EVALUATING THE COMBINED USE OF WOVEN GEOTEXTILE AND WOOD PILES FOR PEAT SOIL IMPROVEMENT (A CASE STUDY IN RUMBAI, PEKANBARU, INDONESIA).

Thesis

Submitted to Fulfill the Requirements for Achieving a Master's Degree in Engineering.

By
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THESIS APPROVAL

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THESIS APPROVAL

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STATEMENT

I hereby declare that this thesis does not contain any work that has ever been submitted to obtain a bachelor's degree at a university. To the best of my knowledge, no work or opinion has ever been written or published by another person, except those referred to in writing in this manuscript and mentioned in the bibliography.

Pekanbaru, January 2025

Wasswa Hassan

FOREWORD

Assalamu'alaikum Warahmatullahi Wabarokatuh,

All praise and gratitude are due to Allah SWT for His blessings and grace, which have enabled the completion of this thesis titled "Evaluating the Combined Use of Woven Geotextile and Wood Piles for Peat Soil Improvement (A Case Study in Rumbai, Pekanbaru, Indonesia)."

This thesis is submitted to Fulfill the Requirements for Achieving a Master's Degree in Engineering (MCE) at the Postgraduate Civil Engineering (Geotechnics and Transportation) Program, Universitas Islam Riau. It focuses on addressing the challenges presented by peat soil's weak engineering properties, which hinder construction efforts in regions like Pekanbaru City. By evaluating the effectiveness of combining woven geotextile and cerucuk wood piles, this research aims to contribute to sustainable and cost-effective solutions for peat soil reinforcement.

Throughout the preparation and completion of this thesis, I have been acutely aware of the limitations of my knowledge and experience. Therefore, I sincerely welcome constructive criticism and suggestions to enhance the quality of this work.

Finally, I express my heartfelt gratitude to my supervisors, colleagues, and everyone who has supported me throughout this journey. Their guidance and encouragement have been invaluable in the successful completion of this thesis.

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May Allah SWT bless all the kindness shown to me. I hope this research benefits all who read it.

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Wasswa Hassan

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SYMBOLS AND ABBREVIATIONS

A	: Area
A_p	: Cross-sectional area of a single pile
A_r	: Area replacement ratio
BH	: Borehole.
BH-2	: Borehole two
BS	: British Standard for Foundations.
BW 250	: A specific woven geotextile product.
CBR	: California Bearing Ratio.
Cerucuk	: Wooden piles used to reinforce soft soils.
C	: Cohesion
cm	: centimetres
D	: Diameter of the pile
2D	: Two dimensions
δ	: Compressibility
CPT	: Cone Penetration Test.
DS	: Disturbed Sample.
E	: Elastic Modulus
FEM	: Finite Element Method
f_i	: Soil friction.
Jl.	: Jalan (Street)
FoS	: Factor of Safety
GP	: Geotechnical Professional.
GWT	: Ground Water Table
Gs	: Specific Gravity of soil
γ_c	: Unit weight of clay
γ_p	: Unit weight of peat
γ_w	: Unit weight of cerucuk wood
IP	: Plasticity Index.
K	: Permeability coefficient
KN	: Kilonewton.

kPa	: Kilo passcals
L_b	: Depth of Penetration into the bearing stratum
Li	: Length of the pile.
m	: metres
MCE	: Master of Civil Engineering.
MCL	: Master of Comparative Law.
MDPJ 2024	: Manual Desain Perkerasan Jalan 2024
NPM	: Student Identification Number.
N	: SPT value
PI	: Plasticity Index.
PLAXIS 2D	: Finite Element Analysis Geotechnical Software applications.
PVD	: Prefabricated Vertical Drains
Q_s	: Skin (shaft) friction surrounding soil.
Q_p	: End-bearing resistance of the pile.
Q_u	: Ultimate bearing capacity of the pile.
(ϕ)	: Shear Angle
S	: Pile spacing
SNI	: Indonesian National Standard (Standar Nasional Indonesia).
SPT	: Standard Penetration Test
STA 4	: Specific station reference in construction.
SWT	: Shear Wave Test.
(U)	: Total displacement
UDS	: Undisturbed Sample.
UFCSI	: Urban Flood Control System Improvement project.
Ψ	: Dilatancy Angle
v	: Poisson's Ratio
W	: Pile surface area
YLPI	: Likely refers to a specific organisation or institution.

ABSTRACT

Peat soils present significant geotechnical challenges because of their high compressibility, low shear strength, and excessive moisture content, making construction difficult in regions such as Rumbai, Pekanbaru, Indonesia. This study aims to evaluate the effectiveness of woven geotextile and cerucuk wood piles for peat soil reinforcement, utilising geotechnical data from the Urban Flood Control System Improvement (UFCSI) project and other geotechnical data resources such as existing published research papers mainly conducted on soft soils. Finite element modelling (FEM) was conducted using PLAXIS 2D, where woven geotextiles were modelled as geogrid elements for lateral restraint, and cerucuk wood piles were modelled as embedded beams to assess load transfer and settlement reduction. The Soft Soil Model was applied to capture the high compressibility and time-dependent consolidation behaviour of peat. A 3.0 m high embankment with a 12 m base width was simulated, incorporating meshing refinement, staged construction, groundwater effects, and consolidation analysis to ensure accurate prediction of soil behaviour. The results indicate that the unreinforced case experienced 1022 mm of settlement, while woven geotextile alone reduced settlement by 69.19% (to 315 mm), and the combination of geotextile and cerucuk wood piles further reduced settlement by 72% (to 286.7 mm). However, despite these improvements, 28% (286.16 mm) of the total settlement (1022 mm) remained, highlighting the limitations of the embedded beam modelling approach, which is more suited for medium to hard soils and may not fully capture the long-term deformation behaviour of highly compressible peat soils. Despite these limitations, the findings demonstrate that integrating woven geotextile with cerucuk wood piles is a cost-effective and sustainable reinforcement technique for improving embankment stability and reducing excessive settlement in peatland conditions. To improve accuracy, future research should explore alternative modelling techniques, such as plate elements or soil elements with interface properties, increased pile density, and preloading techniques for enhanced consolidation. Additionally, a double-layered woven geotextile system and a grid arrangement of cerucuk piles may further improve reinforcement efficiency. Field validation studies should be conducted to compare numerical predictions with real-world settlement behaviour, ensuring a more reliable assessment of peat soil reinforcement.

Keywords: Peat soil reinforcement, woven geotextile, cerucuk wood piles, settlement analysis, PLAXIS 2D simulation, finite element modelling (FEM), embankment stability, sustainable ground improvement.

ABSTRAK

Tanah gambut memiliki tantangan geoteknik yang signifikan karena kompresibilitas tinggi, kekuatan geser rendah, dan kadar air berlebihan, sehingga menyulitkan konstruksi di wilayah seperti Rumbai, Pekanbaru, Indonesia. Studi ini mengevaluasi efektivitas geotekstil anyaman dan cerucuk kayu untuk perkuatan tanah gambut dengan menggunakan data geoteknik dari proyek Urban Flood Control System Improvement (UFCSI) serta sumber data geoteknik lainnya, termasuk penelitian terdahulu yang berfokus pada tanah lunak. Pemodelan elemen hingga (FEM) dilakukan menggunakan PLAXIS 2D, di mana geotekstil anyaman dimodelkan sebagai elemen geogrid untuk perkuatan lateral, sedangkan cerucuk kayu dimodelkan sebagai balok tertanam untuk menilai transfer beban dan reduksi penurunan. Model Tanah Lunak (Soft Soil Model) digunakan untuk menangkap sifat tanah gambut yang sangat dapat dimampatkan dan perilaku konsolidasi jangka panjangnya. Model tanggul setinggi 3,0 m dengan lebar dasar 12 m dibuat dengan mempertimbangkan penyempurnaan meshing, konstruksi bertahap, pengaruh air tanah, dan analisis konsolidasi guna memastikan prediksi perilaku tanah yang lebih akurat. Hasil penelitian menunjukkan bahwa kasus tanpa perkuatan mengalami penurunan sebesar 1022 mm, sementara penggunaan geotekstil anyaman saja mengurangi penurunan sebesar 69,19% (menjadi 315 mm), dan kombinasi geotekstil dengan cerucuk kayu mengurangi penurunan hingga 72% (menjadi 286,7 mm). Namun, meskipun terjadi banyak peningkatan, 28% (286,16 mm) dari total penurunan tetap terjadi, yang menyoroti keterbatasan pendekatan pemodelan balok tertanam, di mana metode ini lebih cocok untuk tanah sedang hingga keras dan mungkin tidak sepenuhnya menangkap deformasi jangka panjang tanah gambut yang sangat kompresibel. Meskipun demikian, temuan ini menunjukkan bahwa integrasi geotekstil anyaman dengan cerucuk kayu merupakan teknik perkuatan yang hemat biaya dan berkelanjutan untuk meningkatkan stabilitas tanggul dan mengurangi penurunan berlebihan pada kondisi tanah gambut. Untuk meningkatkan akurasi pemodelan, penelitian lebih lanjut disarankan untuk mengeksplorasi teknik pemodelan alternatif, seperti elemen pelat atau elemen tanah dengan properti antarmuka, peningkatan kepadatan cerucuk, serta teknik pramuat guna mempercepat konsolidasi. Selain itu, penggunaan sistem geotekstil anyaman berlapis ganda dan pengaturan cerucuk dalam pola grid dapat lebih meningkatkan efisiensi perkuatan. Studi validasi lapangan perlu dilakukan untuk membandingkan prediksi numerik dengan perilaku penurunan nyata, guna memastikan evaluasi yang lebih akurat terhadap perkuatan tanah gambut.

Kata kunci: Perkuatan tanah gambut, geotekstil anyaman, cerucuk kayu, analisis penurunan, simulasi PLAXIS 2D, pemodelan elemen hingga (FEM), stabilitas tanggul, perbaikan tanah berkelanjutan.

CHAPTER 1

INTRODUCTION

1.1 Background

Pekanbaru City, the capital of Riau Province in Indonesia, is experiencing rapid urbanization and infrastructure development. Still, it faces significant challenges due to the unstable nature of its soft soils, including clay and peat. A considerable portion of the Earth's surface is composed of soil, which is commonly used as construction and foundation materials (Das, 2019), Peat soils, which are dark brown to black and have a distinctive organic odour, are formed from the chemical decay and fossilization of plant matter. This organic material accumulates more quickly than it decomposes, resulting in peat exhibiting high compressibility, low undrained shear strength, and high permeability. Its fibrous consistency leads to significant settlement and low bearing capacity (MacFarlane, 1959) .

Globally, Indonesia has extensive peatland areas, covering approximately 14.9 million hectares (Prihatiningsih, 2023). The organic composition, low bearing capacity, and considerable uneven compressibility of peat soils adversely affect their technical performance (Ridwan, 2016). This can cause damage and structural failures in civil engineering projects such as roads, embankments, buildings, and bridges when loads are applied (Talib, 2021) and (Yulianto, 2016), which leads to increased construction and maintenance costs as well as project delays if not properly managed (Dewi, 2020).

As Indonesia continues to grow economically, especially on Sumatra Island and in Pekanbaru city within Riau province, it is important to effectively tackle the challenges that arise. Utilizing peatlands for residential and infrastructural development, such as roads and bridges, is becoming increasingly vital. These developments are essential for improving transportation, supporting the rapidly growing population, and fostering economic growth in the city. However, construction on peatlands poses significant challenges due to the poor physical properties of peat soil. (Yusof, 2023).

