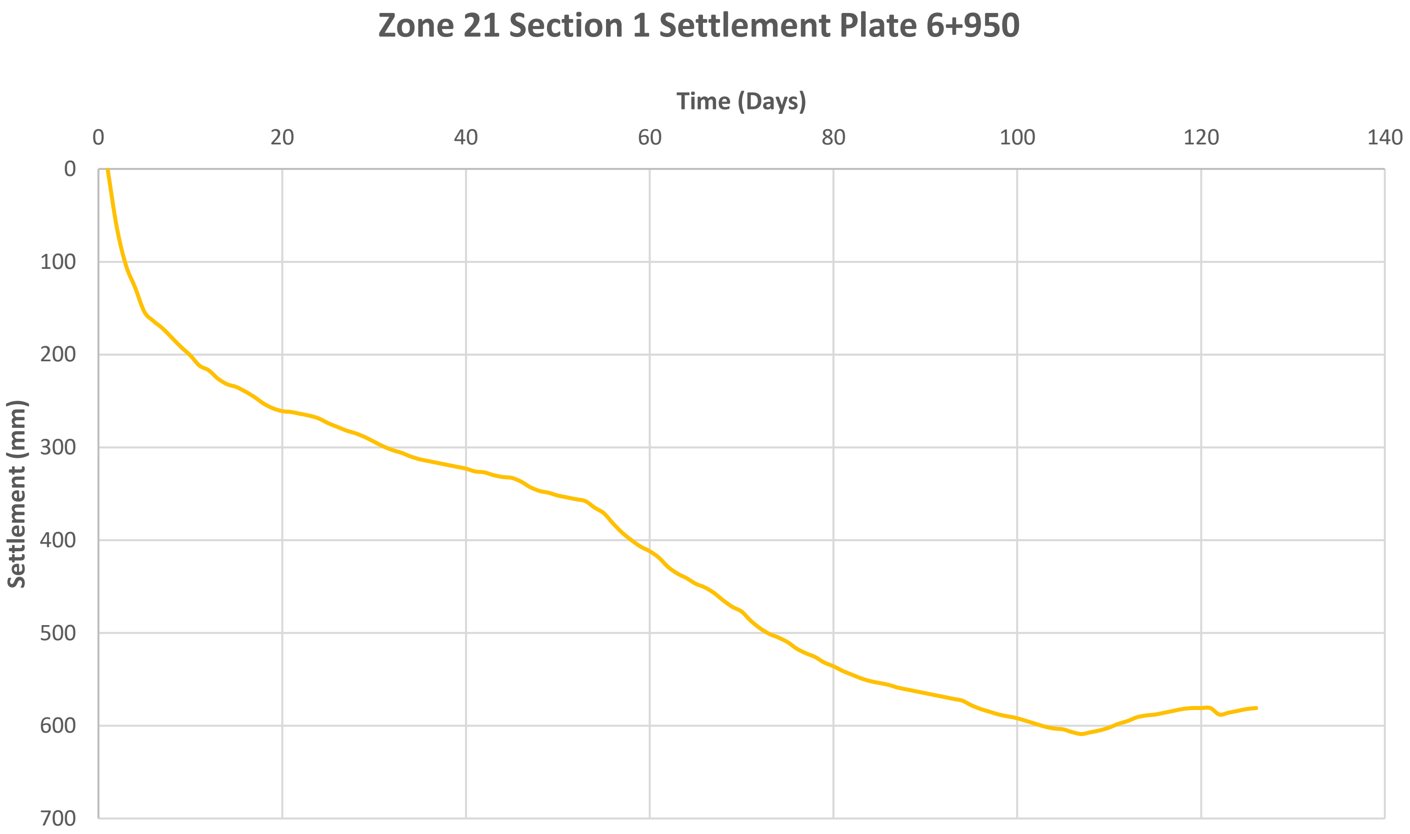
Attachment 5 Settlement Plate SP.03 Monitoring Data

Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement
1	0	24	297	47	344	70	478	93	569	116	574
2	73	25	300	48	346	71	482	94	573	117	573
3	141	26	302	49	348	72	487	95	575	118	571
4	165	27	304	50	351	73	492	96	577	119	569
5	186	28	306	51	353	74	499	97	579	120	567
6	200	29	308	52	355	75	506	98	581	121	566
7	210	30	310	53	356	76	514	99	582	122	576
8	218	31	312	54	359	77	520	100	584	123	574
9	225	32	314	55	361	78	524	101	587	124	573
10	233	33	316	56	363	79	527	102	589	125	571
11	242	34	319	57	366	80	531	103	591	126	569
12	246	35	321	58	387	81	537	104	592		
13	252	36	323	59	401	82	542	105	594		
14	259	37	325	60	411	83	546	106	595		
15	263	38	327	61	423	84	549	107	596		
16	267	39	329	62	436	85	551	108	594		
17	270	40	330	63	444	86	553	109	591		
18	275	41	331	64	451	87	555	110	589		
19	279	42	333	65	456	88	558	111	587		
20	282	43	336	66	460	89	560	112	584		
21	285	44	337	67	466	90	563	113	581		
22	289	45	339	68	470	91	565	114	579		
23	294	46	342	69	473	92	567	115	576		

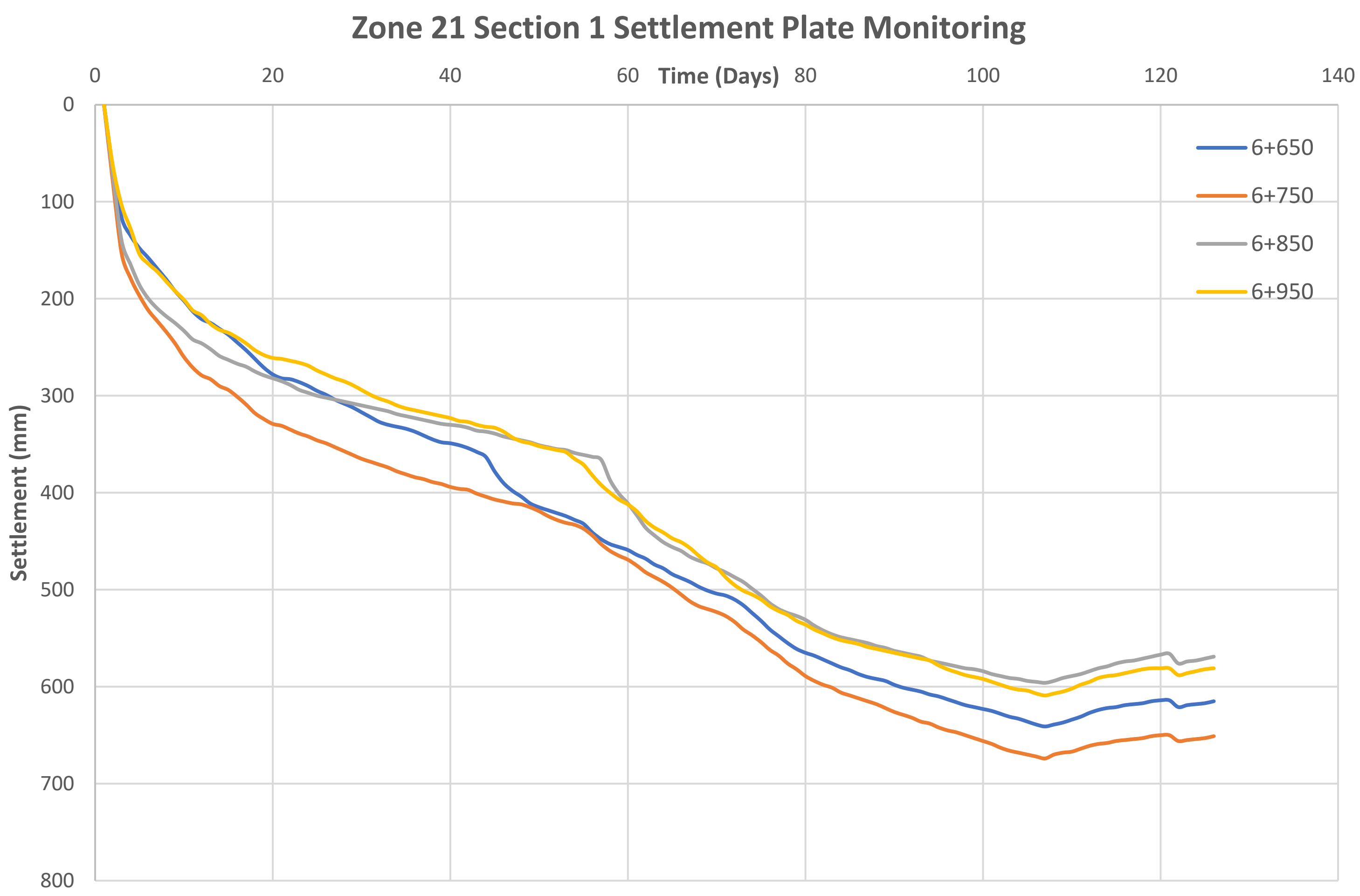

Zone 21 Section 1 Settlement Plate 6+850
Time (Days)
0
20
40
60
80
100
120
140
Settlement (mm)
0
100
200
300
400
500
600
700

Attachment 6 Settlement Plate SP.04 Monitoring Data

Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement	Day no.	Settlement
1	0	24	269	47	343	70	477	93	571	116	586
2	63	25	274	48	347	71	487	94	573	117	584
3	104	26	278	49	349	72	495	95	578	118	582
4	128	27	282	50	352	73	501	96	582	119	581
5	154	28	285	51	354	74	505	97	585	120	581
6	164	29	289	52	356	75	510	98	588	121	581
7	172	30	294	53	358	76	517	99	590	122	588
8	182	31	299	54	365	77	522	100	592	123	586
9	192	32	303	55	371	78	526	101	595	124	584
10	201	33	306	56	382	79	532	102	598	125	582
11	212	34	310	57	392	80	536	103	601	126	581
12	217	35	313	58	400	81	541	104	603		
13	226	36	315	59	407	82	545	105	604		
14	232	37	317	60	412	83	549	106	607		
15	235	38	319	61	419	84	552	107	609		
16	240	39	321	62	429	85	554	108	607		
17	246	40	323	63	436	86	556	109	605		
18	253	41	326	64	441	87	559	110	602		
19	258	42	327	65	447	88	561	111	598		
20	261	43	330	66	451	89	563	112	595		
21	262	44	332	67	457	90	565	113	591		
22	264	45	333	68	465	91	567	114	589		
23	266	46	337	69	472	92	569	115	588		



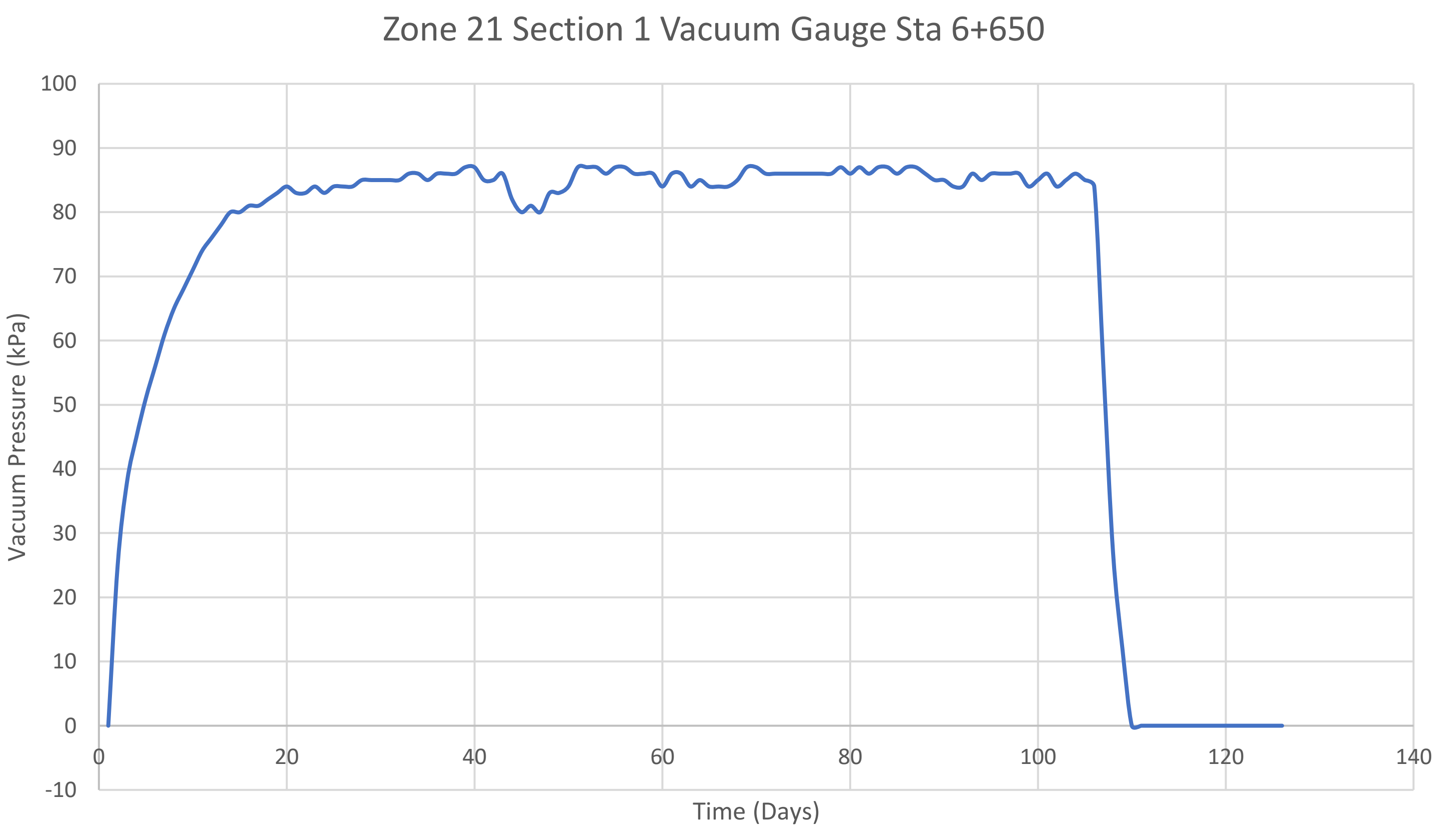
Zone 21 Section 1 Settlement Plate 6+950
Time (Days)
0
20
40
60
80
100
120
140
Settlement (mm)
0
100
200
300
400
500
600
700



Zone 21 Section 1 Settlement Plate Monitoring
Time (Days)
0
20
40
60
80
100
120
140
Settlement (mm)
0
100
200
300
400
500
600
700
800
6+650
6+750
6+850
6+950

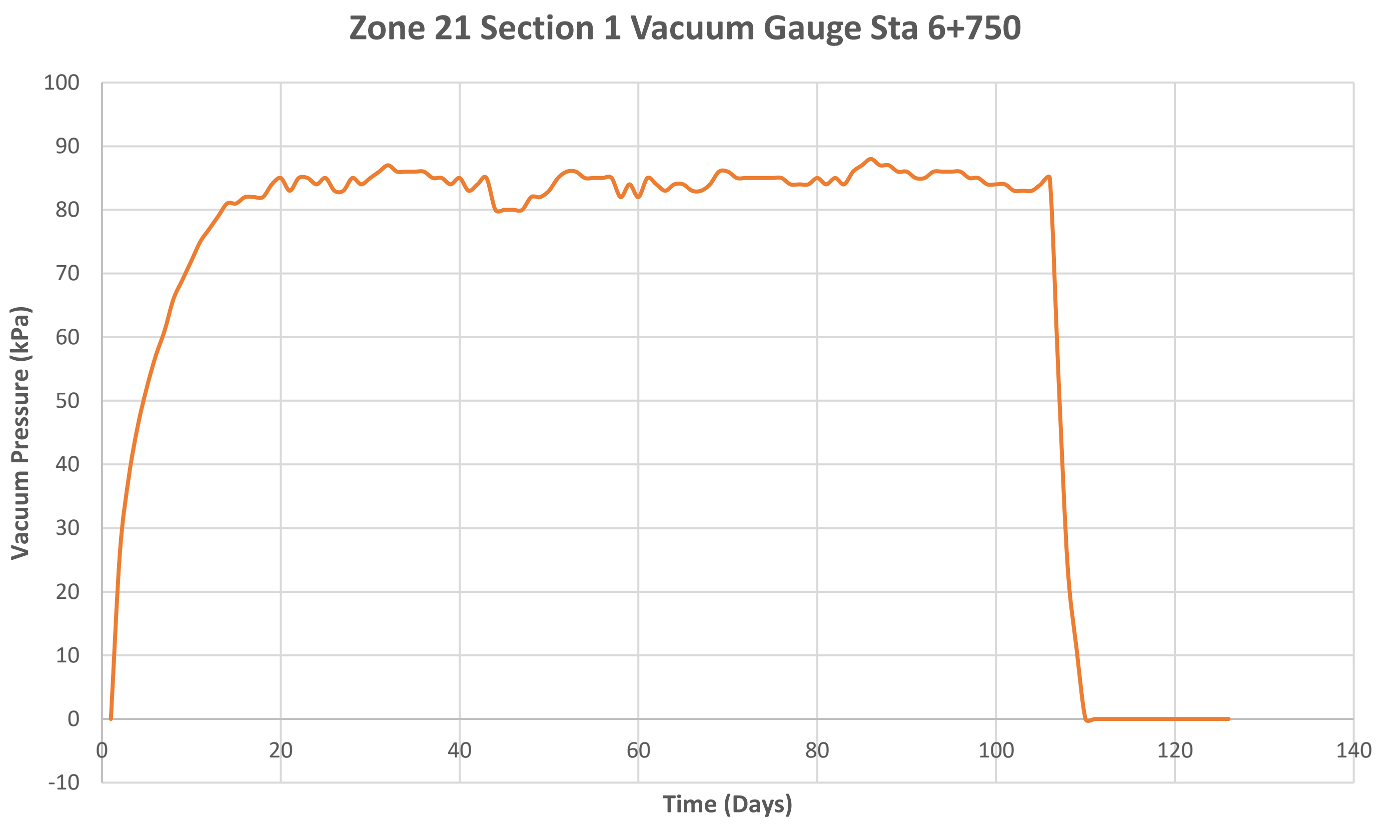
Attachment 7 Vacuum Gauge VG.01 Monitoring Data