The Urban Flood Control System Improvement (UFCSI) project in Pekanbaru City faces several challenges that impact construction and flood control strategies:

1. Geographical Location: Located on Jl. Nelayan Rumbai Pesisir is vulnerable to flooding due to its low-lying topography. The project requires a strong flood control system to mitigate risks from heavy rainfall and rising water levels.
2. Soil Composition: Investigations reveal diverse soil types. Peat Soils dominate the site, and they cause embankment instability and complicate foundation design due to significant settlement. Cohesive and Granular Soils, the presence of cohesive clay and granular sandy soils also necessitates different approaches for stability and drainage.
3. High Groundwater Levels: High groundwater levels and soft soils increase construction costs and raise concerns about the durability of the infrastructure.
4. Site Accessibility: Swampy terrain hinders material and equipment movement, requiring careful planning to prevent environmental impacts.

To combat these issues, a combined approach using woven geotextiles and locally sourced Cerucuk Mahang wood piles can improve soil-bearing capacity, reduce settlement, and support eco-friendly practices (Suyuti and Rizal, 2023).

1.2 Problem Statement

In Pekanbaru, commonly used soil improvement methods such as prefabricated vertical drains (PVD), spun piles, mini piles, grouting, chemical stabilizers, and soil substitution often deliver suboptimal results. Chemical stabilizers are expensive and harmful to the environment, while soil replacement and mechanical compaction require significant labour and may lack long-term stability. These limitations lead to higher construction costs, delays, and compromised structural integrity. Therefore, there is a critical need for innovative, cost-effective, and sustainable soil reinforcement methods to improve the region's construction efficiency, durability, and sustainability.

1.3 Research Questions

Based on the above explanation, the research will address the following questions:

1. What are the properties of existing peat soil, and how do they interact with geotextiles and cerucuk wood piles?
2. How does the combined use of geotextiles and cerucuk wood piles enhance the reinforcement of peat soil?
3. What are the recommended methods for applying geotextiles and cerucuk wood piles in local construction projects?

1.4 Research Objectives

This research aims to achieve the following objectives:

1. To analyze the interaction between the properties of existing peat soil and geotextiles, as well as cerucuk wood piles.
2. To evaluate the improvements in soil reinforcement performance from the combined use of these materials.
3. To develop practical recommendations for implementing this combined method in local construction projects.

1.5 Significance of the Study

The benefits of this research are categorized into three groups: Academic, Practical, and Broader.

1) Academic Benefits

i) Enhance understanding of geotextiles and traditional Cerucuk wood methods for improving peat soil reinforcement.

ii) Enriched combined practices and knowledge in the geotechnical engineering field.

2) Practical Benefits

i) Focus on environmentally friendly methods for the development of sustainable infrastructure.

3) Broader Impact

i) Support for effective soil enhancement techniques in infrastructure development.

ii) A comprehensive guide for civil engineers, construction supervisors, and policymakers in the region that introduces innovative and sustainable soil improvement solutions within advanced geotechnical engineering practices.

1.6 Research Limitations

This study evaluates peat soil reinforcement using woven geotextiles and cerucuk wood piles. However, the research is subject to the following limitations.

1. The study primarily focuses on settlement reduction, other geotechnical aspects, such as bearing capacity, lateral displacement, and creep behaviour, were not analyzed due to time constraints and do not include long-term settlement.
2. The use of embedded beam elements in PLAXIS 2D is more suitable for medium to hard soils. This approach may not fully capture the interaction between cerucuk wood piles and highly compressible peat soils.
3. The thesis relies on geotechnical data from the UFCSI project, and no new field or laboratory tests were conducted.
4. The research findings are based on a case study in Rumbai, Pekanbaru, and may not be directly applicable to other locations with different soil conditions.
5. Differences in wood type, moisture content, installation precision, and degradation over time may influence the long-term performance of cerucuk piles and woven geotextiles.

1.7 Authenticity of Research

This study aims to address a gap in existing soil improvement practices by reinforcing peat soil using geotextiles and Cerucuk wood piles, a method that has not been extensively researched in similar challenging areas around the world. It is expected that this innovative approach will provide significant enhancements in peat soil reinforcement, as well as being cost-effective.

CHAPTER 2
LITERATURE REVIEW

2.1 Previous Research

This chapter presents a systematic compilation of studies relevant to this research, carefully citing the authors' last names and their publication years.

Sari and Istiatun (2022) conducted a study titled "Analysis of Embankment Stability with Geotextile and Cerucuk Reinforcement" to tackle the challenges of constructing embankments in the swampy area of Section 1A of the Serpong–Balaraja Toll Road (STA 4+550 to STA 4+900) in Indonesia. This project is part of the National Strategic Projects (PSN) aimed at improving connectivity between Jakarta, Merak, and Lampung. The site features soft cohesive soils, up to 5.0 meters deep, with a Plasticity Index (PI) of 45.10% and original water content of 68.19%. These conditions lead to low bearing capacity and high consolidation settlement risks. The study evaluated several soil improvement methods, including soil replacement, geotextile reinforcement, a combination of both, and cerucuk (wooden piles) as reinforcement. Using Plaxis 2D v20 software and the Fellenius method, the researchers determined that the original soil had a safety factor below 1.5. Soil replacement improved the safety factor, with optimal thickness beyond which benefits plateaued. The collapse pattern and safety factor obtained by FEM is illustrated in Table 2.1.

Table 2.1 The collapse pattern and SoF (Sari and Istiatun, 2022).

Soil Replacement Thickness(m)	Construction Phase Safety Factor	Post-Construction Safety Factor	Consolidation Settlement U = 90% (m)	Consolidation Time U 90% (days)
3	1.611	1.521	0.887	106.653
5.5	1.798	1.687	0.686	103.845
8	1.798	1.688	0.687	103.845

Geotextile reinforcement tested with 5 m, 9 m, and 13 m layers showed that the safety factor increased with more layers, although consolidation settlement was larger than other methods. The collapse pattern and safety factor obtained by FEM Geotextile reinforcement is illustrated in Table 2.2.

Table 2.2 SoF and Settlement reinforced with Geotextile (Sari and Istiatun, 2022).

Number of Layers	Construction Phase Safety Factor	Post-Construction Safety Factor	Consolidation Settlement U = 90% (m)	Consolidation Time U = 90% (days)
5	1.552	1.448	1.295	103.848
9	1.694	1.582	1.289	105.486
13	1.819	1.697	1.300	106.233

The combination of soil replacement and geotextile significantly improved stability, achieving the highest safety factor with 8 m of replacement soil and 4 layers of geotextile. Ccollapse pattern and safety factor obtained by FEM is illustrated in Table 2.3.

Table 2.3 SoF and Settlement with Combined Method (Sari and Istiatun, 2022).

Soil Replacement Thickness	Number of Layers	Construction Phase Safety Factor	Post-Construction Safety Factor	Consolidation Settlement U = 90% (m)	Consolidation Time U = 90% (days)
3 m	1	1.648	1.555	0.887	105.392
3 m	2	1.685	1.588	0.887	106.061
5.5 m	1	1.835	1.717	0.688	106.974
5.5 m	2	1.940	1.816	0.687	104.651
8 m	1	1.837	1.716	0.688	106.974
8 m	2	1.943	1.817	0.687	104.673
Cerucuk		2.045	1.885	0.873	96.078

The study identified that the most effective method was the use of entirely submerged cerucuk wood piles. This technique achieved the highest safety factor of 2.045 during construction and 1.885 after construction, along with the lowest settlement of 0.873 meters over 96.078 days, Ccollapse pattern and safety factor obtained by FEM is illustrated in Table 2.3 and embankment modelling with cerucuk is depicted in Figure 2.1 (Sari and Istiatun, 2022).

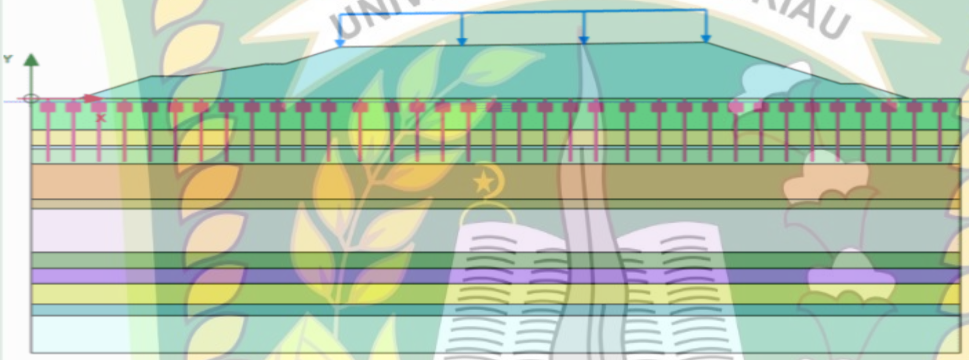


Figure 2.1 Embankment modeling with cerucuk (Sari and Istiatun, 2022).

Dewi (2020) A study titled "Peat Soil Improvement Methods Using Woven Bamboo and Cerucuk" addressed the challenges of peat soils in South Sumatra, Indonesia, which have low bearing capacity and high compressibility, making them unsuitable for direct construction. The research explored various methods for enhancing bearing capacity, including chemical stabilization with admixtures like cement, fly ash, and lime, as well as Vibro-Replacement and preloading. The study specifically examined the use of locally sourced cerucuk wooden piles in combination with woven bamboo as a cost-effective solution. Conducted on a laboratory scale, and evaluated the bearing capacity of both reinforced and unreinforced peat soil. The unreinforced soil had a very low capacity of 5.33 kPa. However, with the addition of submerged cajelput cerucuk at diameters of 1.5 cm and 2 cm and lengths of 40 cm, 50 cm, and 60 cm, the capacity improved significantly, reaching a maximum of 39.33 kPa with two outer rods inclined at 75 degrees and a cerucuk length of 60 cm. The summary of bearing capacity with cerucuk reinforcement is presented in Table 2.4 (Dewi, 2020).

Table 2.4 Bearing Capacity with Cerucuk Reinforcement (Dewi, 2020)

Cerucuk Configuration	Bearing Capacity (kPa)
Perpendicular Cerucuk (60 cm)	31.77
Cerucuk with 75-degree Slope (60 cm)	39.33
Perpendicular 85-degree Slope Cerucuk (60 cm)	33.56

Suyuti and Rizal (2023) conducted a study on “Evaluation of Road Embankment Height on Soft Soil Reinforced with Geotextiles and Cerucuk Foundation”, focused on improving the stability of road embankments in the lowlands of Kalimantan, where soft soil layers can reach depths of 25 meters. The research assessed the critical height (H_{cr}) of embankments reinforced with geotextiles and piles under varying soil cohesion values, pile spacings, and plasticity indices. Results indicated that with a cohesion value of Cu = 11.5 kN/m², the critical height reached 1.06 meters at a pile spacing of 10 times their diameter (10D). For Cu = 17.5 kN/m², the critical height ranged from 1.70 to 1.73 meters. The critical embankment heights with varying soil cohesion are listed in Table 2.5 (Suyuti and Rizal, 2023).

Table 2.5 Critical Embankment Heights with Varying Soil Cohesion (Suyuti and Rizal, 2023)

Soil Cohesion (cu)	Pile Spacing (s)	Critical Height (H_{cr})
11.5 kN/m²	10D	1.06 m
17.5 kN/m²	10D	1.70 - 1.73 m

Closer pile spacing at 3.3D enhanced the ultimate bearing capacity, while variations in the plasticity index (IP from ≤ 7% to ≥ 27%) had no significant impact. Additionally, safety factors influenced allowable embankment heights: with a factor of 1.3, the critical height exceeded 1.25 meters, whereas factors of 1.4 and 1.5 resulted in heights below 1.03 meters. This underscores the importance of pile spacing and safety considerations in ensuring stability in embankment construction on soft soils.