Day no.	Pressure	Day no.	Pressure	Day no.	Pressure	Day no.	Pressure	Day no.	Pressure	Day no.	Pressure
1	0	24	83	47	80	70	87	93	86	116	0
2	25	25	84	48	83	71	86	94	85	117	0
3	38	26	84	49	83	72	86	95	86	118	0
4	45	27	84	50	84	73	86	96	86	119	0
5	51	28	85	51	87	74	86	97	86	120	0
6	56	29	85	52	87	75	86	98	86	121	0
7	61	30	85	53	87	76	86	99	84	122	0
8	65	31	85	54	86	77	86	100	85	123	0
9	68	32	85	55	87	78	86	101	86	124	0
10	71	33	86	56	87	79	87	102	84	125	0
11	74	34	86	57	86	80	86	103	85	126	0
12	76	35	85	58	86	81	87	104	86		
13	78	36	86	59	86	82	86	105	85		
14	80	37	86	60	84	83	87	106	84		
15	80	38	86	61	86	84	87	107	55		
16	81	39	87	62	86	85	86	108	27		
17	81	40	87	63	84	86	87	109	12		
18	82	41	85	64	85	87	87	110	0		
19	83	42	85	65	84	88	86	111	0		
20	84	43	86	66	84	89	85	112	0		
21	83	44	82	67	84	90	85	113	0		
22	83	45	80	68	85	91	84	114	0		
23	84	46	81	69	87	92	84	115	0		


Zone 21 Section 1 Vacuum Gauge Sta 6+650
Vacuum Pressure (kPa)
100
90
80
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
Time (Days)

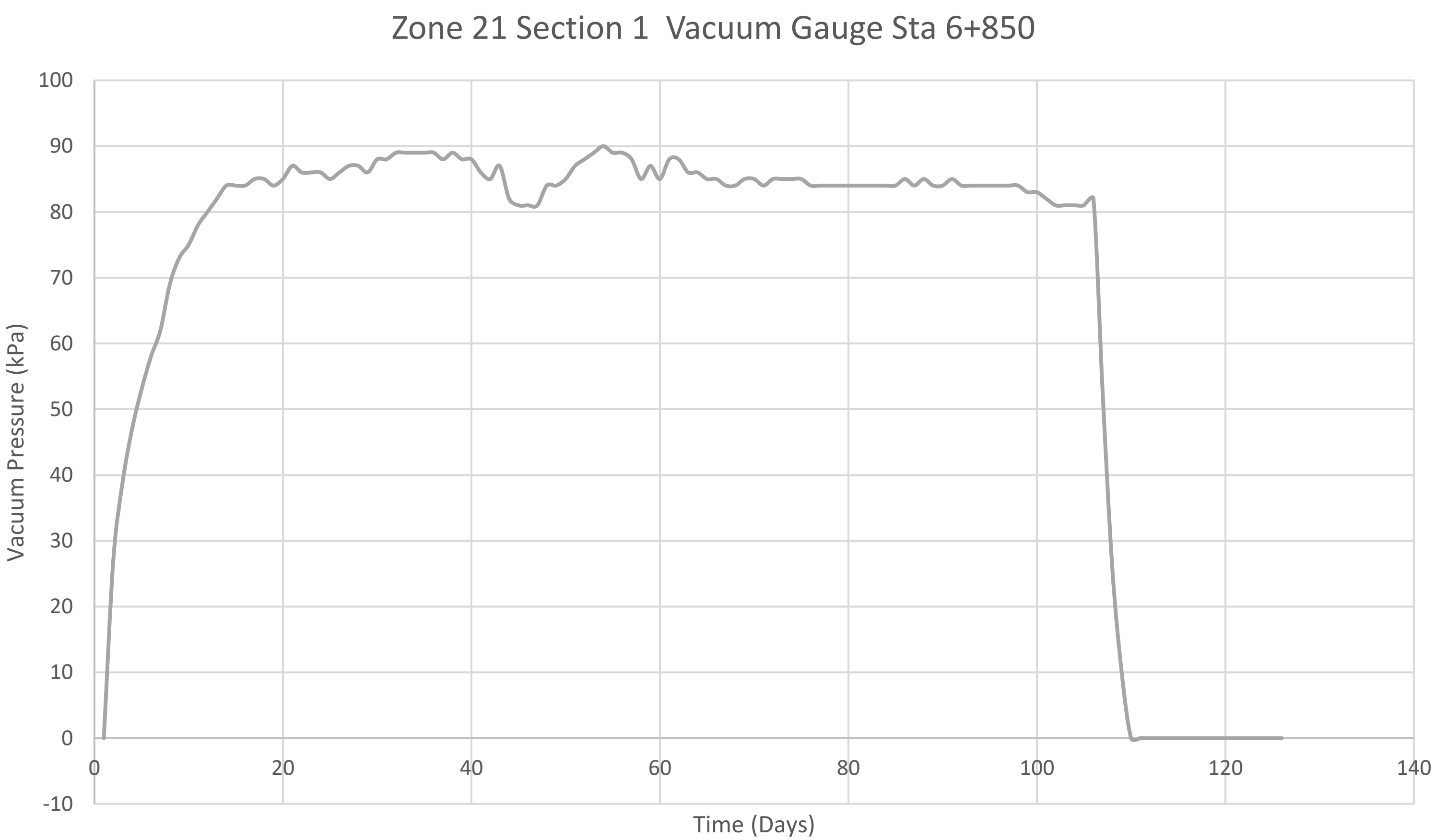
Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)
1	0	24	84	47	80	70	86	93	86	116	0
2	26	25	85	48	82	71	85	94	86	117	0
3	38	26	83	49	82	72	85	95	86	118	0
4	46	27	83	50	83	73	85	96	86	119	0
5	52	28	85	51	85	74	85	97	85	120	0
6	57	29	84	52	86	75	85	98	85	121	0
7	61	30	85	53	86	76	85	99	84	122	0
8	66	31	86	54	85	77	84	100	84	123	0
9	69	32	87	55	85	78	84	101	84	124	0
10	72	33	86	56	85	79	84	102	83	125	0
11	75	34	86	57	85	80	85	103	83	126	0
12	77	35	86	58	82	81	84	104	83		
13	79	36	86	59	84	82	85	105	84		
14	81	37	85	60	82	83	84	106	85		
15	81	38	85	61	85	84	86	107	53		
16	82	39	84	62	84	85	87	108	24		
17	82	40	85	63	83	86	88	109	11		
18	82	41	83	64	84	87	87	110	0		
19	84	42	84	65	84	88	87	111	0		
20	85	43	85	66	83	89	86	112	0		
21	83	44	80	67	83	90	86	113	0		
22	85	45	80	68	84	91	85	114	0		
23	85	46	80	69	86	92	85	115	0		

Attachment 8 Vacuum Gauge VG.02 Monitoring Data



Attachment 9 Vacuum Gauge VG.03 Monitoring Data

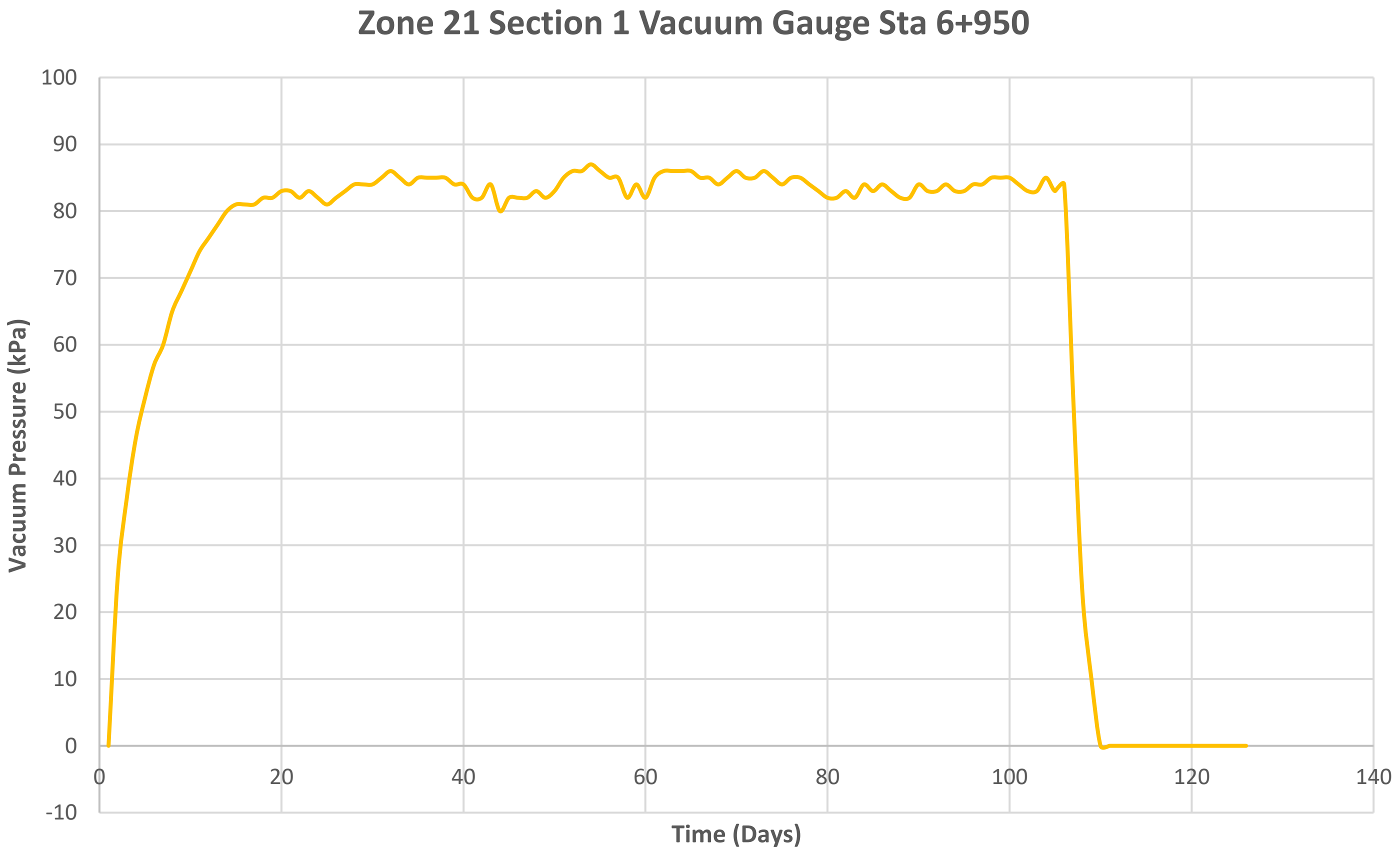
Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)
1	0	24	86	47	81	70	85	93	84	116	0
2	27	25	85	48	84	71	84	94	84	117	0
3	39	26	86	49	84	72	85	95	84	118	0
4	47	27	87	50	85	73	85	96	84	119	0
5	53	28	87	51	87	74	85	97	84	120	0
6	58	29	86	52	88	75	85	98	84	121	0
7	62	30	88	53	89	76	84	99	83	122	0
8	69	31	88	54	90	77	84	100	83	123	0
9	73	32	89	55	89	78	84	101	82	124	0
10	75	33	89	56	89	79	84	102	81	125	0
11	78	34	89	57	88	80	84	103	81	126	0
12	80	35	89	58	85	81	84	104	81		
13	82	36	89	59	87	82	84	105	81		
14	84	37	88	60	85	83	84	106	82		
15	84	38	89	61	88	84	84	107	52		
16	84	39	88	62	88	85	84	108	26		
17	85	40	88	63	86	86	85	109	10		
18	85	41	86	64	86	87	84	110	0		
19	84	42	85	65	85	88	85	111	0		
20	85	43	87	66	85	89	84	112	0		
21	87	44	82	67	84	90	84	113	0		
22	86	45	81	68	84	91	85	114	0		
23	86	46	81	69	85	92	84	115	0		

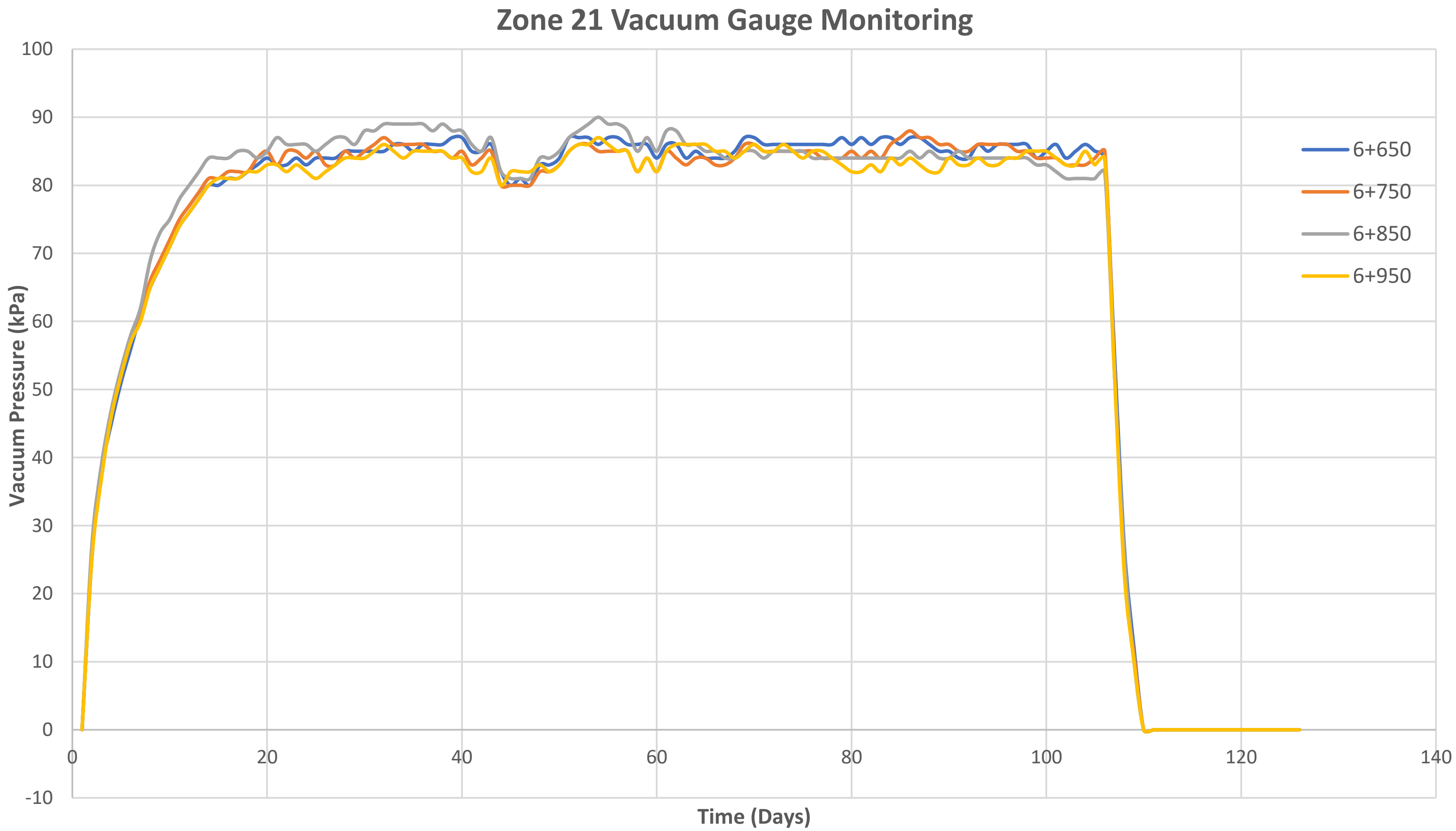


Zone 21 Section 1 Vacuum Gauge Sta 6+850
Vacuum Pressure (kPa)
Time (Days)
100
90
80
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140

Attachment 10 Vacuum Gauge VG.04 Monitoring Data

Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)	Day no.	Pressure (kPa)
1	0	24	82	47	82	70	86	93	84	116	0
2	25	25	81	48	83	71	85	94	83	117	0
3	37	26	82	49	82	72	85	95	83	118	0
4	46	27	83	50	83	73	86	96	84	119	0
5	52	28	84	51	85	74	85	97	84	120	0
6	57	29	84	52	86	75	84	98	85	121	0
7	60	30	84	53	86	76	85	99	85	122	0
8	65	31	85	54	87	77	85	100	85	123	0
9	68	32	86	55	86	78	84	101	84	124	0
10	71	33	85	56	85	79	83	102	83	125	0
11	74	34	84	57	85	80	82	103	83	126	0
12	76	35	85	58	82	81	82	104	85		
13	78	36	85	59	84	82	83	105	83		
14	80	37	85	60	82	83	82	106	84		
15	81	38	85	61	85	84	84	107	52		
16	81	39	84	62	86	85	83	108	23		
17	81	40	84	63	86	86	84	109	10		
18	82	41	82	64	86	87	83	110	0		
19	82	42	82	65	86	88	82	111	0		
20	83	43	84	66	85	89	82	112	0		
21	83	44	80	67	85	90	84	113	0		
22	82	45	82	68	84	91	83	114	0		
23	83	46	82	69	85	92	83	115	0		

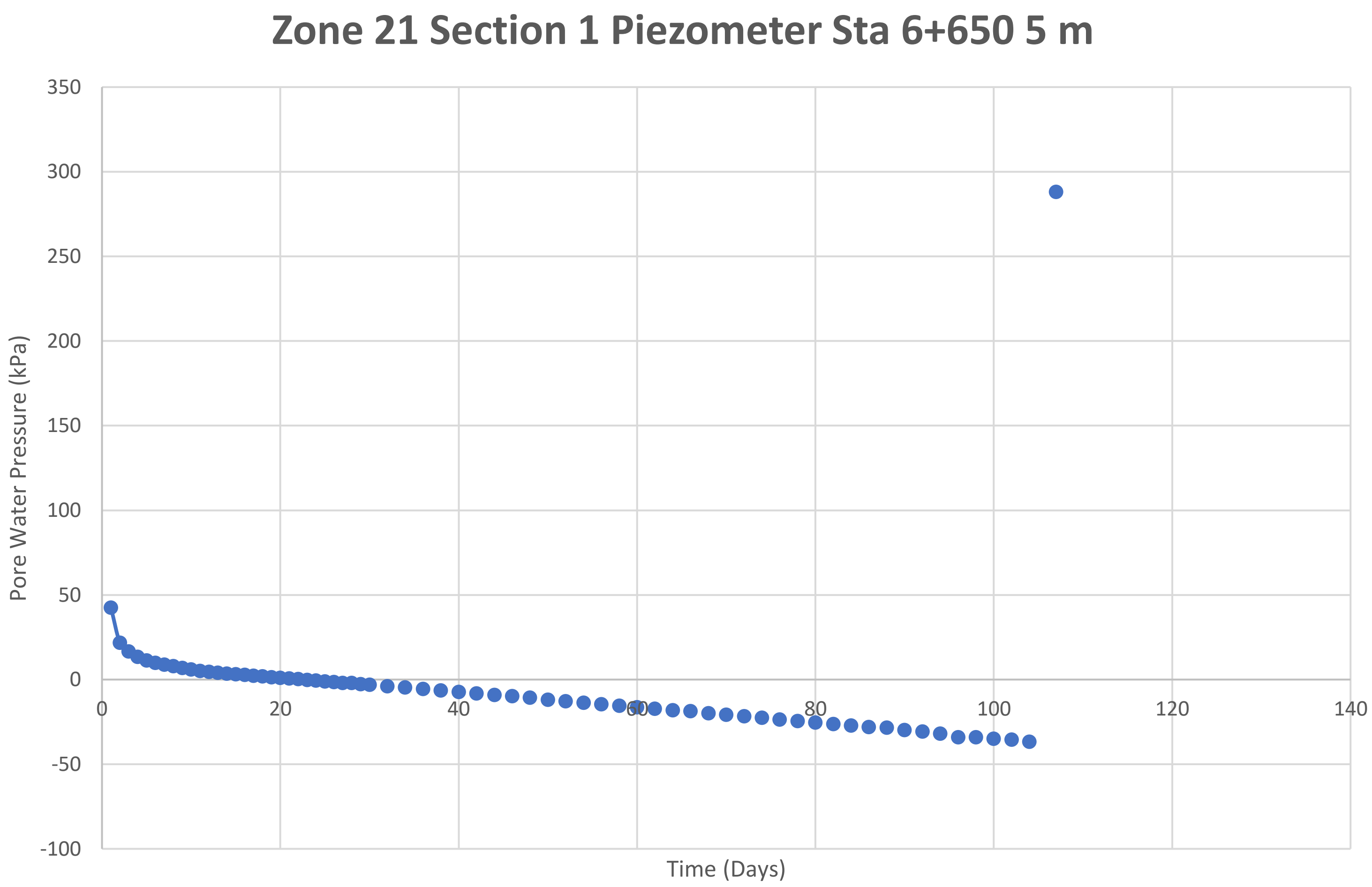

Zone 21 Section 1 Vacuum Gauge Sta 6+950
Vacuum Pressure (kPa)
100
90
80
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
Time (Days)

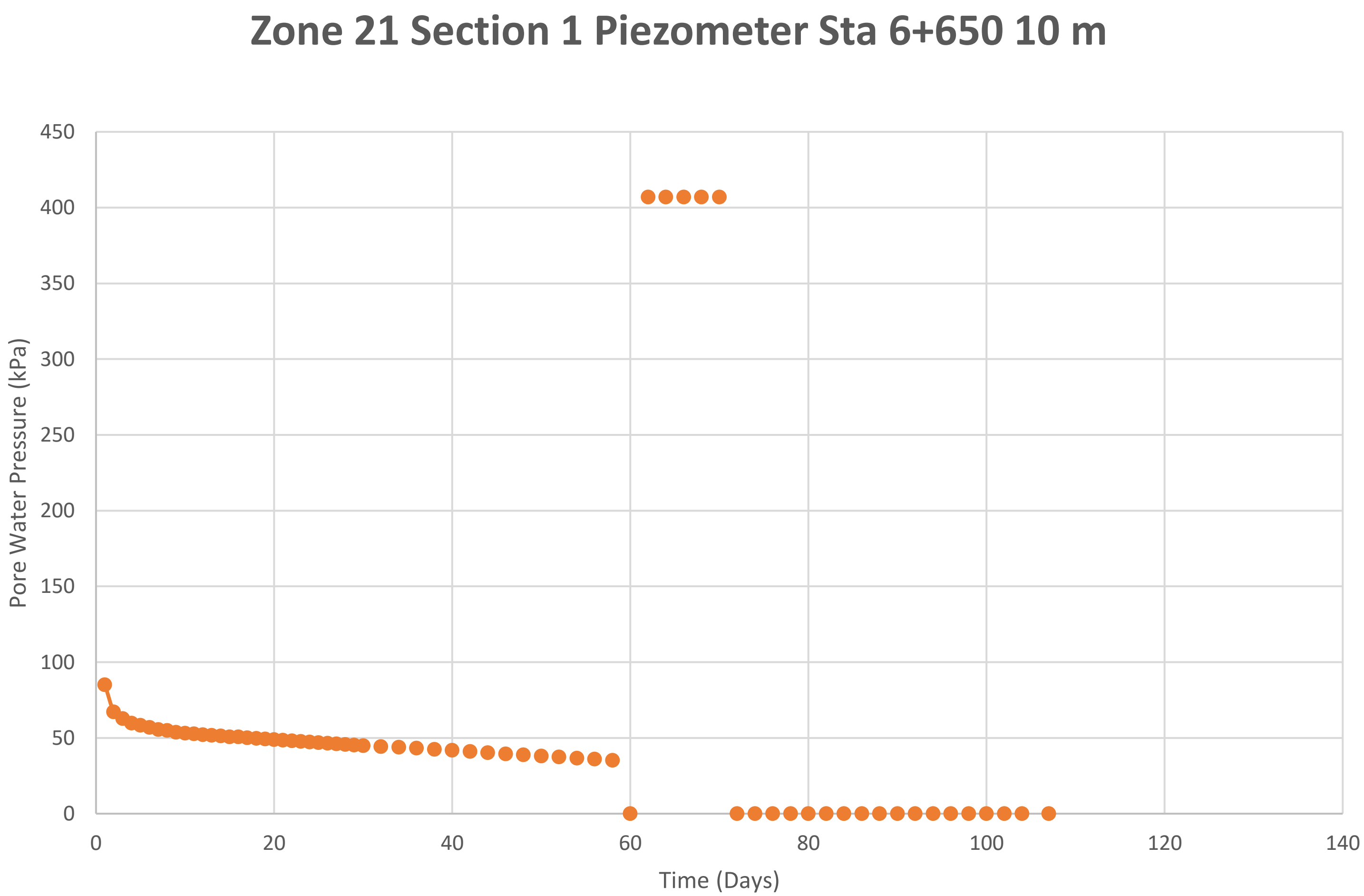

Zone 21 Vacuum Gauge Monitoring
Vacuum Pressure (kPa)
100
90
80
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
Time (Days)
6+650
6+750
6+850
6+950

Attachment 11 Piezometer VWP.01 Monitoring Data

Day no.	Pores Water Pressure		Day no.	Pores Water Pressure		Day no.	Pores Water Pressure	
	Tip 1=10 m	Tip 2=5 m		Tip 1=10 m	Tip 2=5m		Tip 1=10 m	Tip 2=5m
1	85.12	42.58	24	47.29	-0.65	47		
2	67.22	21.78	25	46.94	-1.05	48	38.88	-10.67
3	62.78	16.55	26	46.58	-1.5	49		
4	59.87	13.35	27	46.09	-1.9	50	38.07	-11.97
5	58.31	11.28	28	45.7	-2	51		
6	57.04	9.95	29	45.34	-2.71	52	37.4	-12.8
7	55.65	8.86	30	44.99	-3.06	53		
8	54.9	7.87	31			54	36.68	-13.71
9	53.81	6.83	32	44.23	-3.86	55		
10	53.19	6.03	33			56	36.01	-14.58
11	52.67	5.09	34	43.92	-4.71	57		
12	52.18	4.54	35			58	35.29	-15.49
13	51.7	4.04	36	43.21	-5.57	59		
14	51.3	3.59	37			60	0	-16.36
15	50.82	3.2	38	42.54	-6.38	61		
16	50.74	2.75	39			62	407.03	-17.17
17	50.12	2.3	40	41.83	-7.23	63		
18	49.76	1.9	41			64	407.03	-18.09
19	49.41	1.45	42	41.07	-8.14	65		
20	48.97	1	43			66	407.03	-18.69
21	48.57	0.6	44	40.36	-9.05	67		
22	48.22	0.25	45			68	407.03	-19.88
23	47.78	-0.2	46	39.55	-9.71	69		

Day no.	Pore Water Pressure		Day no.	Pore Water Pressure		Day no.	Pore Water Pressure	
	Tip 1=10 m	**Tip 2=5 m**		**Tip 1=10 m**	**Tip 2=5m**		**Tip 1=10 m**	**Tip 2=5m**
70	407.03	-20.75	93			116		
71			94	0	-31.98	117		
72	0	-21.62	95			118		
73			96	0	-34.05	119		
74	0	-22.59	97			120		
75			98	0	-34.05	121		
76	0	-23.52	99			122		
77			100	0	-34.88	123		
78	0	-24.49	101			124		
79			102	0	-35.4	125		
80	0	-25.37	103			126		
81			104	0	-36.65			
82	0	-26.24	105					
83			106					
84	0	-27.12	107	0	288.08			
85			108					
86	0	-28.05	109					
87			110					
88	0	-28.39	111					
89			112					
90	0	-29.8	113					
91			114					
92	0	-30.73	115					

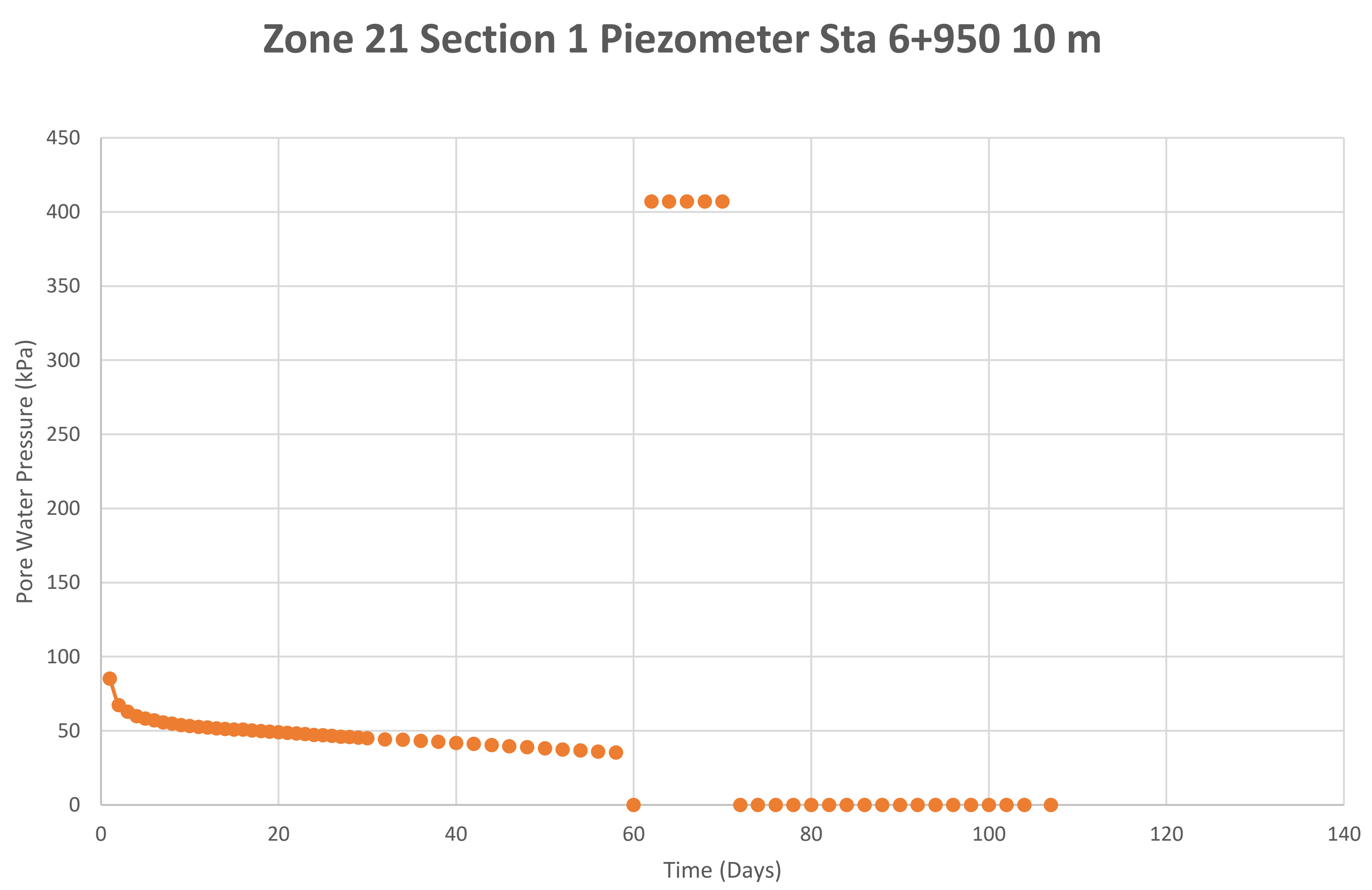

Zone 21 Section 1 Piezometer Sta 6+650 5 m
350
300
250
200
150
100
50
0
-50
-100
Pore Water Pressure (kPa)
0
20
40
60
80
100
120
140
Time (Days)

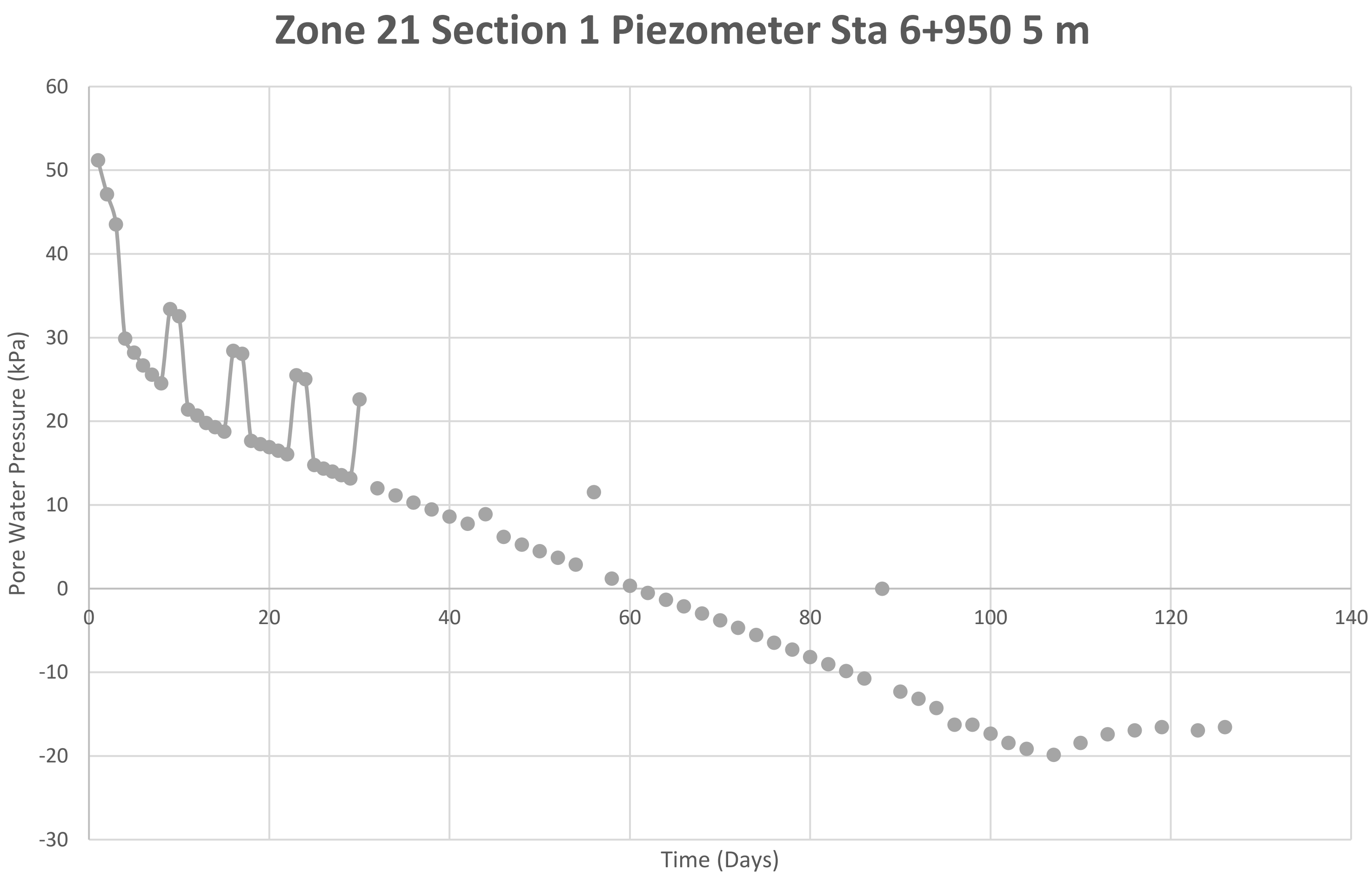

Zone 21 Section 1 Piezometer Sta 6+650 10 m
Pore Water Pressure (kPa)
450
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Time (Days)