Yudiawati and Marzuki (2008) conducted a study on "Shallow Foundation on Soft Soil with Galam Cerucuk Reinforcement Based on Field Experiments", and explored the challenges of constructing shallow foundations on 25-meter-deep soft soils in Banjarmasin, South Kalimantan. These depths presented significant geotechnical issues due to low bearing capacity and high settlement potential. The research focused on the effects of varying the length, spacing, and coverage area of cerucuk (piles) used for reinforcement as presented in Figure 3. Findings indicated that longer, fully submerged cerucuk (up to 2.0 meters) with closer spacing (25 cm) and an expanded coverage area improved ultimate bearing capacity and reduced settlement. Long-term tests revealed that loads below 40% of the ultimate bearing capacity resulted in minimal settlement, suggesting a safety factor greater than 2.5 for optimal performance. The general structure of the experimental setup is shown in Figure 2.2 (Yudiawati and Marzuki, 2008).

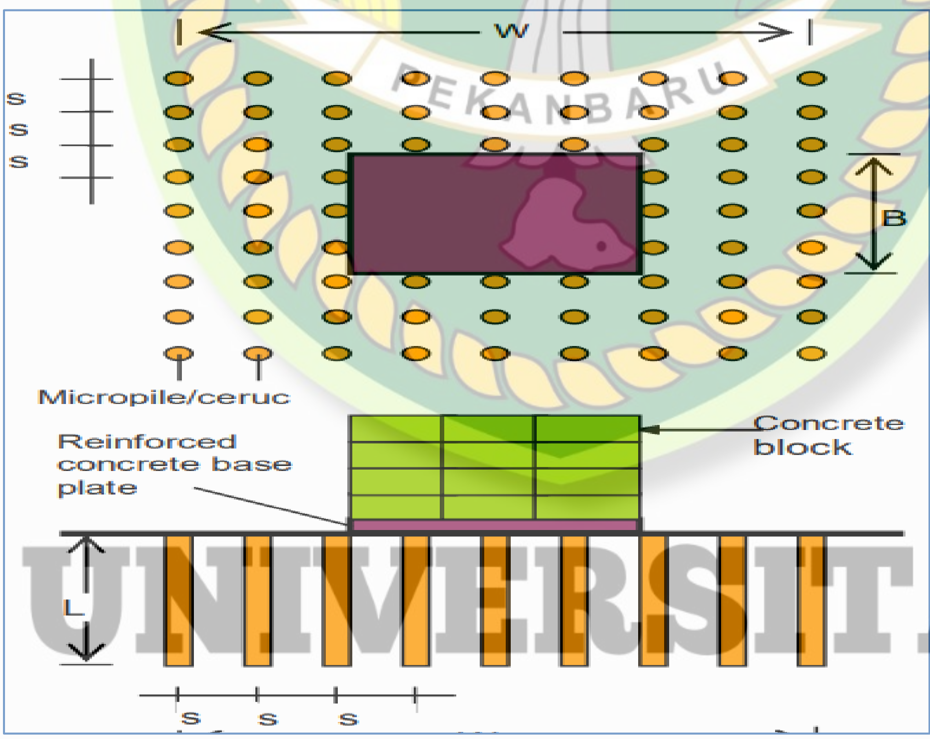


Figure 2.2 General structure of the experiment set (Yudiawati & Marzuki, 2008)

Arsyad et al. (2020) studied "Road Embankment Full-Scale Investigation on Soft Soil with Geotextile Reinforcement" and examined the challenges of constructing roads on soft soils in swampy areas of Tapin, South Kalimantan, using geotextile as a stabilizer. It compared the performance of embankments made with conventional backfill materials to those using locally sourced materials. The main objectives were to evaluate settlement, horizontal displacement, and overall performance through field observations and finite element method (FEM) analysis. The site's soil profile included layers of soft organic clay, silt, and firm to hard clay, with high moisture content and low bearing capacity. Soil testing revealed undrained shear strength values from 16 to 27 kN/m². The study utilized the FEM Mohr-Coulomb model to simulate embankment behaviour under load. Findings indicated that Embankment 1 (conventional materials) initially showed less settlement than Embankment 2 (local materials), but by day 500, Embankment 1 accumulated more settlement (117 mm) compared to Embankment 2 (104 mm). Geotextile layers in Embankment 2 improved performance over time despite its initially weaker soil conditions. Visual assessments noted that both embankments appeared similar initially, but by day 200, Embankment 2 showed more surface water accumulation, indicating drainage issues. However, both maintained comparable surface conditions after traffic was opened. Slope stability analysis revealed safety factors of 1.55 for Embankment 1 and 1.62 for Embankment 2, highlighting that locally sourced materials stabilized with geotextile can effectively serve as alternatives to conventional backfill for road construction on soft soils. Table 2.3 shows Collapse Pattern and Safety factor obtained by FEM.

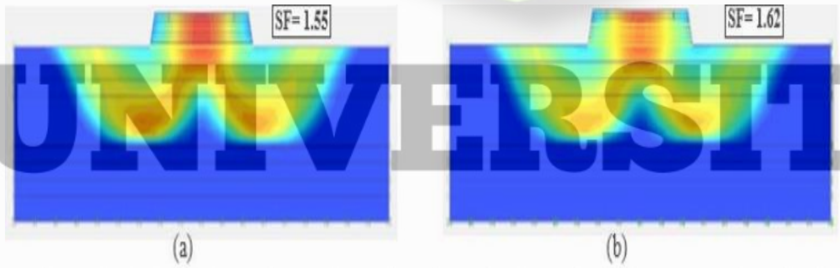


Figure 2.3 FEM Collapse Pattern and Safety factor (Arsyad et al. 2020)

Luthfiyyah, Kusumah (2023) studied the " Analysis of Subgrade Stabilization with Bamboo Cerucuk and Geotextiles," focusing on the stabilization of subgrade soil in Sukabumi. The road section under investigation was constructed on soft soil with low bearing capacity, which presents challenges for supporting heavy traffic. To address this issue, the study explored the use of cerucuk (bamboo piles) combined with geotextiles as reinforcement methods to improve the soil's bearing capacity. This was measured through the California Bearing Ratio (CBR), which is crucial for road stability. Initially, tests showed a very low CBR value of 0.76%, indicating poor subgrade conditions. However, after reinforcing the soil with cerucuk, the CBR value increased significantly to 5.63%, placing the soil in a medium-strength classification. The final stage of stabilization involved applying woven geotextile, which further improved the soil's CBR value to 20.59%, classifying it as excellent.

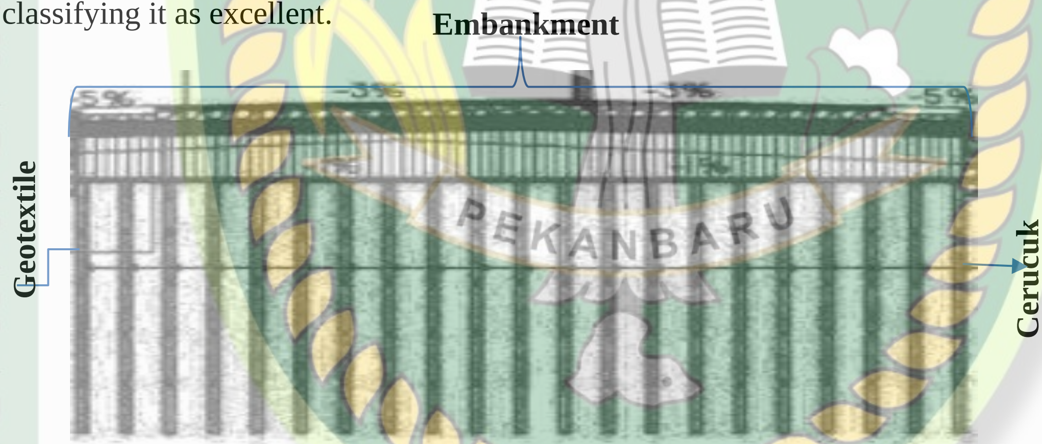


Figure 2.4 Cross-section modelling (Luthfiyyah and Kusumah, 2023).

This method demonstrates the effectiveness of combining locally available and cost-effective bamboo piles and geotextiles to enhance the bearing capacity of the subgrade. The ultimate goal is to improve road durability and safety, making this approach suitable for similar road construction projects in regions with challenging soil conditions. The study recommends further research to optimize the spacing of cerucuk and to explore different types of geotextiles for even better results. The CBR test results after cerucuk and geotextile stabilization are summarized in Table 2.6.

Table 2.6 CBR Test Results After Cerucuk and Geotextile (Luthfiyyah and Kusumah, 2023).

Test Location	Initial CBR (%)	CBR After Cerucuk (%)	CBR After Geotextile (%)
STA 0 + 475	0.76	5.21	20.91
STA 0 + 400	0.76	5.09	19.06
STA 0 + 325	0.76	6.59	21.81

2.2 Summary of Findings from Previous Literature.

The summary of findings from previous literature is illustrated in Table 2.7.

Table 2.7 Summary of Findings from Previous Literature

Study	Focus Area	Key Findings	Limitations
Talib (2021), Yulianto (2016)	Challenges in peat soil reinforcement	Highlighted the inadequacy of traditional methods like soil replacement and chemical stabilization.	Limited exploration of innovative or combined reinforcement techniques.
Sari and Istiatun (2022)	Effectiveness of geotextile reinforcement	Improved safety factors and reduced settlement in cohesive soils.	Did not address geotextile interaction with peat soils.
Arsyad et al. (2020)	Long-term performance of geotextile reinforcement	Demonstrated reduced settlement over time for embankments on soft soils.	Focused on soft soils, excluding highly compressible peat soils.
Dewi (2020)	Role of cerucuk wood piles in soil improvement	Improved bearing capacity of peat soils using submerged cerucuk piles.	Limited to small-scale setups; did not explore combined reinforcement

			methods.
Suyuti and Rizal (2023)	Cerucuk-reinforced embankments	Emphasized the importance of pile spacing and embedment depth for performance.	Did not explore integration with geotextiles.
Luthfiyyah and Kusumah (2023)	Combined reinforcement with bamboo cerucuk and geotextiles	Achieved significant CBR improvement from 0.76% to 20.59%.	Focused on bamboo cerucuk; did not investigate Mahang wood piles.

2.3 Research Gap and Contribution

While previous studies have emphasized the benefits of geotextiles and cerucuk wood piles separately, there is limited research on their combined application in peat soils. This study aims to fill this gap by assessing the combined effects of woven geotextiles and cerucuk wood piles on the stability of peat soils in Pekanbaru. The research seeks to offer practical recommendations for sustainable and cost-effective soil reinforcement methods by addressing this issue.

CHAPTER 3
THEORY

3.1 Problems of Embankments Over Soft Soils

Recent global developments have increased the demand for embankments in various infrastructure projects, including highways, railways, flood control, irrigation, and airport and harbour installations. This surge in construction has made it necessary to build embankments on weaker, more compressible soft soils. However, constructing embankments on these soils is impractical without first implementing soil improvement measures (Russell, 1992). Embankments built on peat, an organic-rich soil, often face significant geotechnical challenges due to the natural properties of the soil (Balasubramaniam, 2010), making them unsuitable for supporting heavy loads without substantial ground improvement techniques (Mamat, 2019). Soft soils are increasingly encountered in road construction projects, which require specialized foundation designs (Chai et al., 1994) to ensure long-term stability and performance (Herrmann, 2014). A successful foundation design is typically evaluated based on several factors, including embankment pavement rideability, reduced maintenance costs, and consistent structural performance. Overall, embankments face a variety of challenges that must be addressed to ensure their effectiveness and durability.

3.1.1 Low Shear Strength

Shear strength is a critical factor in assessing a soil's ability to withstand sliding or failure under various loads. In embankment construction, low shear strength can significantly impact the soil's capacity to support both the embankment and any additional loads, leading to potential stability issues:

1. Slope Instability: Weak soils may be prone to slope failure or sliding, particularly when subjected to lateral loads or water flow.
2. Bearing Capacity Failure: Inadequate shear strength can hinder the soil's ability to support applied loads, which may lead to differential settlement, tilting, or even embankment collapse.

3.1.2 High Compressibility

Compressibility is the tendency of soil to decrease in volume when subjected to load. Peat soils, with their high organic content and low bulk density, exhibit significant compressibility, leading to several issues:

1. Excessive Settlements: Peat undergoes both primary and secondary consolidation, resulting in excessive settlements over time. This can cause uneven surface damage to the embankment and disrupt services situated on it.
2. Long-Term Instability: Due to their high compressibility, peat soils often experience prolonged settlement periods that can last for years or even decades. This continuous settlement undermines the long-term stability and integrity of the embankment, leading to costly maintenance requirements.

3.2 Factors Contributing to Embankment Problems

1. Soil Composition: High organic content, such as decomposed plant material found in peat, decreases its effective strength and increases compressibility.
2. Water Content: Peat typically has a high water content, which reduces shear strength and increases compressibility, leading to further settlement and instability.
3. Load Characteristics: The magnitude, distribution, and loading rate from embankment traffic directly influence soil deformation and settlement.
4. Environmental Conditions: Climatic factors like rainfall, temperature fluctuations, and vegetation growth can alter the physical and chemical properties of peat soil, impacting its strength and compressibility.

3.3 Properties of Peat as a Soft Soil

Peat is a soft soil that forms in swamps, mountains and marshes from the partial decomposition of organic plant material (Prabowo, 2021) and properties include high organic content, low density, and very high moisture content. Marshes are wetlands where water covers the ground for long periods. Unlike swamps dominated by trees, marshes are usually treeless and dominated by grasses and herbaceous plants. These attributes lead to significant construction challenges.

1. High Organic Content: Peat soil consists primarily of organic matter up to 95–99%, which includes plant fibres, roots, and decayed wood, reducing its strength, making it less capable of bearing loads, causing instability and compressibility.
2. Low Density and High-Water Content: Peat density varies greatly depending on water content and degree of decomposition. Wet Peat has an extremely low bulk density ranging between 8.83–12.26 KN/m³, which is much lower than mineral soils. Water content retention attributed to its fibrous-pores structure ranges from 200% to 900% of its dry weight, causing absorption up to 13 times its dry weight. Capillary action makes peat soil very compressible under loads.
3. Compressibility and Construction Challenges: Peat is highly compressible due to its low density, high moisture, and organic content, making it a challenging material for construction. When subjected to loads, it undergoes differential settlement, deformations and instability of Embankments because of low shear strength undermining its ability to support heavy structures effectively.
4. Specific Gravity: Peat soil specific gravity ranges from 1.1 to 1.8, with values exceeding 2.0 in mineral contamination presence. Its low density contributes to compressibility, making it unsuitable for bearing heavy loads without reinforcement.
5. Void Ratio and Shrinkage: Peat soil's high void ratio, a large portion of its volume, is made up of voids. Upon drying, it experiences significant shrinkage, ranging from 23% to 90%, depending on type and location. This shrinkage complicates its use in construction as it leads to settlement and structural instability.
6. Permeability: Peat's high permeability allows water to flow freely through it. However, as peat becomes compressed under load, permeability decreases dramatically. After long-term loading, it drops by several orders of magnitude, slowing the drainage process and extending the time required for consolidation
7. Shear Strength: The shear strength of peat is generally low and varies based on its decomposition and moisture content. Field and laboratory tests indicate that its shear strength increases with depth at deeper levels and it remains low

compared to other soils as shallow peat layers may have a shear strength as low as 3.45 KN/m^2 while deeper layers have a shear strength of 29.21 KN/m^2

8. Bearing Capacity: The bearing capacity of peat is similarly low due to its compressibility and low shear strength. The ultimate bearing capacity of peat can be as low as 68.94 KN/m^2, which is insufficient to support loads. This necessitates the use of reinforced methods, preloading, geotextiles and installation of wooden micro piles (e.g., cerucuk)

3.4 Improving Soft Soil Embankment Stability Using Mechanical Methods

For stability during construction, several techniques can be employed. Stage construction allows for embankments with steeper side slopes by taking advantage of increased undrained shear strength from soil consolidation soils (Chu et al., 2012). Various techniques are employed to improve the stability of embankments on such (Bilal, 2016).

3.4.1 Basal Reinforcement Using Geosynthetics

Basal reinforcement with geosynthetics is a widely adopted method to enhance the stability of embankments on soft soils. This method works by mobilizing the tensile strength of the geosynthetic material, which increases the load-bearing capacity of the foundation and reduces soil deformations. The use of geosynthetic basal reinforcement for embankments is illustrated in Figure 3.1 (Bilal, 2016).

Figure 3.1 Geosynthetic basal reinforcement for embankments (Bilal, 2016)

Basal reinforcement counteracts forces that lead to embankment failure as explained below.

1. Lateral Sliding: Embankment slides over the basal reinforcement layer.
2. Foundation Bearing Capacity Failure: Foundation material deform due to insufficient strength.
3. Rotational Slope Failure: Embankment fails along a circular slip surface.

Basal reinforcement is effective against rotational slope failure which is the most critical under normal conditions by,

a. Providing tensile strength to resist deformations and effectively increasing the foundation bearing capacity.
b. Shear stress reduction in fill material and foundation soil contributes to stability.
c. Prevention of rotational failures effectively preventing rotational slip failures.

3.4.2 Soil Replacement

For soft soils with limited depth and thickness, the removal of unsuitable material and replacement with well-compacted suitable fill are normally carried out. This required on naturally occurring low shear strength and high moisture content soils.

3.4.3 Preloading with PVDs

Preloading is a method that can successfully be used to densify soft cohesive soils (V.N.S. Murthy, 2007). Large construction sites composed of organic soils such as peat and other compressible soils may often be stabilized effectively and economically by preloading. Preloading compresses soils by removing water from the pores of the soil which amounts to artificial consolidation of soil in the field. To remove the water squeezed out of the pores and accelerate the period of consolidation, horizontal and vertical drains are required to be provided in the mass (Abdulnafaa, 2020), Preloading, also known as pre-compression, is applied to stabilize soft soils by compressing them under vertical stress before construction. This process accelerates soil consolidation, enhancing the soil's strength and reducing its compressibility, thereby minimizing future settlement beneath embankments. Typically, preloading involves applying a load in the form of an earth fill, which is left in place long enough to induce consolidation. The progress of consolidation can be monitored by using settlement plates and piezometers. The greater the surcharge load applied, the shorter the time required for consolidation. In the preloading process, a load (usually in the form of an embankment) is applied in stages to prevent stability issues. Initially, the soft soil supports the load through increased pore water pressure, which gradually decreases as the water drains out. A surcharge load is used when the temporary load exceeds the final construction load to ensure proper consolidation. The preloading of soil is depicted in Figure 3.2 (Murthy, 2007).

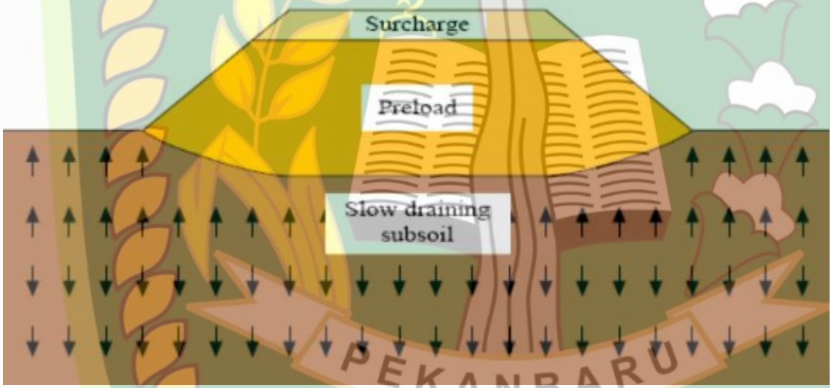


Figure 3.2 Preloading of soil with PVD (Murthy, 2007)

3.4.4 Micro Piles

Micro piles are innovative solutions used in geotechnical engineering to enhance soft soil stability and strengthen foundations. Small-diameter drilled and grouted micro piles have gained widespread adoption in recent years for reinforcing unstable soils by withstanding significant axial and lateral loads. They are effective in areas with limited equipment access, such as steep-slope mountainous regions (Sun, 2014). They can be installed in any soil or rock conditions to resist compression, tension and lateral loads. Their application in slope stabilization involves optimizing pile positions, depth of embedment, and lengths to enhance safety factors and bearing capacity and minimize settlement. The critical embedment depth should be approximately twice the length of the micro pile. Figure 3.3 shows the installation process of micro piles.

Figure 3.3 Micro piles soil reinforcement (Sun, 2014).

3.5 Soil Reinforcement with Geotextiles and Wooden Micro Piles

Wooden piles have been used since ancient times. The lengths of timber piles depend on the types of trees used to harvest the piles, but common lengths are about 6-12 m. To address Embankment Stability challenges on peat soil, an innovative combined reinforcement technique of geotextiles and wooden micro piles has been developed and increasingly employed (Suyuti and Rizal, 2023) in Indonesia.

Geotextiles are increasingly popular synthetic materials used to reinforce and improve soil structural properties by distributing loads and reducing excessive settlement across the embankment. They achieve this by providing a separation layer to prevent the mixing of soil layers, thereby maintaining the integrity of the embankments by providing lateral support and improving the bearing capacity of soft soils. The failure pattern of bearing capacity of soft subgrade reinforced with geotextile is shown in Figure 3.4 (Suyuti and Rizal, 2023).

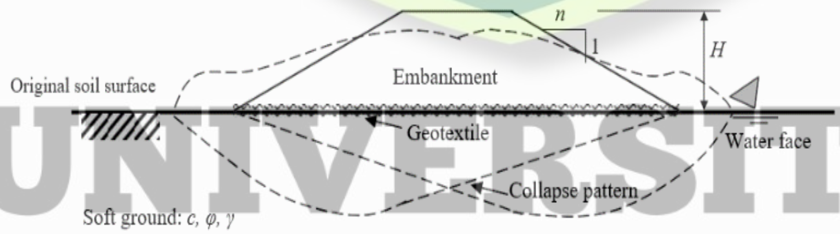


Figure 3.4 Bearing capacity failure pattern of geotextile-reinforced soft subgrade (Suyuti and Rizal, 2023)

Cerucuk wood piles are vertical reinforcement elements used to strengthen soft soils with low shear strength, such as peat (Rusdiansyah, 2016) Typically made from low-quality wood like Mahang (Sudarwanto, 2017), they are installed in a grid pattern using an excavator with a 1-ton force to improve slope stability by limiting soil movement along the sliding surface.

The effectiveness of cerucuk piles depends on factors like embedment length, spacing, diameter, and soil type. Optimal spacing of 3D to 5D enhances shear resistance, while cutting through slip surfaces at 30° and 45° angles improves stability. By transferring loads to deeper, stable soil layers, cerucuk piles reduce settlement and structural failure, making them a cost-effective, sustainable, and eco-friendly reinforcement method.

The combination of woven geotextile and cerucuk wood piles offers a synergistic approach to embankment stability, effectively distributing loads and improving soft soil performance Figure 3.6 (Sudarwanto, 2017).