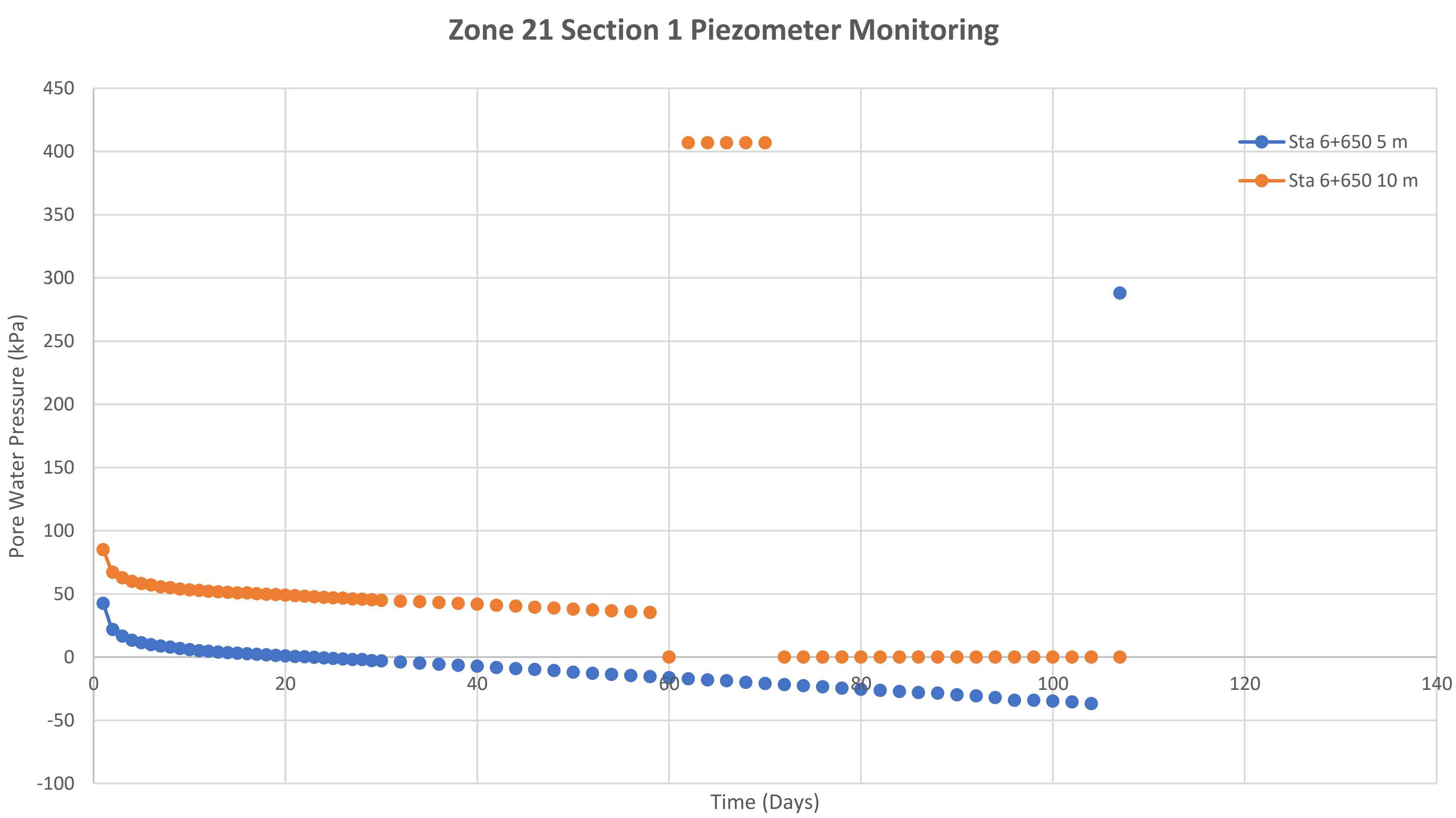
Attachment 12 Piezometer VWP.02 Monitoring Data

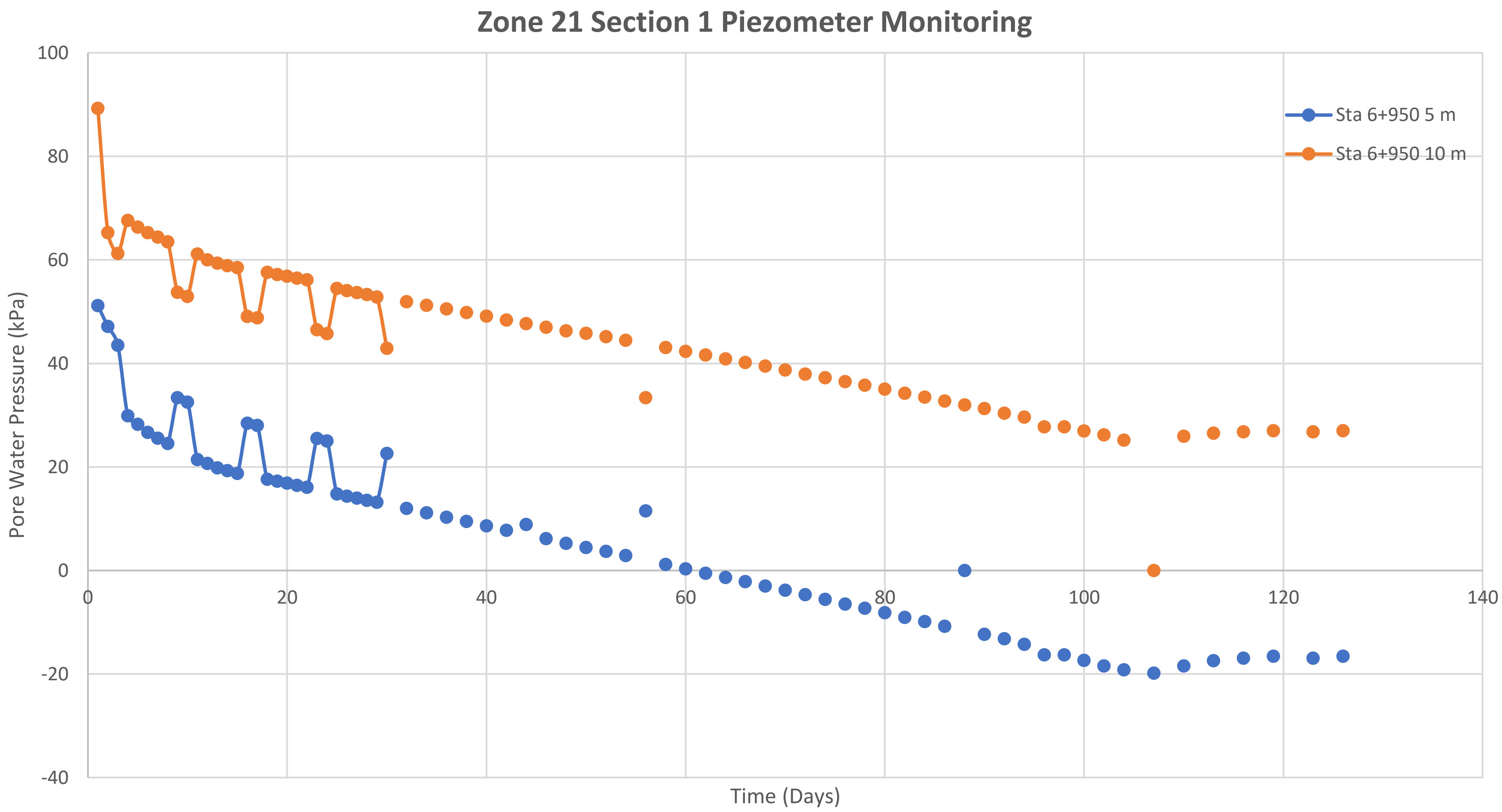
Day no.	Pore Water Pressure		Day no.	Pore Water Pressure		Day no.	Pore Water Pressure	
	Tip 1=10 m	Tip 2=5 m		Tip 1=10 m	Tip 2=5m		Tip 1=10 m	Tip 2=5m
1	89.29	51.18	24	45.78	25.04	47		
2	65.29	47.13	25	54.52	14.78	48	46.27	5.27
3	61.26	43.53	26	54.07	14.35	49		
4	67.6	29.89	27	53.7	13.97	50	45.81	4.46
5	66.32	28.22	28	53.29	13.55	51		
6	65.24	26.68	29	52.84	13.17	52	45.15	3.69
7	64.39	25.57	30	42.94	22.61	53		
8	63.51	24.54	31			54	44.49	2.88
9	53.72	33.4	32	51.9	11.98	55		
10	52.93	32.54	33			56	33.4	11.53
11	61.13	21.41	34	51.25	11.13	57		
12	60.04	20.7	35			58	43.08	1.2
13	59.35	19.81	36	50.55	10.28	59		
14	58.87	19.3	37			60	42.33	0.34
15	58.54	18.78	38	49.85	9.47	61		
16	49.1	28.43	39			62	41.63	-0.53
17	48.79	28.05	40	49.11	8.61	63		
18	57.61	17.65	41			64	40.88	-1.35
19	57.2	17.27	42	48.41	7.75	65		
20	56.84	16.9	43			66	40.17	-2.12
21	56.47	16.47	44	47.71	8.9	67		
22	56.15	16.05	45			68	39.51	-2.99
23	46.49	25.48	46	47.01	6.18	69		

Day no.	Pore Water Pressure		Day no.	Pore Water Pressure		Day no.	Pore Water Pressure	
	Tip 1=10 m	Tip 2=5 m		Tip 1=10 m	Tip 2=5m		Tip 1=10 m	Tip 2=5m
70	38.75	-3.81	93			116	26.8	-16.95
71			94	29.64	-14.26	117		
72	37.96	-4.68	95			118		
73			96	27.73	-16.27	119	27.01	-16.56
74	37.25	-5.55	97			120		
75			98	27.73	-16.27	121		
76	36.5	-6.47	99			122		
77			100	26.97	-17.35	123	26.8	-16.95
78	35.78	-7.29	101			124		
79			102	26.2	-18.43	125		
80	35.03	-8.17	103			126	27.01	-16.56
81			104	25.18	-19.16			
82	34.23	-9.04	105					
83			106					
84	33.48	-9.87	107	24,72	-19.85			
85			108					
86	32.76	-10.75	109					
87			110	25.95	-18.43			
88	32	0-11.53	111					
89			112					
90	31.29	-12.31	113	26.5	-17.4			
91			114					
92	30.36	-13.18	115					


Zone 21 Section 1 Piezometer Sta 6+950 10 m
Pore Water Pressure (kPa)
450
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Time (Days)


Zone 21 Section 1 Piezometer Sta 6+950 5 m
Pore Water Pressure (kPa)
Time (Days)
60
50
40
30
20
10
0
-10
-20
-30
0
20
40
60
80
100
120
140


Zone 21 Section 1 Piezometer Monitoring
Pore Water Pressure (kPa)
450
400
350
300
250
200
150
100
50
0
-50
-100
0
20
40
60
80
100
120
140
Time (Days)
Sta 6+650 5 m
Sta 6+650 10 m


Zone 21 Section 1 Piezometer Monitoring
100
80
60
40
20
0
-20
-40
0
20
40
60
80
100
120
140
Pore Water Pressure (kPa)
Time (Days)
Sta 6+950 5 m
Sta 6+950 10 m

Attachment 13 Theoretical Settlement Analysis Result STA 6+650

Depth (m)	Cc	e0	γ_w (t/m³)	γ_{sat} (t/m³)	Cs
0-6	0.81	2.78	0.981	1.338	0.135
6-12	0.25	1.187	0.981	1.664	0.042
Average	**0.53**	**1.98**	**1.501**	**0.91**	**0.0885**

Phase	Vacuum Duration		Vacuum			
	From (Day)	Until (Day)	Pressure (kPa)	Δσ' (t/m)	Settlement (mm)	
Existing	0	0	0	0	0	0
I	1	18	82	8.2	283	283
II	19	36	85	8.5	94	377
III	37	54	86	8.6	59	436
IV	55	72	86	8.6	43	480
V	73	90	85	8.5	34	514
VI	91	108	27	2.7	26	541
VII	109	126	0	0	0	541
		Total				**541**

Phase I

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	0,179	2,179	8,3785	3,845994951	0,05969743
2	1	1,5	0,536	2,536	8,7355	3,445277066	0,043304582
3	1	2,5	0,893	2,893	9,0925	3,143474503	0,036002682
4	1	3,5	1,250	3,250	9,4495	2,907985844	0,031381163
5	1	4,5	1,607	3,607	9,8065	2,719118259	0,028058332
6	1	5,5	1,964	3,964	10,1635	2,564274	0,025500442
7	1	6,5	4,440	6,440	12,6395	1,962807671	0,008726395
8	1	7,5	5,123	7,123	13,3225	1,87048087	0,007971814
9	1	8,5	5,806	7,806	14,0055	1,794311703	0,007344891
10	1	9,5	6,489	8,489	14,6885	1,730399953	0,006814354
11	1	10,5	7,172	9,172	15,3715	1,676007196	0,006358693
12	1	11,5	7,855	9,855	16,0545	1,629154194	0,005962545
13	1	12,5	8,538	10,538	16,7375	1,588374852	0,005614593
14	1	13,5	9,221	11,221	17,4205	1,552560046	0,005306291
15	1	14,5	9,904	11,904	18,1035	1,520855211	0,005031048
				Total			0,283075256

Phase II

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	8,3785	10,379	16,8785	1,626294744	0,010863128
2	1	1,5	8,736	10,736	17,2355	1,60546784	0,010540576
3	1	2,5	9,093	11,093	17,5925	1,585981519	0,010237295
4	1	3,5	9,450	11,450	17,9495	1,56771038	0,009951555
5	1	4,5	9,807	11,807	18,3065	1,550544192	0,009681832
6	1	5,5	10,164	12,164	18,6635	1,534385662	0,009426779
7	1	6,5	12,640	14,640	21,1395	1,444004235	0,004289585
8	1	7,5	13,323	15,323	21,8225	1,424212759	0,004115861
9	1	8,5	14,006	16,006	22,5055	1,4061104	0,003955913
10	1	9,5	14,689	16,689	23,1885	1,389489768	0,003808138
11	1	10,5	15,372	17,372	23,8715	1,374176093	0,003671178
12	1	11,5	16,055	18,055	24,5545	1,360021047	0,003543869
13	1	12,5	16,738	18,738	25,2375	1,346897932	0,003425213
14	1	13,5	17,421	19,421	25,9205	1,334697871	0,003314347
15	1	14,5	18,104	20,104	26,6035	1,323326784	0,003210517
				Total			0,094035784

Phase III

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	16,879	18,879	25,4785	1,349604047	0,006326146
2	1	1,5	17,236	19,236	25,8355	1,343115594	0,006218169
3	1	2,5	17,593	19,593	26,1925	1,336863596	0,006113862
4	1	3,5	17,950	19,950	26,5495	1,330835359	0,00601304
5	1	4,5	18,307	20,307	26,9065	1,325019083	0,005915528
6	1	5,5	18,664	20,664	27,2635	1,31940378	0,005821166
7	1	6,5	21,140	23,140	29,7395	1,285226561	0,002818747
8	1	7,5	21,823	23,823	30,4225	1,277049008	0,002743549
9	1	8,5	22,506	24,506	31,1055	1,269327294	0,002672292
10	1	9,5	23,189	25,189	31,7885	1,262024337	0,002604673
11	1	10,5	23,872	25,872	32,4715	1,255106971	0,002540416
12	1	11,5	24,555	26,555	33,1545	1,248545444	0,002479277
13	1	12,5	25,238	27,238	33,8375	1,242312988	0,002421031
14	1	13,5	25,921	27,921	34,5205	1,236385452	0,002365478
15	1	14,5	26,604	28,604	35,2035	1,230740993	0,002312432
				Total			0,059365806

Phase IV

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	25,479	27,479	34,0785	1,240187783	0,004510951
2	1	1,5	25,836	27,836	34,4355	1,237107291	0,004456769
3	1	2,5	26,193	28,193	34,7925	1,234104815	0,004403882
4	1	3,5	26,550	28,550	35,1495	1,231177429	0,004352243
5	1	4,5	26,907	28,907	35,5065	1,22832235	0,004301809
6	1	5,5	27,264	29,264	35,8635	1,225536932	0,004252538
7	1	6,5	29,740	31,740	38,3395	1,207942784	0,00211849
8	1	7,5	30,423	32,423	39,0225	1,203562341	0,002076382
9	1	8,5	31,106	33,106	39,7055	1,199362644	0,002035924
10	1	9,5	31,789	33,789	40,3885	1,195332732	0,00199702
11	1	10,5	32,472	34,472	41,0715	1,191462513	0,001959582
12	1	11,5	33,155	35,155	41,7545	1,187742679	0,001923527
13	1	12,5	33,838	35,838	42,4375	1,184164632	0,001888781
14	1	13,5	34,521	36,521	43,1205	1,180720417	0,001855273
15	1	14,5	35,204	37,204	43,8035	1,177402664	0,001822938
			Total				0,043956107

Phase V

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	34,079	36,079	42,5785	1,180162701	0,003453925
2	1	1,5	34,436	36,436	42,9355	1,178397442	0,00342179
3	1	2,5	34,793	36,793	43,2925	1,17666644	0,003390251
4	1	3,5	35,150	37,150	43,6495	1,174968708	0,00335929
5	1	4,5	35,507	37,507	44,0065	1,173303294	0,003328892
6	1	5,5	35,864	37,864	44,3635	1,171669286	0,00329904
7	1	6,5	38,340	40,340	46,8395	1,161132389	0,001670125
8	1	7,5	39,023	41,023	47,5225	1,158449631	0,001643592
9	1	8,5	39,706	41,706	48,2055	1,155854743	0,001617892
10	1	9,5	40,389	42,389	48,8885	1,153343478	0,001592985
11	1	10,5	41,072	43,072	49,5715	1,150911856	0,001568835
12	1	11,5	41,755	43,755	50,2545	1,148556149	0,001545409
13	1	12,5	42,438	44,438	50,9375	1,146272855	0,001522674
14	1	13,5	43,121	45,121	51,6205	1,144058687	0,001500601
15	1	14,5	43,804	45,804	52,3035	1,141910553	0,001479159
				Total			0,034394461

Phase VI

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	42,579	44,579	45,2785	1,015702637	0,000953631
2	1	1,5	42,936	44,936	45,6355	1,015577884	0,002801659
3	1	2,5	43,293	45,293	45,9925	1,015455097	0,002780507
4	1	3,5	43,650	45,650	46,3495	1,015334231	0,002759674
5	1	4,5	44,007	46,007	46,7065	1,015215241	0,002739151
6	1	5,5	44,364	46,364	47,0635	1,015098084	0,002718933
7	1	6,5	46,840	48,840	49,5395	1,014332661	0,001390839
8	1	7,5	47,523	49,523	50,2225	1,014134989	0,001372407
9	1	8,5	48,206	50,206	50,9055	1,013942696	0,001354459
10	1	9,5	48,889	50,889	51,5885	1,013755564	0,001336974
11	1	10,5	49,572	51,572	52,2715	1,013573388	0,001319937
12	1	11,5	50,255	52,255	52,9545	1,013395975	0,001303329
13	1	12,5	50,938	52,938	53,6375	1,01322314	0,001287134
14	1	13,5	51,621	53,621	54,3205	1,013054709	0,001271338
15	1	14,5	52,304	54,304	55,0035	1,012890514	0,001255925
			Total				0,026645897

Attachment 14 Theoretical Settlement Analysis Result STA 6+750

Depth (m)	Cc	e0	γ_w (t/m³)	γ_{sat} (t/m³)	Cs
0-6	0.81	2.78	0.981	1,338	0,135
6-12	0.25	1.187	0.981	1,664	0,042
Average	**0.53**	**1.98**	**1.54**	**1,501**	**0.0885**

Phase	Vacuum Duration		Vacuum Pressure (kPa)	Δσ' (t/m)	Settlement (mm)	
	From (Day)	Until (Day)				
Existing	0	0	0	0	0	0
I	1	18	82	8.2	283	283
II	19	36	86	8.6	95	378
III	37	54	85	8.5	60	438
IV	55	72	85	8.5	44	481
V	73	90	86	8.6	35	516
VI	91	108	24	2.4	27	543
VII	109	126	0	0	0	543
			Total			**543**

Phase I

No	**H (m)**	**Z (m)**	**σ′₀**	**σ′c**	**σ′₀ + Δσ**	**(σ′₀ + Δσ)/σ′₀**	**Sc (m)**
1	1	0,5	0,179	2,179	8,3785	3,845994951	0,05969743
2	1	1,5	0,536	2,536	8,7355	3,445277066	0,043304582
3	1	2,5	0,893	2,893	9,0925	3,143474503	0,036002682
4	1	3,5	1,250	3,250	9,4495	2,907985844	0,031381163
5	1	4,5	1,607	3,607	9,8065	2,719118259	0,028058332
6	1	5,5	1,964	3,964	10,1635	2,564274	0,025500442
7	1	6,5	4,440	6,440	12,6395	1,962807671	0,008726395
8	1	7,5	5,123	7,123	13,3225	1,87048087	0,007971814
9	1	8,5	5,806	7,806	14,0055	1,794311703	0,007344891
10	1	9,5	6,489	8,489	14,6885	1,730399953	0,006814354
11	1	10,5	7,172	9,172	15,3715	1,676007196	0,006358693
12	1	11,5	7,855	9,855	16,0545	1,629154194	0,005962545
13	1	12,5	8,538	10,538	16,7375	1,588374852	0,005614593
14	1	13,5	9,221	11,221	17,4205	1,552560046	0,005306291
15	1	14,5	9,904	11,904	18,1035	1,520855211	0,005031048
				Total			0,283075256

Phase II

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	8,379	10,379	16,9785	1,635930048	0,010954752
2	1	1,5	8,736	10,736	17,3355	1,61478273	0,010630307
3	1	2,5	9,093	11,093	17,6925	1,594996619	0,010325211
4	1	3,5	9,450	11,450	18,0495	1,576444386	0,010037727
5	1	4,5	9,807	11,807	18,4065	1,559014102	0,009766328
6	1	5,5	10,164	12,164	18,7635	1,54260698	0,009509663
7	1	6,5	12,640	14,640	21,2395	1,45083507	0,004328946
8	1	7,5	13,323	15,323	21,9225	1,430739109	0,004153993
9	1	8,5	14,006	16,006	22,6055	1,412358252	0,00399289
10	1	9,5	14,689	16,689	23,2885	1,395481919	0,003844029
11	1	10,5	15,372	17,372	23,9715	1,379932648	0,003706043
12	1	11,5	16,055	18,055	24,6545	1,365559833	0,003577767
13	1	12,5	16,738	18,738	25,3375	1,352234823	0,003458195
14	1	13,5	17,421	19,421	26,0205	1,339847069	0,003346461
15	1	14,5	18,104	20,104	26,7035	1,328301042	0,003241809
			Total				0,09487412

Phase III

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	16,979	18,979	25,4785	1,342492821	0,006356277
2	1	1,5	17,336	19,336	25,8355	1,336169222	0,006248509
3	1	2,5	17,693	19,693	26,1925	1,330074902	0,006144381
4	1	3,5	18,050	20,050	26,5495	1,324197611	0,00604371
5	1	4,5	18,407	20,407	26,9065	1,31852596	0,005946325
6	1	5,5	18,764	20,764	27,2635	1,313049341	0,005852064
7	1	6,5	21,240	23,240	29,7395	1,279696207	0,002835475
8	1	7,5	21,923	23,923	30,4225	1,271710733	0,002760247
9	1	8,5	22,606	24,606	31,1055	1,26416858	0,002688942
10	1	9,5	23,289	25,289	31,7885	1,25703383	0,002621257
11	1	10,5	23,972	25,972	32,4715	1,250274339	0,002556921
12	1	11,5	24,655	26,655	33,1545	1,243861262	0,002495692
13	1	12,5	25,338	27,338	33,8375	1,237768633	0,002437346
14	1	13,5	26,021	28,021	34,5205	1,23197302	0,002381684
15	1	14,5	26,704	28,704	35,2035	1,22645322	0,002328524
			Total				0,059697354

Phase IV

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	25,479	27,479	33,9785	1,236548574	0,00446537
2	1	1,5	25,836	27,836	34,3355	1,233514756	0,004411661
3	1	2,5	26,193	28,193	34,6925	1,230557772	0,004359237
4	1	3,5	26,550	28,550	35,0495	1,22767474	0,004308053
5	1	4,5	26,907	28,907	35,4065	1,22486292	0,004258064
6	1	5,5	27,264	29,264	35,7635	1,222119705	0,004209229
7	1	6,5	29,740	31,740	38,2395	1,204792136	0,002096707
8	1	7,5	30,423	32,423	38,9225	1,200478063	0,002054982
9	1	8,5	31,106	33,106	39,6055	1,196341998	0,002014892
10	1	9,5	31,789	33,789	40,2885	1,192373145	0,001976344
11	1	10,5	32,472	34,472	40,9715	1,188561565	0,00193925
12	1	11,5	33,155	35,155	41,6545	1,184898093	0,001903528
13	1	12,5	33,838	35,838	42,3375	1,181374259	0,001869104
14	1	13,5	34,521	36,521	43,0205	1,177982229	0,001835908
15	1	14,5	35,204	37,204	43,7035	1,174714745	0,001803876
				Total			0,043506205

Phase V

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	33,979	35,979	42,5785	1,18344289	0,003499506
2	1	1,5	34,336	36,336	42,9355	1,181640544	0,003466898
3	1	2,5	34,693	36,693	43,2925	1,179873271	0,003434895
4	1	3,5	35,050	37,050	43,6495	1,178140056	0,00340348
5	1	4,5	35,407	37,407	44,0065	1,176439924	0,003372637
6	1	5,5	35,764	37,764	44,3635	1,174771936	0,00334235
7	1	6,5	38,240	40,240	46,8395	1,164017943	0,001691908
8	1	7,5	38,923	40,923	47,5225	1,161280469	0,001664993
9	1	8,5	39,606	41,606	48,2055	1,158632873	0,001638924
10	1	9,5	40,289	42,289	48,8885	1,156070799	0,001613661
11	1	10,5	40,972	42,972	49,5715	1,15359017	0,001589167
12	1	11,5	41,655	43,655	50,2545	1,151187163	0,001565408
13	1	12,5	42,338	44,338	50,9375	1,14885819	0,001542351
14	1	13,5	43,021	45,021	51,6205	1,146599882	0,001519965
15	1	14,5	43,704	45,704	52,3035	1,144409072	0,001498221
			Total				0,034844363

Phase VI

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	42,579	44,579	44,9785	1,008972935	0,000850522
2	1	1,5	42,936	44,936	45,3355	1,008901648	0,002831785
3	1	2,5	43,293	45,293	45,6925	1,008831484	0,002810426
4	1	3,5	43,650	45,650	46,0495	1,008762418	0,002789388
5	1	4,5	44,007	46,007	46,4065	1,008694424	0,002768664
6	1	5,5	44,364	46,364	46,7635	1,008627476	0,002748246
7	1	6,5	46,840	48,840	49,2395	1,008190092	0,001405897
8	1	7,5	47,523	49,523	49,9225	1,008077137	0,001387281
9	1	8,5	48,206	50,206	50,6055	1,007967255	0,001369154
10	1	9,5	48,889	50,889	51,2885	1,007860322	0,001351495
11	1	10,5	49,572	51,572	51,9715	1,007756222	0,001334286
12	1	11,5	50,255	52,255	52,6545	1,007654843	0,001317512
13	1	12,5	50,938	52,938	53,3375	1,00755608	0,001301154
14	1	13,5	51,621	53,621	54,0205	1,007459833	0,001285199
15	1	14,5	52,304	54,304	54,7035	1,007366008	0,001269631
			Total				0,026820639

Attachment 15 Theoretical Settlement Analysis Result STA 6+850

Depth (m)	**Cc**	**e0**	**γ_w (t/m^3)**	**γ_{sat} (t/m^3)**	**Cs**
0-6	0,81	2,78	0,981	1,338	0,135
6-12	0,25	1,187	0,981	1,664	0,042
Average	**0,53**	**1,9835**	**0,981**	**1,501**	**0,0885**

Phase	**Vacuum Duration**		**Vacuum**			
	From (Day)	**Until (Day)**	**Pressure (kPa)**	**Δσ' (t/m)**	**Settlement (mm)**	
Existing	0	0	0	0	0	0
I	1	18	85	8.5	287	287
II	19	36	89	8.9	95	382
III	37	54	90	9	59	442
IV	55	72	85	8.5	42	484
V	73	90	84	8.4	33	518
VI	91	108	26	2.6	25	543
VII	109	126	0	0	0	543
			Total			**561**

Phase I

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ +Δσ	(σ′₀ +Δσ)/σ′₀	Sc (m)
1	1	0,5	0,179	2,179	8,679	3,983704384	0,060243087
2	1	1,5	0,536	2,536	9,0355	3,563596924	0,043828311
3	1	2,5	0,893	2,893	9,3925	3,247191011	0,036506178
4	1	3,5	1,250	3,250	9,7495	3,00030774	0,031865932
5	1	4,5	1,607	3,607	10,1065	2,8023014	0,028525716
6	1	5,5	1,964	3,964	10,4635	2,639964678	0,025951645
7	1	6,5	4,440	6,440	12,9395	2,009395139	0,008922041
8	1	7,5	5,123	7,123	13,6225	1,912600913	0,008157542
9	1	8,5	5,806	7,806	14,3055	1,832746141	0,007521657
10	1	9,5	6,489	8,489	14,9885	1,765741886	0,006982982
11	1	10,5	7,172	9,172	15,6715	1,708717222	0,006519901
12	1	11,5	7,855	9,855	16,3545	1,659597138	0,006116958
13	1	12,5	8,538	10,538	17,0375	1,616844603	0,00576276
14	1	13,5	9,221	11,221	17,7205	1,579296823	0,005448698
15	1	14,5	9,904	11,904	18,4035	1,546057882	0,005168126
				Total			0,287521535

Phase II

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	8,679	10,679	17,5785	1,646158168	0,010947755
2	1	1,5	9,036	11,036	17,9355	1,625254859	0,010634332
3	1	2,5	9,393	11,393	18,2925	1,605661619	0,010338995
4	1	3,5	9,750	11,750	18,6495	1,587259032	0,010060173
5	1	4,5	10,107	12,107	19,0065	1,569941767	0,009796477
6	1	5,5	10,464	12,464	19,3635	1,55361656	0,009546674
7	1	6,5	12,940	14,940	21,8395	1,461862847	0,004365642
8	1	7,5	13,623	15,623	22,5225	1,441670667	0,004193466
9	1	8,5	14,306	16,306	23,2055	1,423170096	0,00403461
10	1	9,5	14,989	16,989	23,8885	1,406157106	0,003887558
11	1	10,5	15,672	17,672	24,5715	1,390459214	0,003751023
12	1	11,5	16,355	18,355	25,2545	1,375929609	0,003623897
13	1	12,5	17,038	19,038	25,9375	1,362442548	0,003505228
14	1	13,5	17,721	19,721	26,6205	1,349889709	0,003394188
15	1	14,5	18,404	20,404	27,3035	1,338177274	0,003290056
				Total			0,095370075

Phase III

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	17,579	19,579	26,5785	1,357535051	0,006353984
2	1	1,5	17,936	19,936	26,9355	1,351132402	0,006249864
3	1	2,5	18,293	20,293	27,2925	1,344955033	0,006149145
4	1	3,5	18,650	20,650	27,6495	1,338991259	0,006051662
5	1	4,5	19,007	21,007	28,0065	1,333230191	0,005957258
6	1	5,5	19,364	21,364	28,3635	1,327661666	0,005865789
7	1	6,5	21,840	23,840	30,8395	1,293630319	0,002850971
8	1	7,5	22,523	24,523	31,5225	1,285452136	0,002777418
9	1	8,5	23,206	25,206	32,2055	1,277717165	0,002707598
10	1	9,5	23,889	25,889	32,8885	1,270390328	0,002641231
11	1	10,5	24,572	26,572	33,5715	1,263440152	0,002578065
12	1	11,5	25,255	27,255	34,2545	1,25683832	0,002517871
13	1	12,5	25,938	27,938	34,9375	1,250559284	0,002460445
14	1	13,5	26,621	28,621	35,6205	1,244579934	0,002405597
15	1	14,5	27,304	29,304	36,3035	1,238879315	0,002353157
Total							0,059920055

Phase IV

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	26,579	28,579	35,0785	1,227443708	0,004303948
2	1	1,5	26,936	28,936	35,4355	1,224637556	0,004254054
3	1	2,5	27,293	29,293	35,7925	1,221899804	0,004205311
4	1	3,5	27,650	29,650	36,1495	1,21922798	0,004157679
5	1	4,5	28,007	30,007	36,5065	1,216619732	0,00411112
6	1	5,5	28,364	30,364	36,8635	1,214072818	0,004065598
7	1	6,5	30,840	32,840	39,3395	1,197932368	0,002030317
8	1	7,5	31,523	33,523	40,0225	1,19389962	0,001991179
9	1	8,5	32,206	34,206	40,7055	1,190027919	0,001953529
10	1	9,5	32,889	34,889	41,3885	1,186307809	0,001917282
11	1	10,5	33,572	35,572	42,0715	1,182730557	0,001882361
12	1	11,5	34,255	36,255	42,7545	1,179288088	0,001848695
13	1	12,5	34,938	36,938	43,4375	1,175972927	0,001816217
14	1	13,5	35,621	37,621	44,1205	1,17277814	0,001784864
15	1	14,5	36,304	38,304	44,8035	1,169697286	0,001754579
				Total			0,042076735

Phase V

No	H (m)	Z (m)	σ'_0	$\sigma'c$	$\sigma'_0 + \Delta\sigma$	$(\sigma'_0 + \Delta\sigma)/\sigma'_0$	Sc (m)
1	1	0,5	35,079	37,079	43,4785	1,172606767	0,003329769
2	1	1,5	35,436	37,436	43,8355	1,170960719	0,00329955
3	1	2,5	35,793	37,793	44,1925	1,16934577	0,003269876
4	1	3,5	36,150	38,150	44,5495	1,167761045	0,003240734
5	1	4,5	36,507	38,507	44,9065	1,166205706	0,003212107
6	1	5,5	36,864	38,864	45,2635	1,16467894	0,003183984
7	1	6,5	39,340	41,340	47,7395	1,154815612	0,00161411
8	1	7,5	40,023	42,023	48,4225	1,152299363	0,001589029
9	1	8,5	40,706	42,706	49,1055	1,149863601	0,001564717
10	1	9,5	41,389	43,389	49,7885	1,147504523	0,00154114
11	1	10,5	42,072	44,072	50,4715	1,145218565	0,001518265
12	1	11,5	42,755	44,755	51,1545	1,14300238	0,001496061
13	1	12,5	43,438	45,438	51,8375	1,14085282	0,001474498
14	1	13,5	44,121	46,121	52,5205	1,138766926	0,00145355
15	1	14,5	44,804	46,804	53,2035	1,13674191	0,00143319
Total							0,033220581

Phase VI

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	43,479	45,479	46,0785	1,013193047	0,000900849
2	1	1,5	43,836	45,836	46,4355	1,01309029	0,002719278
3	1	2,5	44,193	46,193	46,7925	1,012989122	0,002699116
4	1	3,5	44,550	46,550	47,1495	1,012889505	0,002679251
5	1	4,5	44,907	46,907	47,5065	1,012791404	0,002659677
6	1	5,5	45,264	47,264	47,8635	1,012694786	0,002640388
7	1	6,5	47,740	49,740	50,3395	1,012062847	0,00135181
8	1	7,5	48,423	50,423	51,0225	1,01189945	0,001334189
9	1	8,5	49,106	51,106	51,7055	1,011740419	0,001317023
10	1	9,5	49,789	51,789	52,3885	1,011585584	0,001300293
11	1	10,5	50,472	52,472	53,0715	1,011434779	0,001283984
12	1	11,5	51,155	53,155	53,7545	1,01128785	0,00126808
13	1	12,5	51,838	53,838	54,4375	1,011144648	0,001252566
14	1	13,5	52,521	54,521	55,1205	1,011005035	0,001237427
15	1	14,5	53,204	55,204	55,8035	1,010868876	0,001222651
				Total			0,025866583

Attachment 16 Theoretical settlement analysis result STA 6+950

Depth (m)	Cc	e0	ϒw (t/m^3)	ϒsat (t/m^3)	Cs
0 - 5	0,81	2,78	0,981	1,338	0,135
6 - 15	0,25	1,187	0,981	1,664	0,042
Average	**0,53**	**1,9835**	**0,981**	**1,501**	**0,0885**