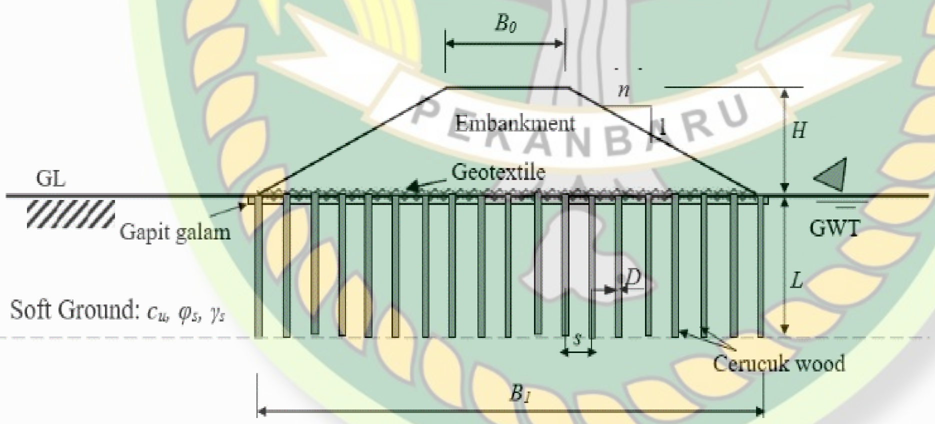


Figure 3.5 Integration of woven Geotextile and cerucuk wood piles on soft soil for Embankment construction (Sudarwanto, 2017)

Woven geotextiles help to manage and distribute loads effectively across the embankment, while wooden micro piles provide essential support by anchoring the structure and transferring loads from the embankment to more stable hard soil layers. This integrated method not only enhances the stability and durability of embankments on soft soils but also aligns with sustainability and environmentally friendly.

3.6 Theoretical Analysis of Embankment on Soft Soil

The analysis of embankments on soft soils involves understanding both the stability and settlement of the soil and structure system. Theoretical approaches to analyze the embankments are categorized into analytical and numerical methods. These methods are essential for modelling the behavior of the embankment and predicting its performance under various conditions.

3.6.1 Analytical Methods by Meyerhof's Bearing Capacity Theory (1976)

Meyerhof proposed a widely accepted empirical method in geotechnical engineering for determining the bearing capacity of a pile foundation. This method is shown in Figure 3.7, which provides a practical approach for design by linking measurable soil properties, such as Standard Penetration Test (SPT) N-values, to the pile's load-carrying capacity. It's particularly beneficial when direct testing or advanced numerical modelling is not feasible.

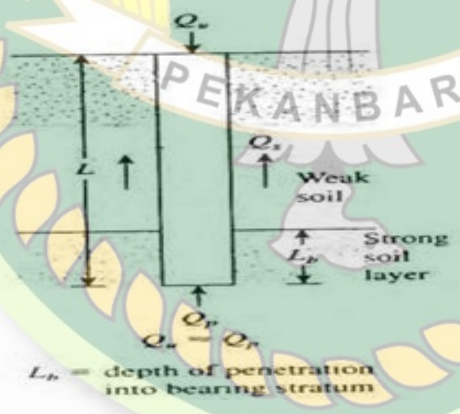


Figure 3.6 Meyerhof's Ultimate load distribution of piles (Das,2009)

Meyerhof proposed empirical relationships that link soil parameters (such as SPT N-values) with the pile's ultimate capacity, combining skin friction and end-bearing resistance as given by equation 3. Skin (shaft) friction accounts for friction between the pile surface and the surrounding soil. This frictional resistance is often derived using empirical relationships equation 1.

$$Q_s = W \times f_i \times Li \quad (1)$$

End-bearing resistance, which depends on the pile's cross-sectional area and the soil strength at the pile tip, is typically estimated using the SPT N-value as given by equation 2.

$$Q\_p = k \times N \times A \quad (2)$$

$$Q\_u = Q_p + Q_s \quad (3)$$

3.6.2 Finite Element Method (FEM)

Finite Element Method (FEM) is a robust numerical method, and a tool approach extensively employed in geotechnical engineering (Khan, 2014) for analysing soil-structure interactions. It subdivides a complex domain into smaller, simpler elements, enabling the precise computation of stresses, strains, and displacements. FEM is particularly effective for geotechnical problems involving layered soils, structural reinforcements, and time-dependent consolidation behaviour. Among the available tools, PLAXIS 2D a finite element pack (Khan and Abbas, 2014) age, developed specifically for the analysis of deformation and stability in geotechnical engineering projects (Bentley, 2012) stands out as a specialized geotechnical finite element software designed to assess and analyze soil deformation and stability. It integrates user-friendly graphical interfaces, robust and reliable calculation algorithms, and comprehensive detailed output visualization, making it highly effective for addressing complex geotechnical challenges.

In this study, a FEM analysis on embankments is constructed over soft soil (Wulandari and Tjandra, 2015). This allows for the detailed simulation analysis of complex soil behaviors, enabling a precise evaluation of settlement patterns under various loading conditions before and after soil reinforcement techniques are added using Cerucuk wood piles and woven geotextiles, providing insights into their combined impact on enhancing the embankment's reduced settlement.

3.6.3 Basic Finite Element Method Theory

FEM is based on the principle that a complex system can be divided into smaller elements connected at nodes. Each element is assigned properties such as stiffness, strength, and material behaviour, and the governing equations are solved using numerical integration. The fundamental steps in FEM include.

1. Discretization (Meshing)

   The domain (soil, structure) is divided into finite elements, such as triangular or quadrilateral elements, allowing numerical calculations to approximate stress and strain distributions.

2. Constitutive Soil Models

   Different soil models can be used based on the material behaviour, including:

   a) Mohr-Coulomb Model: A basic elastic-plastic model suitable for general soil analysis.

   b) Hardening Soil Model: Accounts for non-linear stress-strain behavior, appropriate for compressible peat soils.

   c) Soft Soil Model: Captures the high compressibility and low shear strength of organic peat.

3. Selection of Element Type

   In geotechnical applications, elements commonly used include

   a) Continuum elements (for soil layers)

   b) Beam elements (for structural components like cerucuk wood piles)

   c) Interface elements (to simulate interactions between soil and reinforcement)

4. Boundary Conditions and Load Application

   Defining constraints, loading conditions, and external influences such as groundwater pressure and surcharge loads.

5. Solution Process

   FEM software like PLAXIS 2D solves these equations iteratively, using numerical solvers such as Newton-Raphson for nonlinear problems.

6. Load Application

   Embankment loads, traffic loads, and water table effects are included to reflect real-world construction conditions.

7. Staged Construction Simulation

   Load increments are applied progressively to mimic actual construction sequences and consolidation effects.

3.6.4 FEM Implementation in PLAXIS 2D for Peat and Cerucuk Wood Piles

PLAXIS 2D is a specialized FEM software designed for geotechnical analysis, allowing for the simulation of complex soil-structure interactions.

1. Soil Model Representation

Peat soil exhibits highly nonlinear and time-dependent behaviour due to its high organic content and compressibility. To accurately model peat in PLAXIS 2D, the Soft Soil Model, is specifically designed for highly compressible soils like peat, incorporating creep behavior.

Key soil input parameters include:

a) Shear strength parameters (cohesion, friction angle)
b) Elastic modulus (E) and Poisson’s ratio (v)
c) Permeability (k) and consolidation properties
d) Unit weight and void ratio

2. Cerucuk Wood Pile Modeling

Cerucuk wood piles act as vertical reinforcement elements to improve the bearing capacity of peat soil and reduce settlement. In PLAXIS 2D, cerucuk can be modelled as Embedded Beam Elements, representing the piles as beam elements that interact with the surrounding soil through skin friction and end-bearing resistance.

Key input parameters for cerucuk modelling include

i) Young’s modulus (E) of the wood
ii) Diameter and length of the piles
iii) Skin friction and end-bearing capacity
iv) Installation depth relative to groundwater level

3.6.5 Key Features of PLAXIS 2D

1) Soil-Structure Interaction: The finite element method models the interaction between the embankment and underlying soft soils, capturing stress distributions, deformations, and changes in pore water pressure. This feature is particularly vital for peat soils. The software utilizes advanced constitutive models, such as Mohr-Coulomb and Hardening Soil, to represent the nonlinear and time-dependent behaviour of peat.

2) Construction Phasing: The staged construction modeling feature enables the simulation of real-world embankment construction processes. This approach allows for incremental loading, which helps to account for the consolidation of soft soils over time, a critical factor for achieving stability.

3) Pore Pressure and Consolidation: The software effectively models and simulates the effects of pore water pressure, as well as the long-term consolidation behavior of soft soils. This capability is essential for predicting both immediate and delayed settlements at the UFCSI site, ensuring accurate long-term settlement predictions and performance evaluations of the embankment system over peat soil.

3.6.6 Model Setup and Analysis in PLAXIS 2D

To accurately simulate the behaviour of the embankment on peat soil reinforced with cerucuk piles, the following steps are undertaken in PLAXIS 2D.

1. Geometry Definition: The embankment, peat soil layers, and cerucuk pile arrangement are defined within the model.
2. Mesh Generation: A finite element mesh is created, with a finer mesh applied around cerucuk piles and soil-structure interfaces to enhance accuracy, particularly in high-stress concentration areas such as beneath the embankment base.
3. Boundary Conditions: Real-world constraints are replicated by fixing lateral and bottom boundaries to simulate field conditions effectively.
4. Load Application: The embankment load, traffic loads, and water table effects are incorporated into the model to reflect actual construction conditions.
5. Staged Construction Simulation: Incremental loading is applied to mirror real-world construction sequences and assess consolidation behaviour over time.
6. Settlement and Consolidation Analysis: The software calculates total displacement, stress distributions, and settlement behaviour, ensuring accurate performance evaluation of the embankment system.

3.7 Input Parameters for the PLAXIS 2D Model

The model incorporates geotechnical parameters derived from site-specific laboratory tests and field data, ensuring realistic simulations.

a) Soil Properties:

The mechanical properties of peat, such as Cohesion, internal friction angle, permeability, and compressibility, are derived from laboratory tests. These properties are critical for modelling the real behaviour of the underlying peat soil.

b) Geotextile Reinforcement: Geotextiles are modelled as geogrid elements acting as a separation layer and providing lateral stability to the Embankment. They will be simulated to evaluate their role in reinforcing the embankment, improving the bearing capacity and stability, and minimizing excessive deformation and settlement.

c) Cerucuk Wood piles: Represented as plate reinforcement elements in the model, Cerucuk wood piles transfer the embankment's loads to deeper and more stable soil layers. They significantly improve bearing capacity and mitigate settlement.

3.7.1 Analytical Approach

a) Mesh Generation: A finite element mesh will be generated for both the embankment and the underlying peat soil. A finer mesh will be used in areas with expected high-stress concentrations, such as beneath the embankment base and near the wooden piles to ensure better accuracy in simulating soil behaviour.

b) Boundary Conditions: Appropriate boundary conditions will be applied to the model, reflecting real-world constraints such as fixed or free-soil boundaries, crucial for accurately predicting soil deformations and stress distributions.

c) Loading Conditions: loads will be applied simulating the actual construction process and subsequent traffic loads. This approach allows for an accurate analysis of the embankment’s behaviour under various real-world conditions.

d) Settlement and Consolidation Analysis: The software will calculate the total settlement of the embankment.