Phase	Vacuum Duration		Vacuum Pressure (kPa)	Δσ' (t/m)	Settlement (mm)	
	From (Day)	Until (Day)				
Existing	0	0	0	0	0	0
I	1	18	82	8.2	283	283
II	19	36	85	8.5	94	377
III	37	54	87	8.7	59	436
IV	55	72	85	8.5	43	479
V	73	90	84	8.4	34	513
VI	91	108	23	2.3	26	540
VII	109	126	0	0	0	540
			Total			**540**

Phase I

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	0,179	2,179	8,3785	3,845994951	0,05969743
2	1	1,5	0,536	2,536	8,7355	3,445277066	0,043304582
3	1	2,5	0,893	2,893	9,0925	3,143474503	0,036002682
4	1	3,5	1,250	3,250	9,4495	2,907985844	0,031381163
5	1	4,5	1,607	3,607	9,8065	2,719118259	0,028058332
6	1	5,5	1,964	3,964	10,1635	2,564274	0,025500442
7	1	6,5	4,440	6,440	12,6395	1,962807671	0,008726395
8	1	7,5	5,123	7,123	13,3225	1,87048087	0,007971814
9	1	8,5	5,806	7,806	14,0055	1,794311703	0,007344891
10	1	9,5	6,489	8,489	14,6885	1,730399953	0,006814354
11	1	10,5	7,172	9,172	15,3715	1,676007196	0,006358693
12	1	11,5	7,855	9,855	16,0545	1,629154194	0,005962545
13	1	12,5	8,538	10,538	16,7375	1,588374852	0,005614593
14	1	13,5	9,221	11,221	17,4205	1,552560046	0,005306291
15	1	14,5	9,904	11,904	18,1035	1,520855211	0,005031048
				Total			0,283075256

Phase II

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	8,379	10,379	16,8785	1,626294744	0,010863128
2	1	1,5	8,736	10,736	17,2355	1,60546784	0,010540576
3	1	2,5	9,093	11,093	17,5925	1,585981519	0,010237295
4	1	3,5	9,450	11,450	17,9495	1,56771038	0,009951555
5	1	4,5	9,807	11,807	18,3065	1,550544192	0,009681832
6	1	5,5	10,164	12,164	18,6635	1,534385662	0,009426779
7	1	6,5	12,640	14,640	21,1395	1,444004235	0,004289585
8	1	7,5	13,323	15,323	21,8225	1,424212759	0,004115861
9	1	8,5	14,006	16,006	22,5055	1,4061104	0,003955913
10	1	9,5	14,689	16,689	23,1885	1,389489768	0,003808138
11	1	10,5	15,372	17,372	23,8715	1,374176093	0,003671178
12	1	11,5	16,055	18,055	24,5545	1,360021047	0,003543869
13	1	12,5	16,738	18,738	25,2375	1,346897932	0,003425213
14	1	13,5	17,421	19,421	25,9205	1,334697871	0,003314347
15	1	14,5	18,104	20,104	26,6035	1,323326784	0,003210517
			Total				0,094035784

Phase III

No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	16,879	18,879	25,5785	1,354901078	0,006326146
2	1	1,5	17,236	19,236	25,9355	1,348314315	0,006218169
3	1	2,5	17,593	19,593	26,2925	1,34196759	0,006113862
4	1	3,5	17,950	19,950	26,6495	1,335848016	0,00601304
5	1	4,5	18,307	20,307	27,0065	1,329943614	0,005915528
6	1	5,5	18,664	20,664	27,3635	1,324243231	0,005821166
7	1	6,5	21,140	23,140	29,8395	1,289548175	0,002818747
8	1	7,5	21,823	23,823	30,5225	1,281246721	0,002743549
9	1	8,5	22,506	24,506	31,2055	1,27340801	0,002672292
10	1	9,5	23,189	25,189	31,8885	1,265994402	0,002604673
11	1	10,5	23,872	25,872	32,5715	1,258972228	0,002540416
12	1	11,5	24,555	26,555	33,2545	1,252311284	0,002479277
13	1	12,5	25,238	27,238	33,9375	1,245984397	0,002421031
14	1	13,5	25,921	27,921	34,6205	1,239967049	0,002365478
15	1	14,5	26,604	28,604	35,3035	1,234237069	0,002312432
				Total			0,059365806

Phase IV

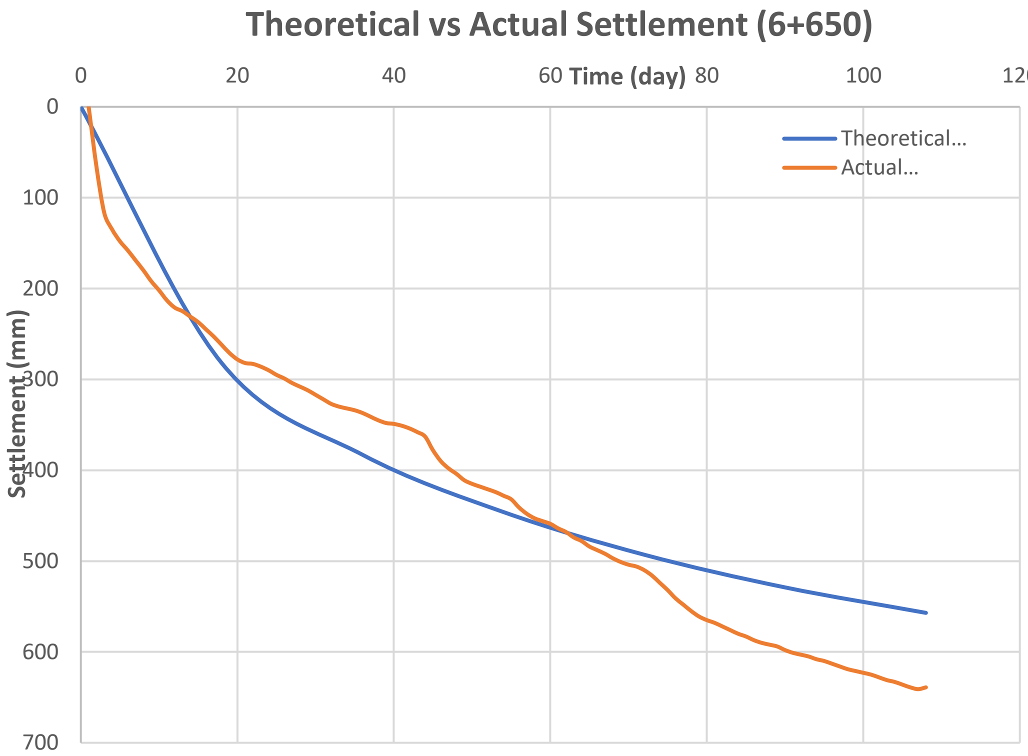
No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	25,579	27,579	34,0785	1,235690846	0,004450193
2	1	1,5	25,936	27,936	34,4355	1,232678849	0,004396849
3	1	2,5	26,293	28,293	34,7925	1,229742865	0,004344777
4	1	3,5	26,650	28,650	35,1495	1,22688005	0,004293932
5	1	4,5	27,007	29,007	35,5065	1,224087704	0,00424427
6	1	5,5	27,364	29,364	35,8635	1,221363257	0,004195751
7	1	6,5	29,840	31,840	38,3395	1,204148934	0,002090492
8	1	7,5	30,523	32,523	39,0225	1,199861634	0,002049012
9	1	8,5	31,206	33,206	39,7055	1,195750704	0,002009154
10	1	9,5	31,889	33,889	40,3885	1,19180548	0,001970824
11	1	10,5	32,572	34,572	41,0715	1,18801614	0,001933936
12	1	11,5	33,255	35,255	41,7545	1,184373626	0,001898409
13	1	12,5	33,938	35,938	42,4375	1,180869565	0,001864169
14	1	13,5	34,621	36,621	43,1205	1,177496211	0,001831147
15	1	14,5	35,304	37,304	43,8035	1,174246384	0,001799279
				Total			0,043372194

Phase V

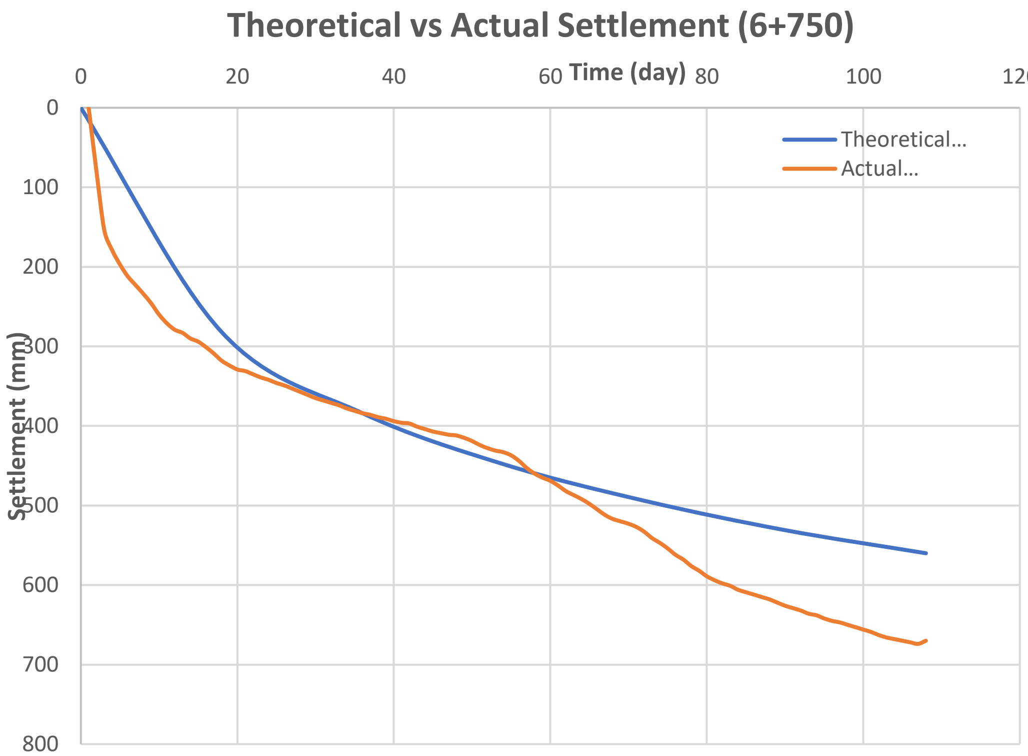
No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	34,079	36,079	42,4785	1,177390967	0,003417454
2	1	1,5	34,436	36,436	42,8355	1,175652866	0,003385623
3	1	2,5	34,793	36,793	43,1925	1,173948495	0,003354382
4	1	3,5	35,150	37,150	43,5495	1,172276881	0,003323715
5	1	4,5	35,507	37,507	43,9065	1,17063709	0,003293606
6	1	5,5	35,864	37,864	44,2635	1,16902822	0,003264039
7	1	6,5	38,340	40,340	46,7395	1,158653429	0,0016523
8	1	7,5	39,023	41,023	47,4225	1,156011945	0,001626023
9	1	8,5	39,706	41,706	48,1055	1,153456978	0,001600572
10	1	9,5	40,389	42,389	48,7885	1,150984347	0,001575907
11	1	10,5	41,072	43,072	49,4715	1,148590135	0,001551993
12	1	11,5	41,755	43,755	50,1545	1,146270669	0,001528796
13	1	12,5	42,438	44,438	50,8375	1,144022504	0,001506285
14	1	13,5	43,121	45,121	51,5205	1,1418424	0,001484428
15	1	14,5	43,804	45,804	52,2035	1,139727313	0,001463198
				Total			0,034028321

Phase VI

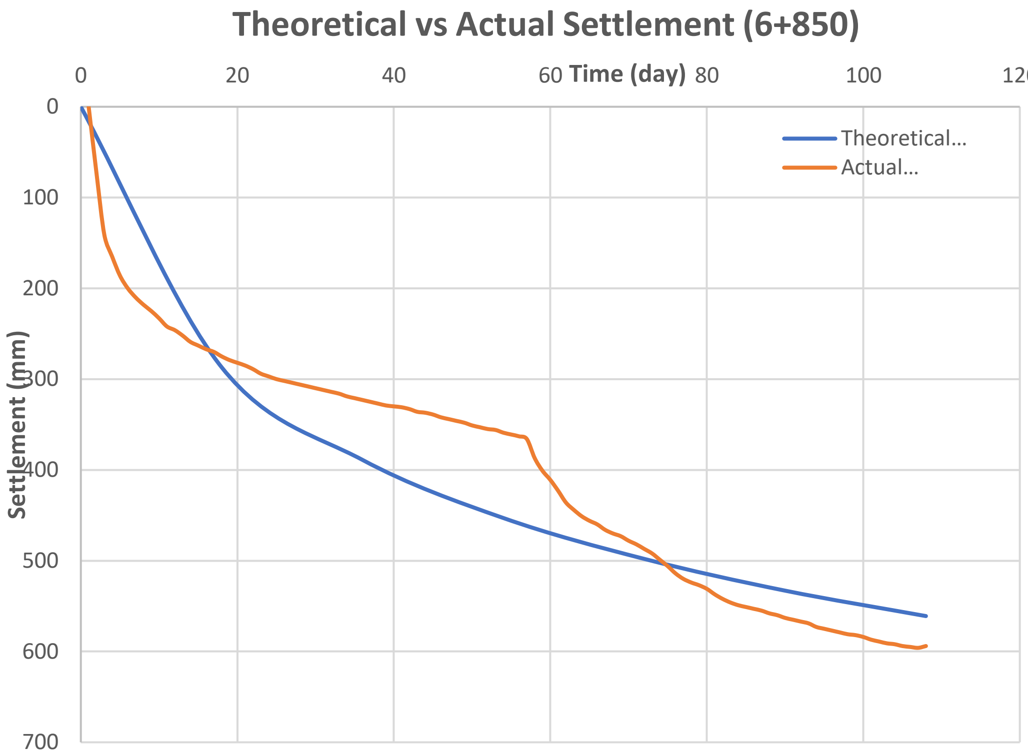
No	H (m)	Z (m)	σ′₀	σ′c	σ′₀ + Δσ	(σ′₀ + Δσ)/σ′₀	Sc (m)
1	1	0,5	42,479	44,479	44,7785	1,006744832	0,00081787
2	1	1,5	42,836	44,836	45,1355	1,006691126	0,002777398
3	1	2,5	43,193	45,193	45,4925	1,00663827	0,002756365
4	1	3,5	43,550	45,550	45,8495	1,006586241	0,00273565
5	1	4,5	43,907	45,907	46,2065	1,006535022	0,002715244
6	1	5,5	44,264	46,264	46,5635	1,006484594	0,002695142
7	1	6,5	46,740	48,740	49,0395	1,006155172	0,001378467
8	1	7,5	47,423	49,423	49,7225	1,00607011	0,001360148
9	1	8,5	48,106	50,106	50,4055	1,005987367	0,00134231
10	1	9,5	48,789	50,789	51,0885	1,005906849	0,001324935
11	1	10,5	49,472	51,472	51,7715	1,005828468	0,001308004
12	1	11,5	50,155	52,155	52,4545	1,00575214	0,001291502
13	1	12,5	50,838	52,838	53,1375	1,005677786	0,001275412
14	1	13,5	51,521	53,521	53,8205	1,005605329	0,001259719
15	1	14,5	52,204	54,204	54,5035	1,005534698	0,001244408
				Total			0,026282575

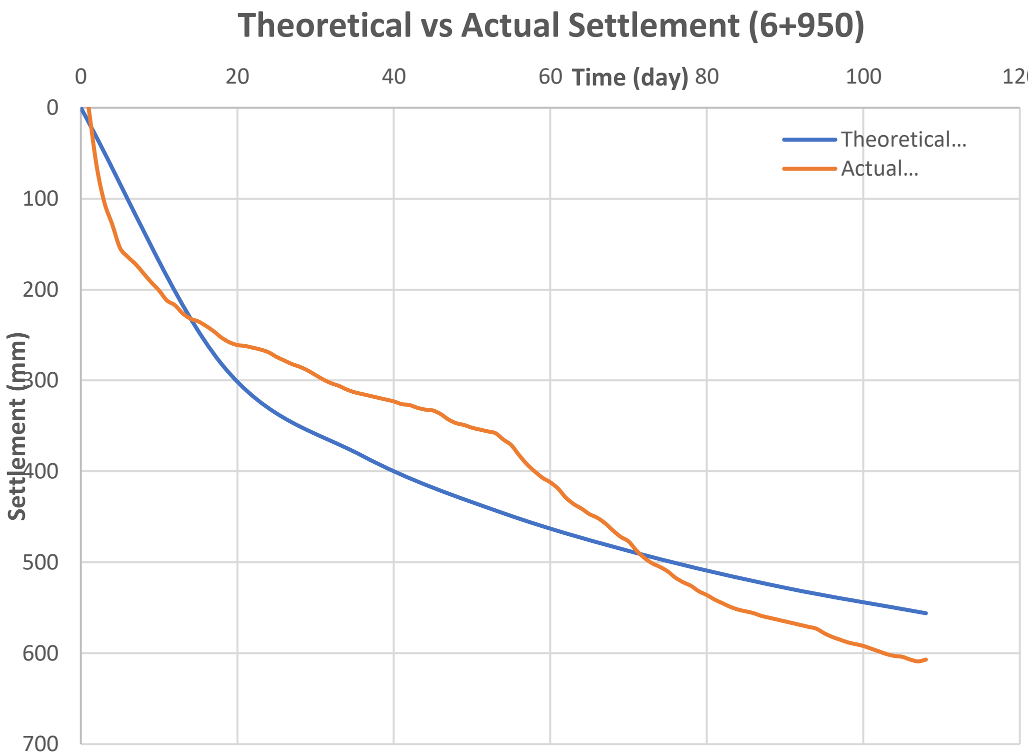


Theoretical vs Actual Settlement (6+650)
Time (day)
0
20
40
60
80
100
120
Settlement (mm)
0
100
200
300
400
500
600
700
Theoretical...
Actual...