3.8 Limitations of Wooden Piles in Soft Soil

Wooden piles, such as Cerucuk, have been traditionally used in Indonesia for geotechnical engineering in reinforcing soft soils. Wood piles are susceptible to termites, marine organisms, and rot within zones exposed to seasonal changes. While they offer an environmentally friendly and cost-effective solution for improving the stability of embankments on peat soils, they come with several limitations that must be considered to ensure their long-term effectiveness.

1. Submersion below the groundwater table: One of the most critical requirements for the effective use of wooden piles is that they must remain submerged below the groundwater table by at least 30 cm. This is essential to prevent the decay of the timber, which is vulnerable to deterioration if exposed to air due to oxygen-dependent microbial activity. Prolonged exposure to oxygen can cause fungal decay, significantly reducing the strength and lifespan of the piles.
2. Code and standards: Standards such as BS 8004 recommend that untreated wooden piles remain continuously submerged to prevent decay. If the groundwater level fluctuates, proper monitoring and adjustments may be required to ensure the piles remain below the critical depth.
3. Durability and material quality: The quality and type of wood used for Cerucuk piles can also affect their performance in soft soils. Mahang wood, commonly used for Cerucuk, is not as durable as other types of timber, especially when exposed to harsh environmental conditions. Over time, wooden piles may experience loss of strength due to,
   a) Biological degradation: If the piles are not treated or preserved properly, they are prone to rot, particularly in environments where they are exposed to wet-dry cycles or high-organic-content soils like peat.
   b) Mechanical damage: Driving the piles into the ground may cause structural damage, such as cracking or splitting, that can reduce load-bearing capacity.
   c) Water Absorption and Swelling: Excessive water retention can lead to dimensional instability, reducing the structural integrity of the piles.
   d) Chemical Deterioration: Prolonged exposure to acidic peat conditions may weaken the wood fibres, accelerating degradation.

e) Rot and Fungal Growth: When exposed to fluctuating groundwater levels, cerucuk piles may decay faster due to fungal colonization, particularly if they are not submerged continuously.

4. Load-bearing capacity: Although wooden piles provide increased bearing capacity for soft soils, their load-bearing capacity is generally lower compared to other modern reinforcement materials such as steel or concrete piles. In cases where heavy loads or large embankments are involved, Cerucuk piles may not offer sufficient support without additional reinforcement methods like geotextiles.
5. Limited depth of penetration: Cerucuk piles typically have limited lengths, and their installation depth is constrained. In very deep layers of soft peat soils, wooden piles may not reach the more competent soil layers needed to fully transfer loads. This can limit the effectiveness of the reinforcement in providing long-term stability, especially for high embankments.
6. Susceptibility to lateral movements: In soft soils, lateral movements can pose a challenge for wooden piles. When subjected to lateral loads or significant soil movement, such as in areas prone to flooding or settlement, wooden piles can bend or break, compromising the stability of the embankment. This makes them less suitable in situations where horizontal forces are prevalent.
7. Maintenance requirements: Wooden piles may require ongoing maintenance or monitoring, particularly if groundwater levels fluctuate or if the environment becomes more prone to decay. Inspections are necessary to ensure the piles are performing as intended and have not been compromised by environmental or mechanical factors.

3.9 Properties of Geotextiles

1. Tensile Strength: Geotextiles, particularly woven types, exhibit distinct responses to tensile loading due to being more extensible and less stiff, making them suitable for specific applications. These tensile properties are typically tested under confined stresses, with methods such as strip or grab tests commonly used to measure strength and elongation characteristics.

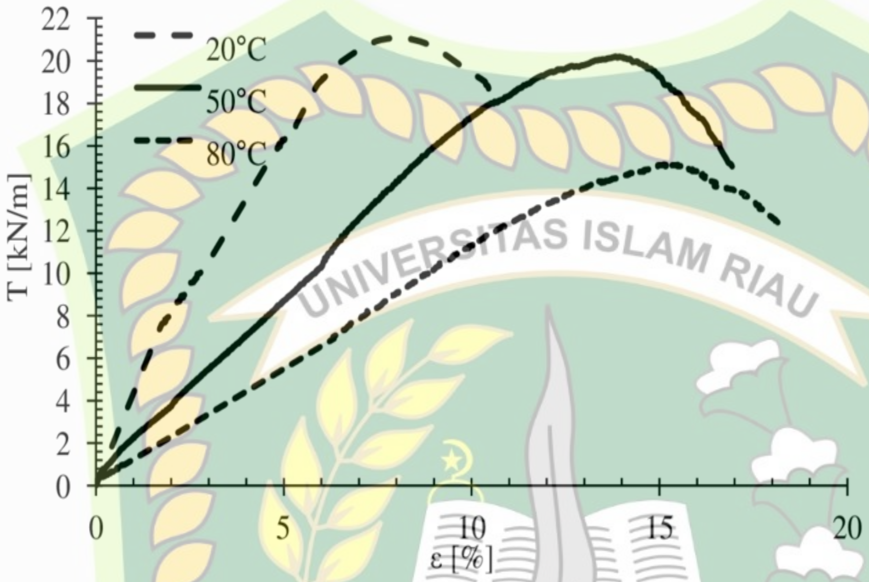


Figure 3.7 Relationship between load per unit and strain for tested woven geotextile (Koda et al., 2018)

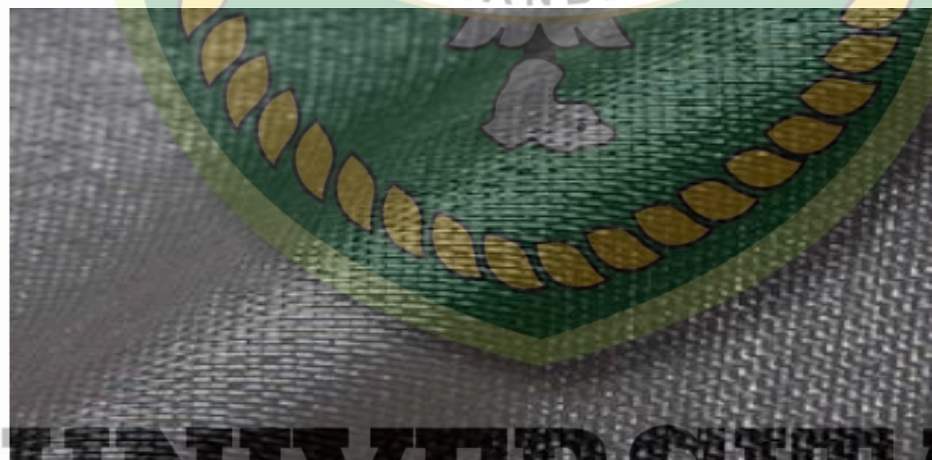


Figure 3.8 Geotex 315ST - Woven Geotextile Fabric - 12.5' x 360'

2. Frictional Behavior: Geotextiles depend on surface friction and interlocking with the surrounding soil to improve stability. The interaction between soil and geotextile is classified into two main mechanisms: shearing and pull-out interactions. These mechanisms are crucial for applications such as road and railway embankment reinforcements, where they contribute to the overall stability and load distribution of the structure.
3. Compressive Behavior: Geotextiles absorb energy from both static and dynamic loads, such as those generated by road traffic. Their compression characteristics are essential in assessing how well the geotextile retains its structural integrity after being subjected to loading, ensuring long-term performance and durability in various applications.
4. Permeability: Geotextiles possess hydraulic properties determined by their porosity, with in-plane transmissivity and cross-plane permeability governing the movement of water through the material. These characteristics are crucial for applications involving filtration and drainage, where effective water management is necessary to maintain stability and prevent erosion.

3.10 Soil Parameters and Their Importance

Soil parameters serve as measurements or benchmarks to assess changes occurring within the soil, including its physical properties and type. The following are several parameters that can be used as references.

3.10.1 Shear Angle (φ)

The shear angle (φ) represents the internal friction angle of the soil, which is a measure of its ability to resist shearing forces. This angle is formed by the relationship between normal stress and shear stress within soil or rock material. It represents the fracture angle created when a material is subjected to stress or force exceeding its shear strength. The larger the internal friction angle of a material, the more resistant it is to external stresses. Together with cohesion, the internal friction angle is a soil parameter used to determine the soil's resistance to deformation caused by applied stress, particularly lateral movement, depending on the soil type.

The magnitude of the internal friction angle is also related to the density of a specific soil type. The relationship between the internal friction angle and soil type is illustrated in Table 3.1

Table 3.1 Shear Angle Based on Soil Density (Bowles, 1989)

Density	Shear Angle (φ)
Very loose	<30°
Loose	30°–35°
Moderately dense	35°–40°
Dense	40°–45°
Very dense	>45°

3.10.2 Cohesion (C)

Cohesion is the soil's ability to stick together, which directly influences its shear strength. It is proportional to soil density. Cohesion is also defined as the attractive force between soil particles. The cohesion value (C) is obtained through laboratory tests, such as the direct shear strength test and the triaxial test. Soil cohesion increases as its shear strength becomes greater. The magnitude of cohesion is also influenced by the density and spacing between molecules in a material. Cohesion is directly proportional to the density of a material; thus, higher density results in greater cohesion. Deformation occurs due to a combination of critical conditions involving normal stress and shear stress that do not align with the planned safety factor (Hardiyatmo, 2002). The relationship between unconfined compressive strength (qu) and the consistency of clay soil is illustrated in Table 3.2.

Table 3.2 Unconfined Compressive Strength (qu) (Hardiyatmo, 2003)

Consistency	q_u (KN/m²)
Hard clay	>400
Very stiff clay	200–400
Stiff clay	100–200
Medium clay	50–100
Soft clay	25–50
Very soft clay	<25

3.10.3 Poisson Ratio (μ)

Poisson's ratio (μ) is defined as the ratio of axial compression to lateral expansion strain. In soil mechanics, Poisson's ratio is often assumed to range between 0.2 and 0.4. The specific value of Poisson's ratio can be determined based on the soil type is illustrated in Table 3.3 (Hardiyatmo, 2002).

Table 3.3 Estimated Poisson Ratio (μ) (Hardiyatmo, 2002)

Soil type	Poisson Ratio (μ)
Saturated clay	0.4–0.5
Unsaturated clay	0.1–0.3
Sandy clay	0.2–0.3
Silt	0.3–0.35
Dense sand	0.2–0.4
Coarse sand	0.15
Fine sand	0.25
Rock	0.1–0.4

3.10.4 Specific Gravity (Gs)

The specific gravity of soil is the ratio of the unit weight of the material to the unit weight of water. The value of G_s can also be determined based on the soil type. The specific gravity values for different soil types are illustrated in Table 3.4.

Table 3.4 Specific Gravity Based on Soil Type (Hardiyatmo, 2002)

Soil type	Specific Gravity (Gs)
Gravel	2.65–2.68
Sand	2.65–2.68
Inorganic silt	2.62–2.68
Organic clay	2.58–2.65
Inorganic clay	2.68–2.75
Humus	1.37
Peat	1.25–1.80

3.10.5 Dilatancy Angle (ψ)

The dilatancy angle (ψ) is the angle formed between the horizontal plane and the direction of expansion when soil particles are subjected to stress. Clay soils tend to show no dilatancy, meaning $\psi = 0$. The dilatancy in sandy soils depends on the density and shear angle. The dilatancy angle can be calculated using $\Psi = \phi' - 30^0$.

3.10.6 Permeability (k)

Permeability measures how easily water flows through soil. The permeability coefficient based on soil type is given in Table 3.5.