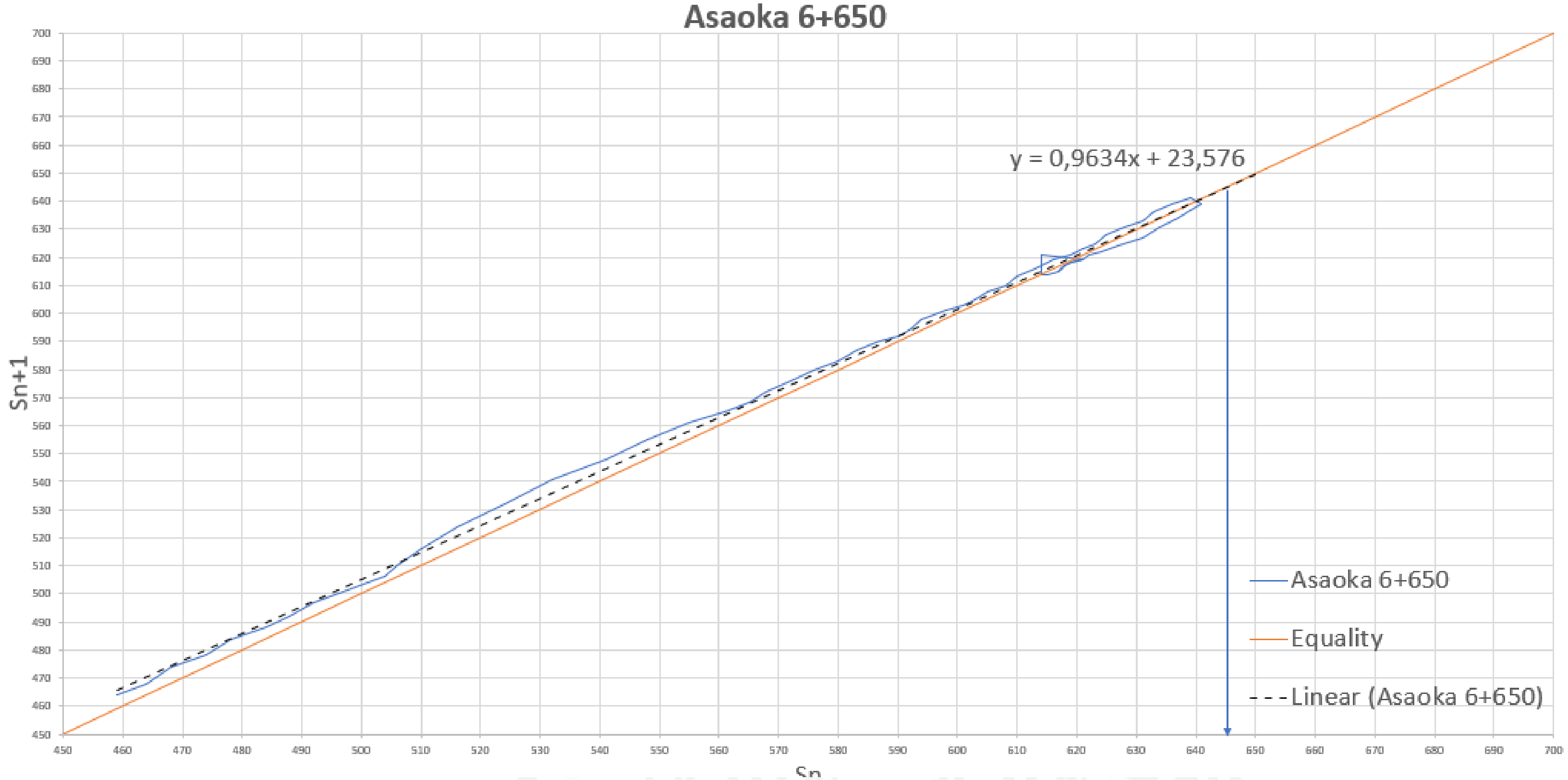
Theoretical vs Actual Settlement (6+750)
Time (day)
0
20
40
60
80
100
120
Settlement (mm)
0
100
200
300
400
500
600
700
800
Theoretical...
Actual...

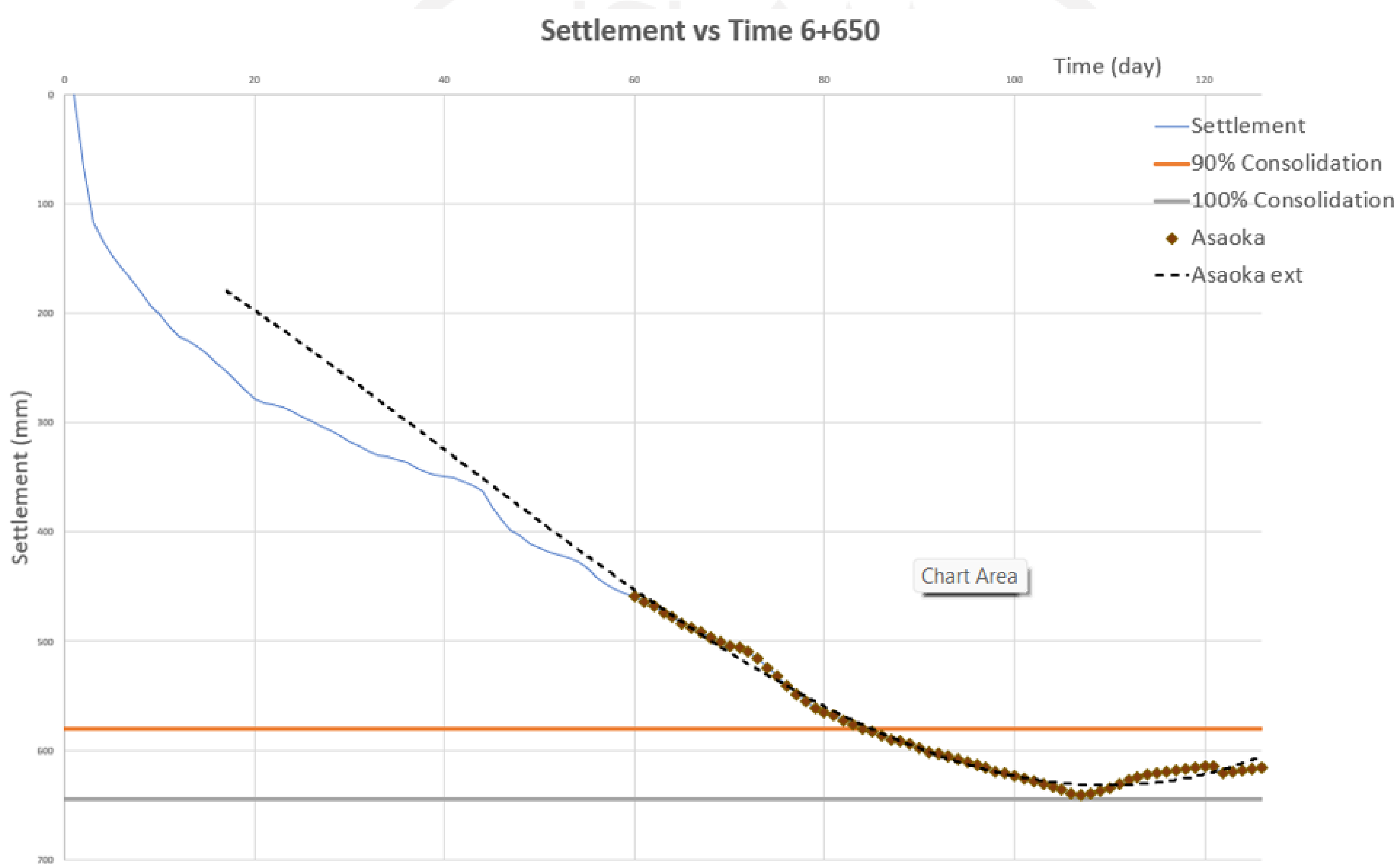

Theoretical vs Actual Settlement (6+850)
Time (day)
0
20
40
60
80
100
120
Settlement (mm)
0
100
200
300
400
500
600
700
Theoretical...
Actual...


Theoretical vs Actual Settlement (6+950)
Time (day)
0
20
40
60
80
100
120
Settlement (mm)
0
100
200
300
400
500
600
700
Theoretical...
Actual...

Attachment 17 Asaoka estimation SP.01

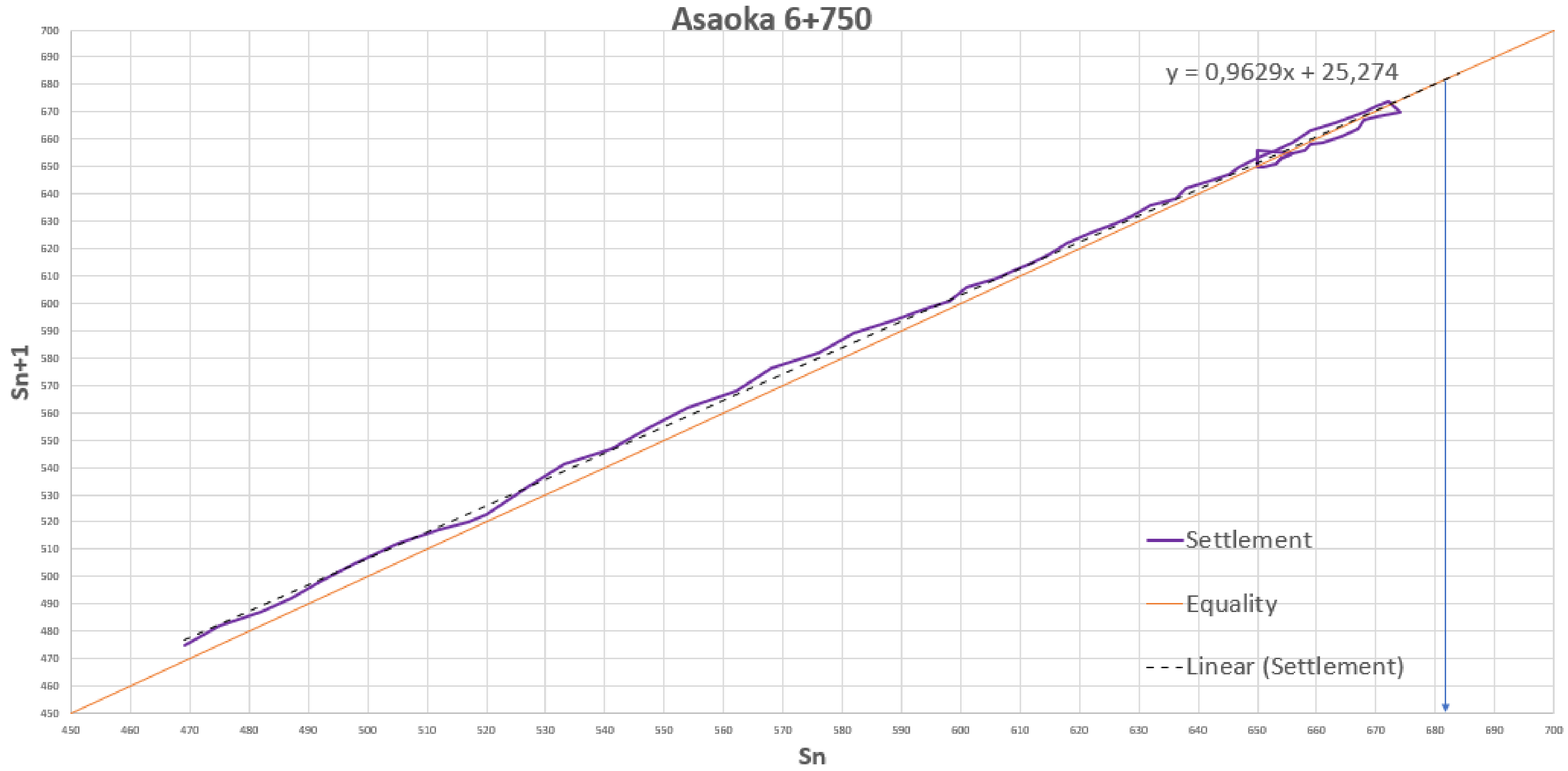
Day-n	Sn	Sn+1	Day-n	Sn	Sn+1	Day-n	Sn	Sn+1
60	459	464	87	590	592	114	622	621
61	464	468	88	592	594	115	621	619
62	468	474	89	594	598	116	619	618
63	474	478	90	598	601	117	618	617
64	478	484	91	601	603	118	617	615
65	484	488	92	603	605	119	615	614
66	488	492	93	605	608	120	614	614
67	492	497	94	608	610	121	614	621
68	497	501	95	610	613	122	621	619
69	501	504	96	613	616	123	619	618
70	504	506	97	616	619	124	618	617
71	506	510	98	619	621	125	617	615
72	510	516	99	621	623	126	615	
73	516	524	100	623	625			
74	524	532	101	625	628			
75	532	541	102	628	631			
76	541	548	103	631	633			
77	548	555	104	633	636			
78	555	561	105	636	639			
79	561	565	106	639	641			
80	565	568	107	641	639			
81	568	572	108	639	637			
82	572	576	109	637	634			
83	576	580	110	634	631			
84	580	583	111	631	627			
85	583	587	112	627	624			
86	587	590	113	624	622			


Asaoka 6+650
y = 0,9634x + 23,576
Sn+1
Sn
Asaoka 6+650
Equality
Linear (Asaoka 6+650)

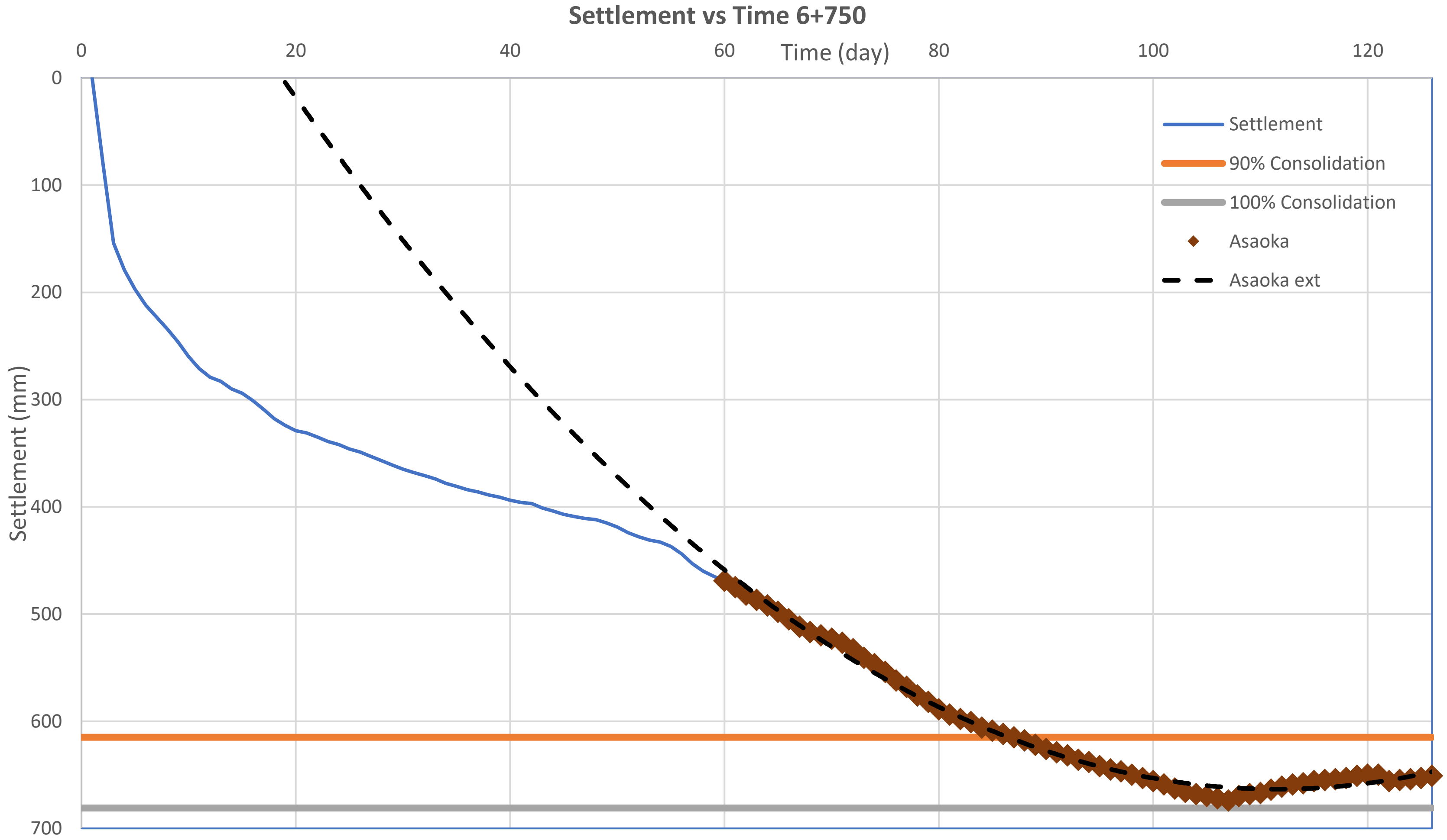

Settlement vs Time 6+650
Time (day)
Settlement (mm)
Settlement
90% Consolidation
100% Consolidation
Asaoka
Asaoka ext
Chart Area
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700

Attachment 18 Asaoka estimation SP.02

Day-n	Sn	Sn+1	Day-n	Sn	Sn+1	Day-n	Sn	Sn+1
60	469	475	87	615	618	114	658	656
61	475	482	88	618	622	115	656	655
62	482	487	89	622	626	116	655	654
63	487	492	90	626	629	117	654	653
64	492	498	91	629	632	118	653	651
65	498	505	92	632	636	119	651	650
66	505	512	93	636	638	120	650	650
67	512	517	94	638	642	121	650	656
68	517	520	95	642	645	122	656	655
69	520	523	96	645	647	123	655	654
70	523	527	97	647	650	124	654	653
71	527	533	98	650	653	125	653	651
72	533	541	99	653	656	126	651	
73	541	547	100	656	659			
74	547	554	101	659	663			
75	554	562	102	663	666			
76	562	568	103	666	668			
77	568	576	104	668	670			
78	576	582	105	670	672			
79	582	589	106	672	674			
80	589	594	107	674	670			
81	594	598	108	670	668			
82	598	601	109	668	667			
83	601	606	110	667	664			
84	606	609	111	664	661			
85	609	612	112	661	659			
86	612	615	113	659	658			

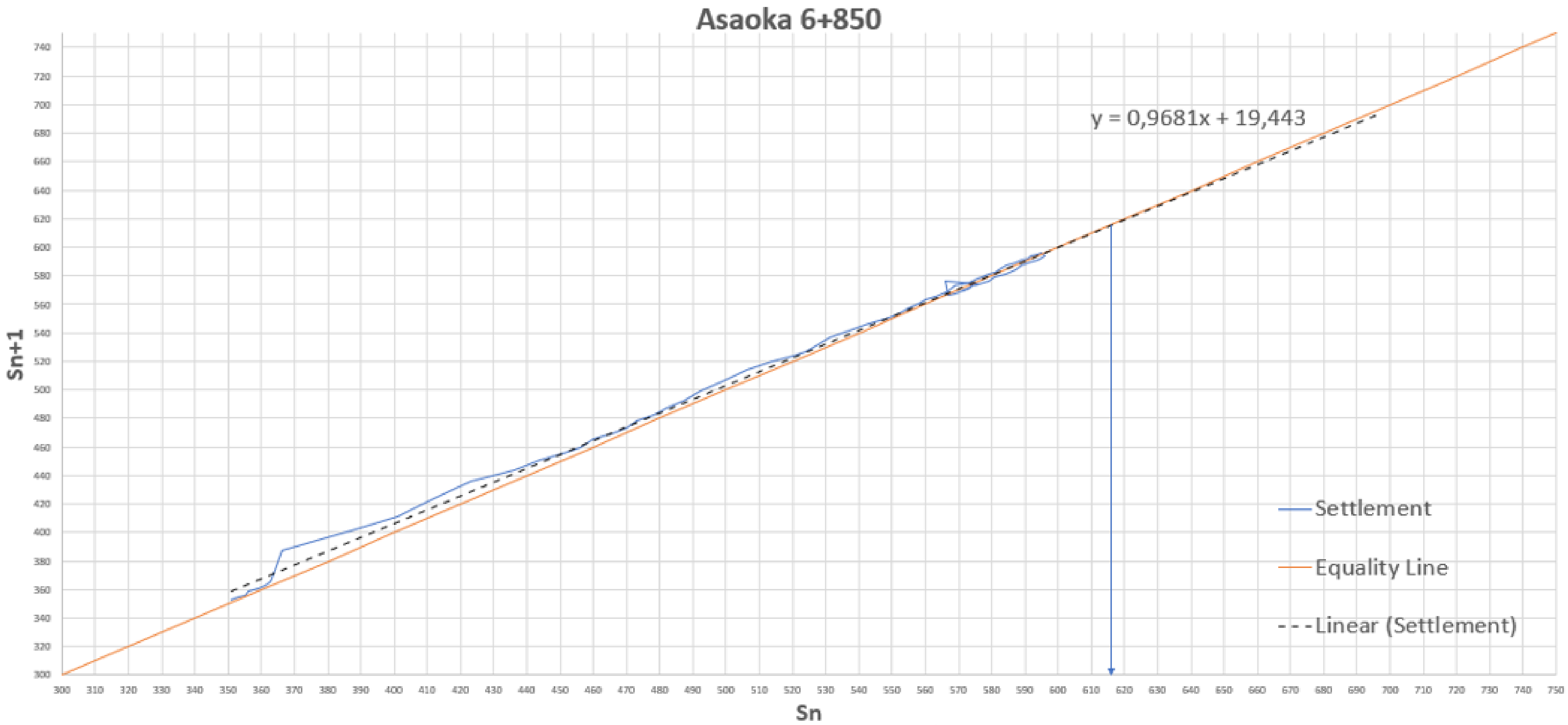


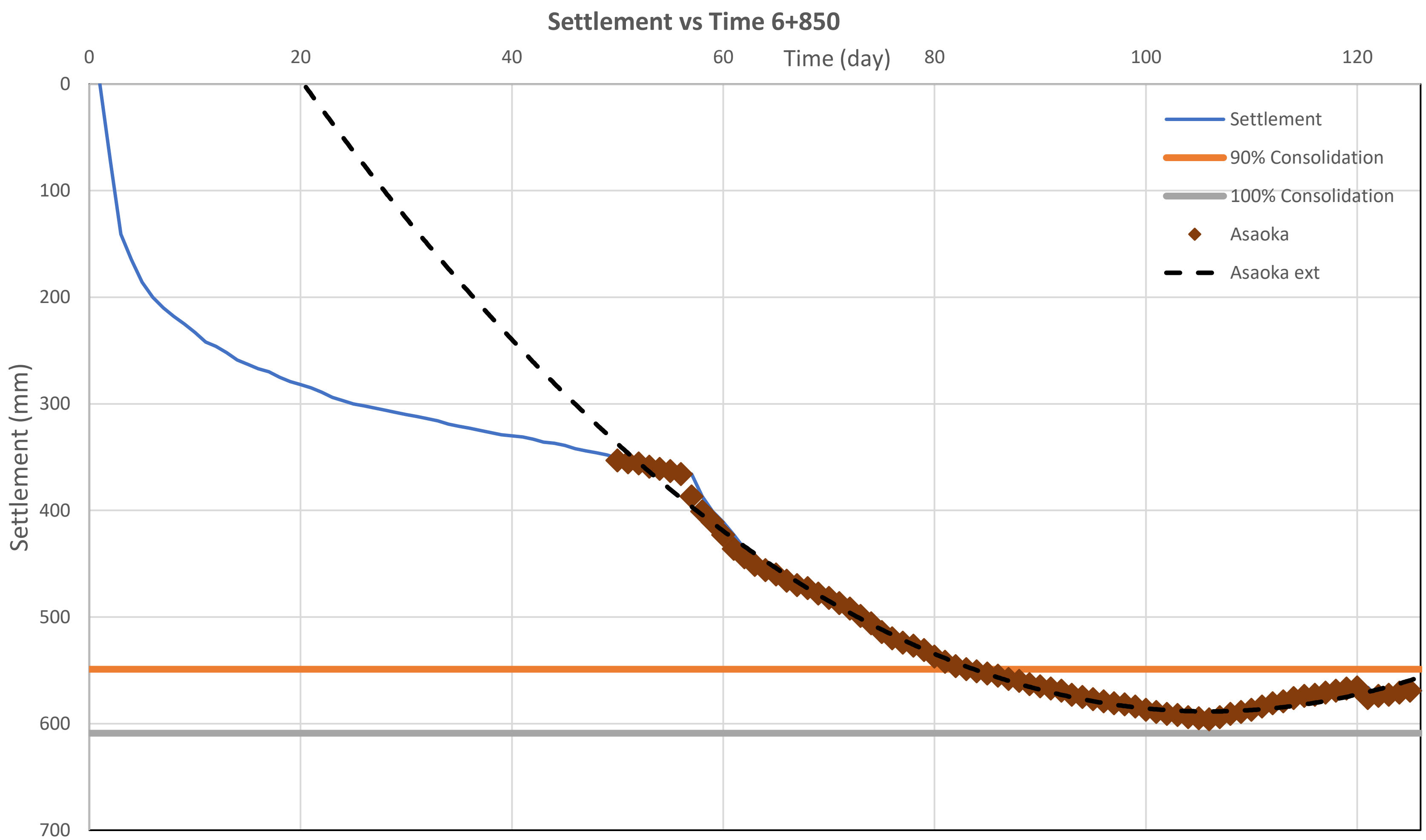
Asaoka 6+750
y = 0,9629x + 25,274
Sn+1
Sn
Settlement
Equality
Linear (Settlement)


Settlement vs Time 6+750
Time (day)
0
20
40
60
80
100
120
Settlement (mm)
0
100
200
300
400
500
600
700
Settlement
90% Consolidation
100% Consolidation
Asaoka
Asaoka ext

Attachment 19 Asaoka estimation SP.03

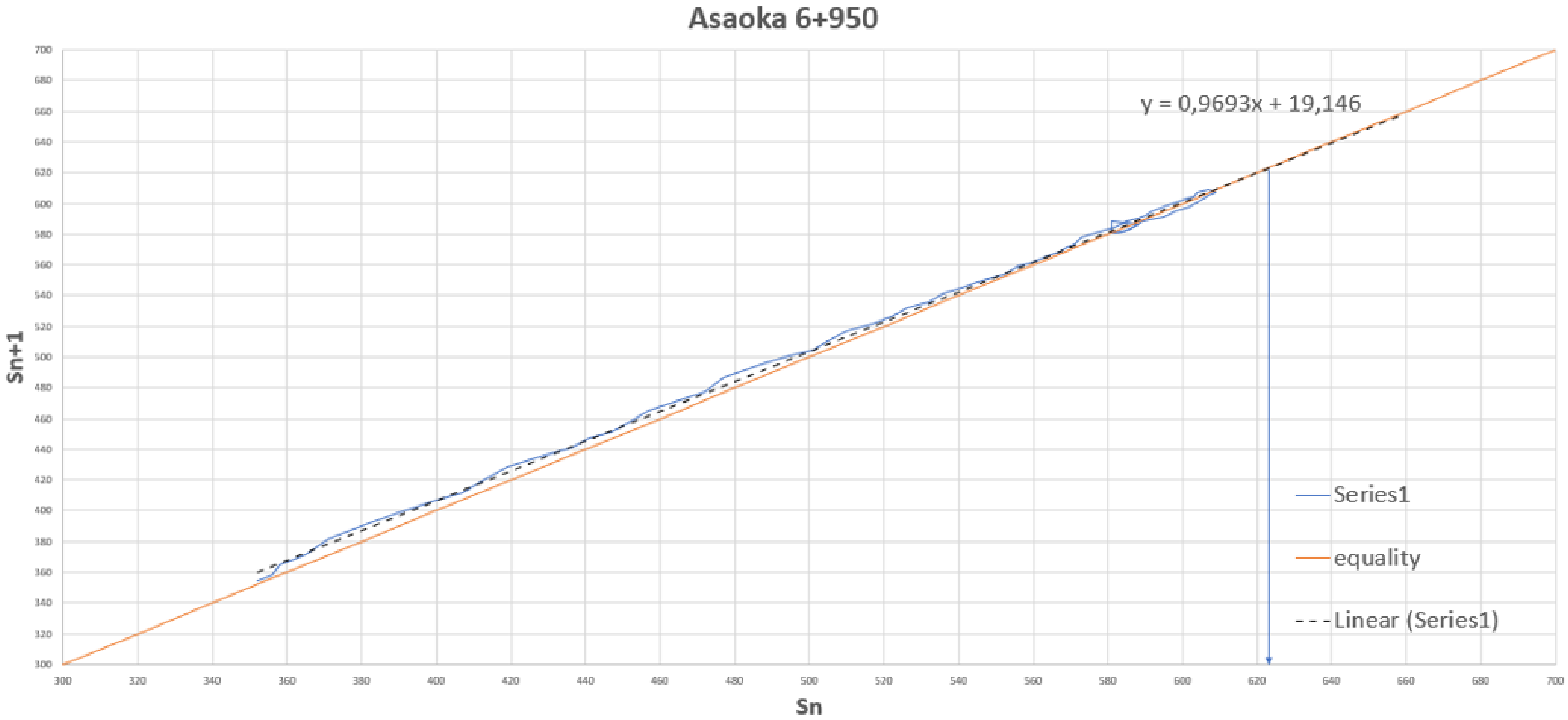
Day-n	Sn	Sn+1	Day-n	Sn	Sn+1	Day-n	Sn	Sn+1
50	351	353	87	555	558	124	573	571
51	353	355	88	558	560	125	571	569
52	355	356	89	560	563	126	569	
53	356	359	90	563	565			
54	359	361	91	565	567			
55	361	363	92	567	569			
56	363	366	93	569	573			
57	366	387	94	573	575			
58	387	401	95	575	577			
59	401	411	96	577	579			
60	411	423	97	579	581			
61	423	436	98	581	582			
62	436	444	99	582	584			
63	444	451	100	584	587			
64	451	456	101	587	589			
65	456	460	102	589	591			
66	460	466	103	591	592			
67	466	470	104	592	594			
68	470	473	105	594	595			
69	473	478	106	595	596			
70	478	482	107	596	594			
71	482	487	108	594	591			
72	487	492	109	591	589			
73	492	499	110	589	587			
74	499	506	111	587	584			
75	506	514	112	584	581			
76	514	520	113	581	579			
77	520	524	114	579	576			
78	524	527	115	576	574			
79	527	531	116	574	573			
80	531	537	117	573	571			
81	537	542	118	571	569			
82	542	546	119	569	567			
83	546	549	120	567	566			
84	549	551	121	566	576			
85	551	553	122	576	574			
86	553	555	123	574	573			

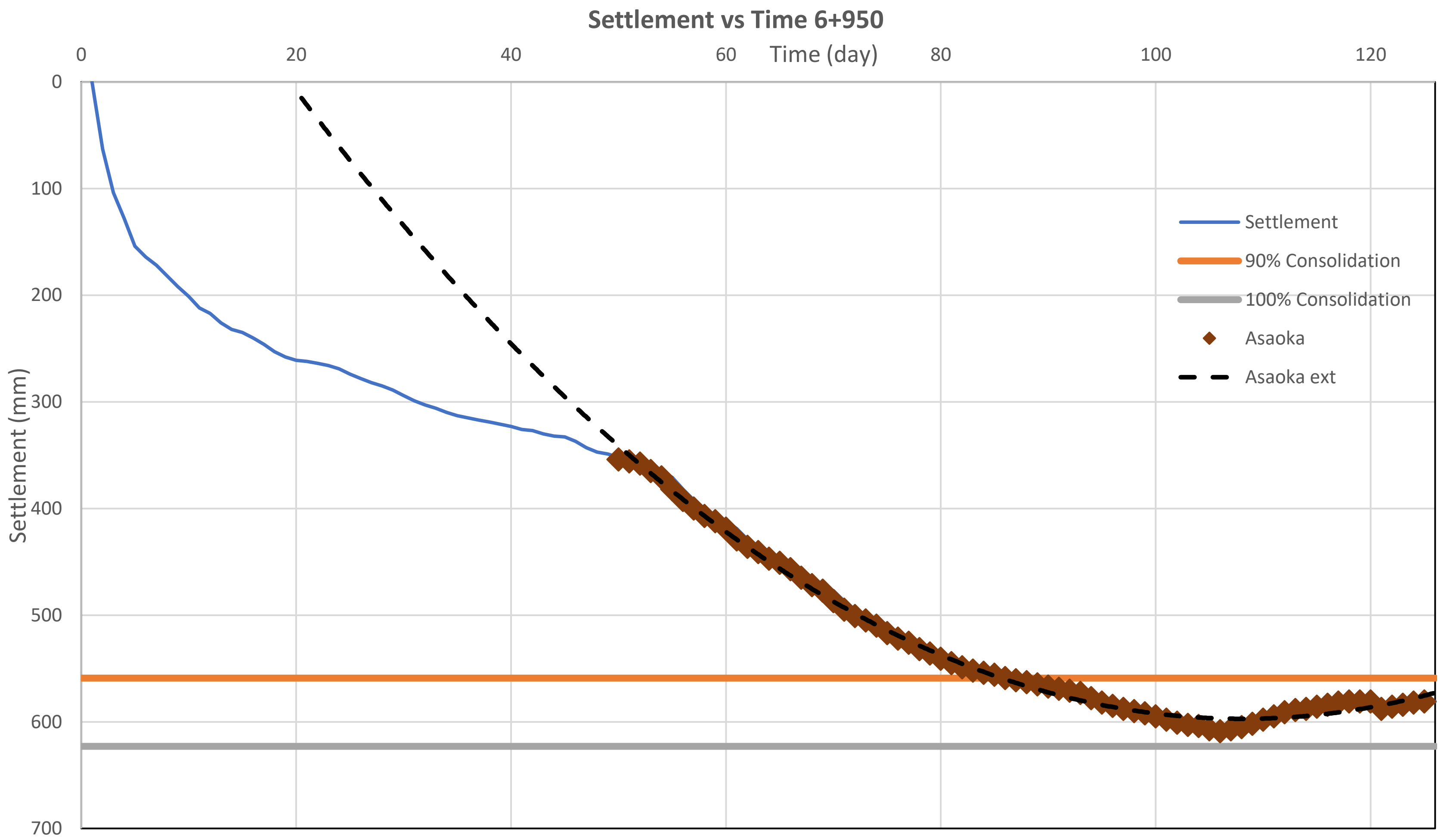

Asaoka 6+850
y = 0,9681x + 19,443
Sn+1
Sn
Settlement
Equality Line
Linear (Settlement)


Settlement vs Time 6+850
0
20
40
60
Time (day)
80
100
120
0
100
200
300
400
500
600
700
Settlement (mm)
Settlement
90% Consolidation
100% Consolidation
Asaoka
Asaoka ext

Attachment 20 Asaoka estimation SP.04

Day-n	Sn	Sn+1	Day-n	Sn	Sn+1	Day-n	Sn	Sn+1
50	352	354	87	559	561	124	584	582
51	354	356	88	561	563	125	582	581
52	356	358	89	563	565	126	581	
53	358	365	90	565	567			
54	365	371	91	567	569			
55	371	382	92	569	571			
56	382	392	93	571	573			
57	392	400	94	573	578			
58	400	407	95	578	582			
59	407	412	96	582	585			
60	412	419	97	585	588			
61	419	429	98	588	590			
62	429	436	99	590	592			
63	436	441	100	592	595			
64	441	447	101	595	598			
65	447	451	102	598	601			
66	451	457	103	601	603			
67	457	465	104	603	604			
68	465	472	105	604	607			
69	472	477	106	607	609			
70	477	487	107	609	607			
71	487	495	108	607	605			
72	495	501	109	605	602			
73	501	505	110	602	598			
74	505	510	111	598	595			
75	510	517	112	595	591			
76	517	522	113	591	589			
77	522	526	114	589	588			
78	526	532	115	588	586			
79	532	536	116	586	584			
80	536	541	117	584	582			
81	541	545	118	582	581			
82	545	549	119	581	581			
83	549	552	120	581	581			
84	552	554	121	581	588			
85	554	556	122	588	586			
86	556	559	123	586	584			


Asaoka 6+950
y = 0,9693x + 19,146
Sn+1
Sn
Series1
equality
Linear (Series1)


Settlement vs Time 6+950
Time (day)
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
Settlement (mm)
Settlement
90% Consolidation
100% Consolidation
Asaoka
Asaoka ext