Table 3.5 Permeability Coefficient Based on Soil Type (Das, 1995)

Soil type	k (cm/s)	k (ft/min)
Clean gravel	1.0–100	2.0–200
Coarse sand	1.0–0.01	2.0–0.02
Fine sand	0.01–0.001	0.02–0.002
Silt	0.001–0.00001	0.002–0.00002
Clay	<0.000001	<0.000002

3.10.7 Elastic Modulus (E)

The elastic modulus (E) measures soil stiffness and its resistance to deformation under load. It indicates soil elasticity and can be determined from stress-strain curves obtained from triaxial tests. Various methods exist for calculating the elastic modulus. The estimated elastic modulus based on soil type is detailed in Table 3.6.

Table 3.6 Estimated Elastic Modulus Based on Soil Type (Bowles, 1997)

Soil type	Elasticity Modulus (E) (kN/m^2)
Clay	
Very soft	300 – 3000
Soft	2000 – 4000
Medium	4500 – 9000
Hard	7000 – 20000
Sandy soil	
Sand	30000 – 42500
Silty soil	
Silty sand	5000 – 20000
Loose	10000 – 14000
Dense	20000 – 100000
Gravel and Sand	
Dense	80000 – 200000
Loose	50000 – 140000
Silt	2000 – 20000
Loess	15000 – 60000
Shale	140000 – 1400000

CHAPTER 4
METHODOLOGY

4.1 Introduction

This chapter describes the methodology for evaluating the combined use of woven geotextiles and cerucuk wood piles to improve peat soil at the Urban Flood Control System Improvement (UFCSI) site in Rumbai, Pekanbaru City, Indonesia. Based on secondary data from prior field investigations and geotechnical reports, the study employs finite element modelling. This involves defining soil layers, incorporating reinforcement elements, simulating embankment loading scenarios, and interpreting results to achieve the research objectives, ensuring accuracy and replicability in analyzing soil behaviour.

4.2 Research Location

The study area is the Urban Flood Control System Improvement (UFCSI) project located on Jl. Nelayan Rumbai Pesisir in Pekanbaru, Indonesia, as illustrated in Figure 4.1. The site features clay and peat that extend up to 11 meters deep. These materials exhibit high water content, low shear strength, and high compressibility, which pose significant challenges for construction.

Figure 4.1 Research location at UFCSI in Rumbai Jl. Nelayan Pekanbaru

4.3 Research Tools

This study primarily uses secondary data and the following tools for data processing and analysis:

1. Laptop/PC: For running analysis software and preparing documentation.

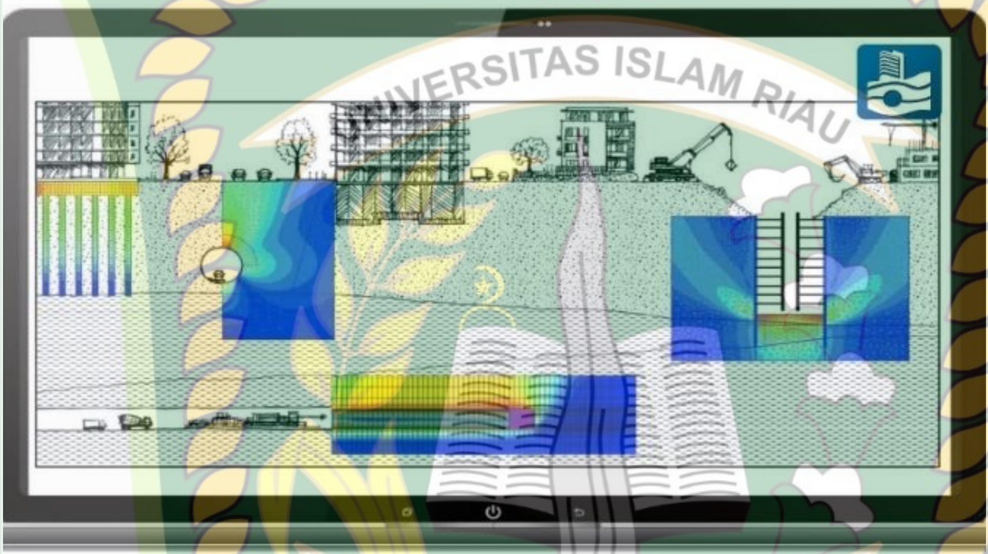


Figure 4.2 Laptop for Storing Data and Running Analysis Software

2. PLAXIS 2D Software: A geotechnical analysis tool used for simulating soil behaviour and evaluating the performance of woven geotextiles and cerucuk wood piles in improving peat soil.
3. Microsoft Excel: For organizing raw data (SPT results and geotechnical parameters) and performing basic calculations.

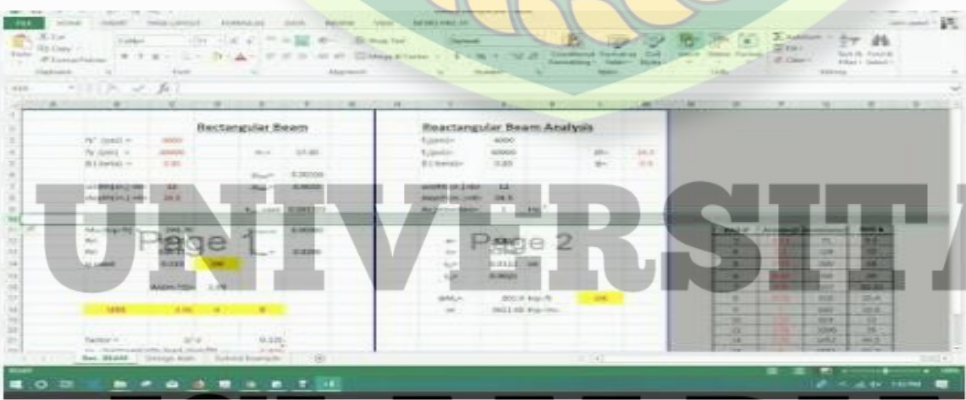


Figure 4.3 Microsoft Excel for organizing and processing raw data

4. Draw.io: Used to create flowcharts that visually represent the research procedure.

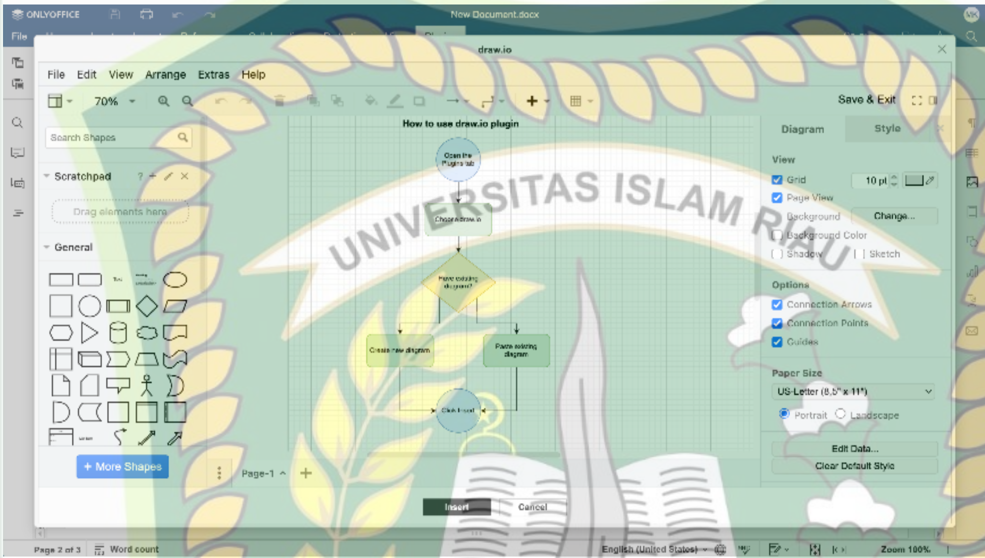


Figure 4.4 Draw.io flowcharts

5. Standard Office Tools: For preparing reports and organizing the final documentation.

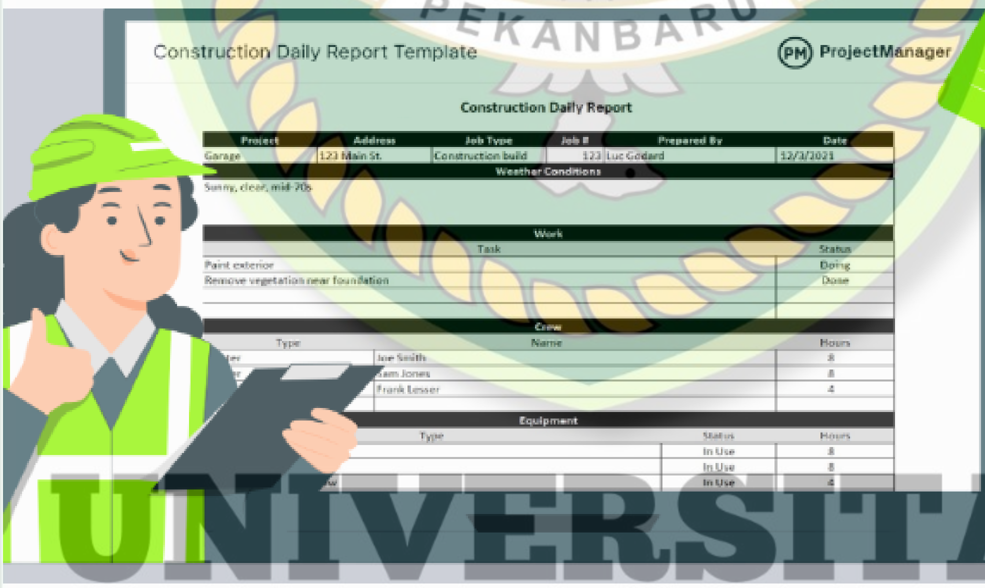


Figure 4.5 Microsoft Word for organizing data, writing reports.

6. Geotechnical Reports, Google Scholar, Field and Lab Data: Providing data on peat soil properties, including CPT and SPT results and laboratory tests.

4.4 Research Design

This research employs a secondary data analysis approach, relying on existing data from previous studies and official reports. The study does not involve field experiments but relies on existing data and software modelling for analysis. The research focuses on three (3) cases:

1. **Case 1**: Embankment on natural peat soil without reinforcement.
2. **Case 2:** Embankment on peat soil reinforced with woven geotextile only.
3. **Case 3**: Embankment on peat soil reinforced with cerucuk wood piles and woven geotextile.

4.5 Numerical modelling of Cerucuk Embedded Beams for the embankment

The numerical modeling of the embankment was conducted using the Finite Element Method (FEM) in PLAXIS 2D. The embankment had a height of 3.0 m and a width of 12 m, constructed over a subsoil profile extending 60 m in length. The subsoil consisted of the following layers, Clay layer 2 m Peat layer 9 m and Sand layer: 39 m as observed from borehole data (Figure 5.4 and Table 5.7)

4.5.1 Cerucuk Wood Embedded Beams

To model the reinforcement effect of cerucuk wood piles, the Embedded Beam Element Approach was employed in PLAXIS 2D. Each cerucuk pile had a diameter of 15 cm and a length of 4 m. This method represents slender reinforcement elements in soil environments, commonly used for pile foundations in medium to hard soil conditions (Sluis and Besseling, 2014). Unlike conventional plate elements, embedded beams do not require a direct connection to a soil cluster. Instead, they transfer loads through interface elements, allowing a more realistic representation of the pile-soil interaction (Sluis and Witteveen+Bos, 2013).

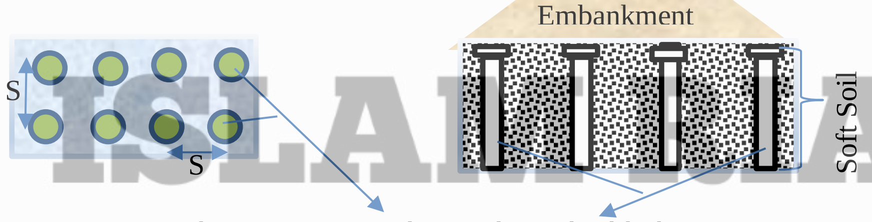


Figure 4.6 Cerucuk Wood - Embedded Beam

While embedded beams are an efficient tool for modelling pile reinforcement, their applicability in highly compressible peat soils is limited. Peat soils exhibit significant deformation characteristics, which may not be fully captured using the embedded beam formulation. Despite these limitations, this modelling approach was employed to analyze the load transfer behaviour and structural contribution of cerucuk reinforcement in peat soil conditions.

Further discussions on the performance, limitations, and potential refinements of this modelling approach are provided in the subsequent analysis and conclusion sections.

4.6 Research Procedure

The research procedure follows a systematic approach to data collection and analysis. Below is a generalized flow of the procedure:

1. Data Collection

   The data for this study is sourced from existing site geotechnical reports and previous Research Journal studies conducted in the research area particularly focusing on:

   a) SPT and CPT data mainly from the urban flood control system improvement (UFCSI) Jl. Nelayan, Rumbai, Pekanbaru City Indonesia.

   b) Geotechnical reports from Google Scholar and other geotechnical-related journals and reports concerning both soft soils, Geotextile and Cerucuk wood.

2. Data Analysis

The collected secondary data will be used as Input Data for finite element, a widely used, powerful, and user-friendly finite element software intended for 2D analysis of deformation and stability in geotechnical engineering and Rock mechanics. This study focuses on the deformation performance of embankment constructed over peat soil while addressing the three (3) cases we have discussed above.

This stage will follow a 5-step procedure for a well-organized and professional flow to produce realistic results for the analysis.

a) Soil Mode

i) Start the Input program and select Start a new project from the Quick Select dialog box.

ii) Define the subsoil properties layers and water lever in a borehole, construct the embankment over the subsoil and assign its properties.

Figure 4.7 Plaxis 2D Project Input Properties

iii) Modify soil layers in the Borehole

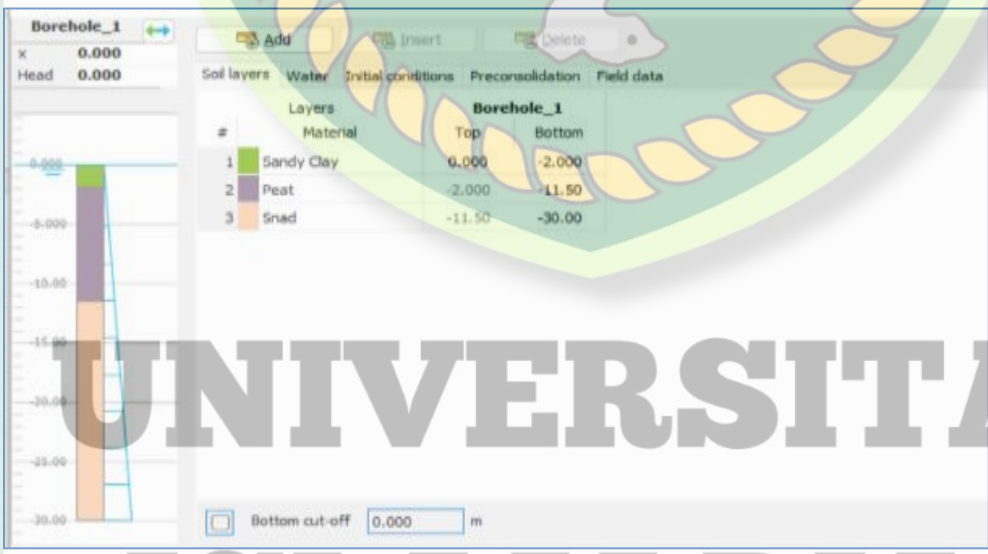


Figure 4.8 Modifying Soil Layers in the Borehole

iv) Material sets

Soil interfaces of Clay, peat, Sand and Embankment fill are set with their respective properties as well as Embedded beams for Cerucuk wood piles and Geogrids for Woven Geotextile.

Figure 4.9 Soil Interfaces Input Plaxis2D

b) Geometry model for discrete Cerucuk Wood pile modelled as Embedded Beams in Plaxis 2D.

A geometry structure for the embankment 3m high and B = 12 m wide is constructed over the soft soil, a surcharge of 5.2 KN/m^2 is applied on top of the embankment.

c) Mesh Generation

A medium mesh is required for a faster analysis and better results

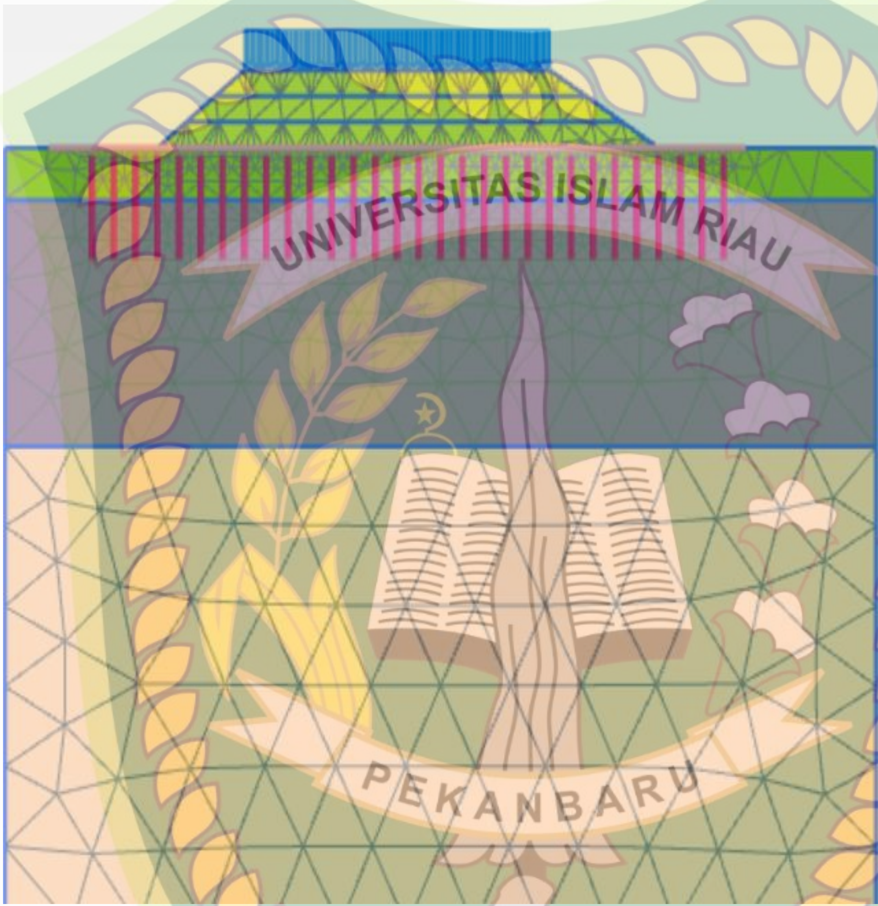


Figure 4.10 Generating mesh

d) Flow condition setup

Groundwater flow boundary conditions are applied to simulate drainage and pore pressure changes and consolidation against time phases is set for analysis

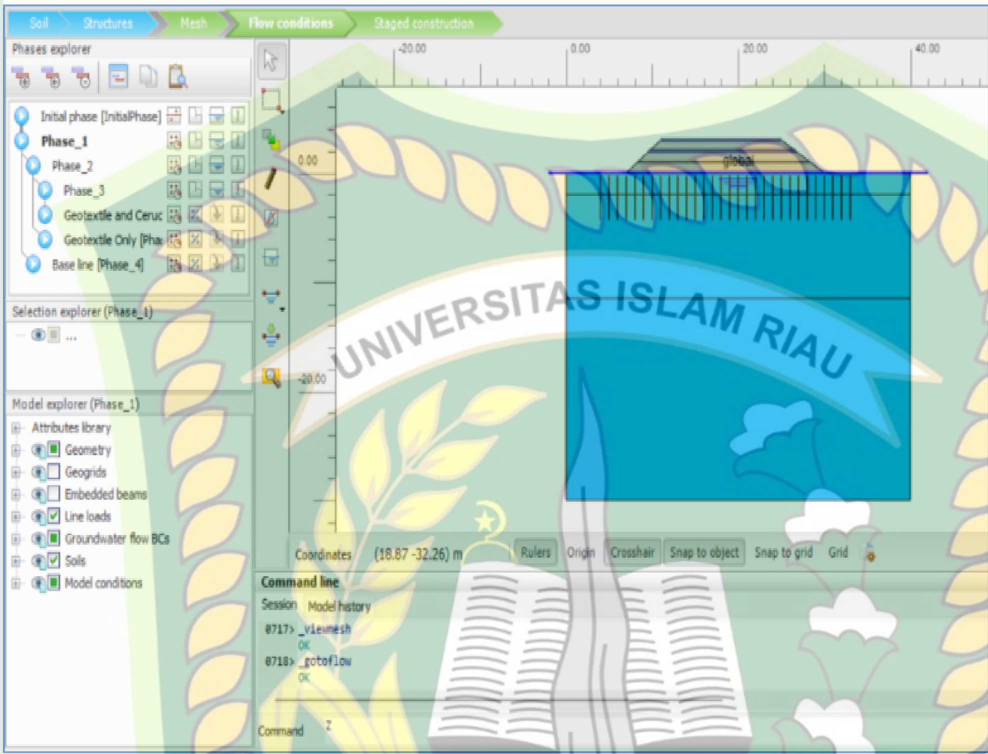


Figure 4.11 Flow condition setup

e) Calculations and Stage Construction

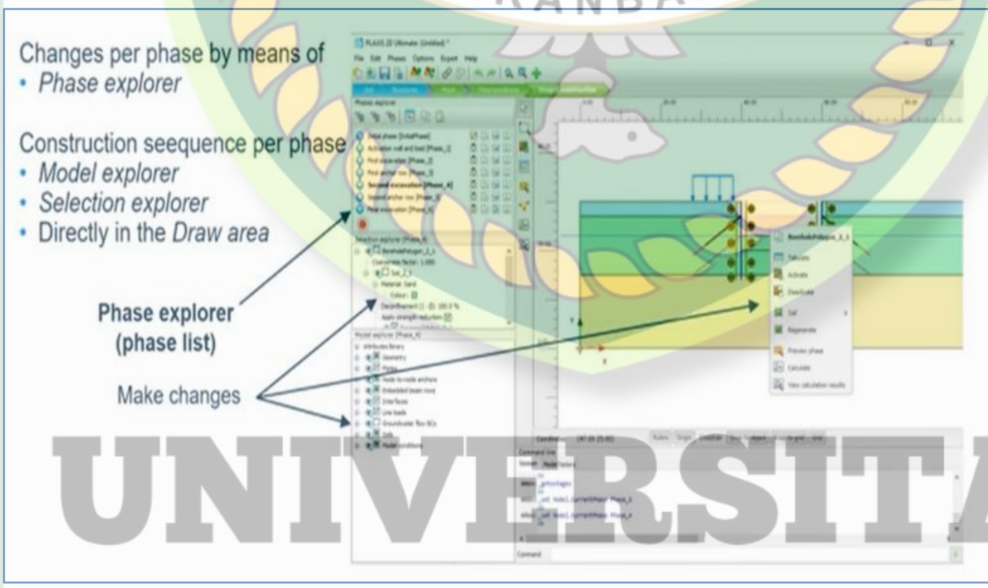


Figure 4.12 Calculations and Stage Construction by Bentley

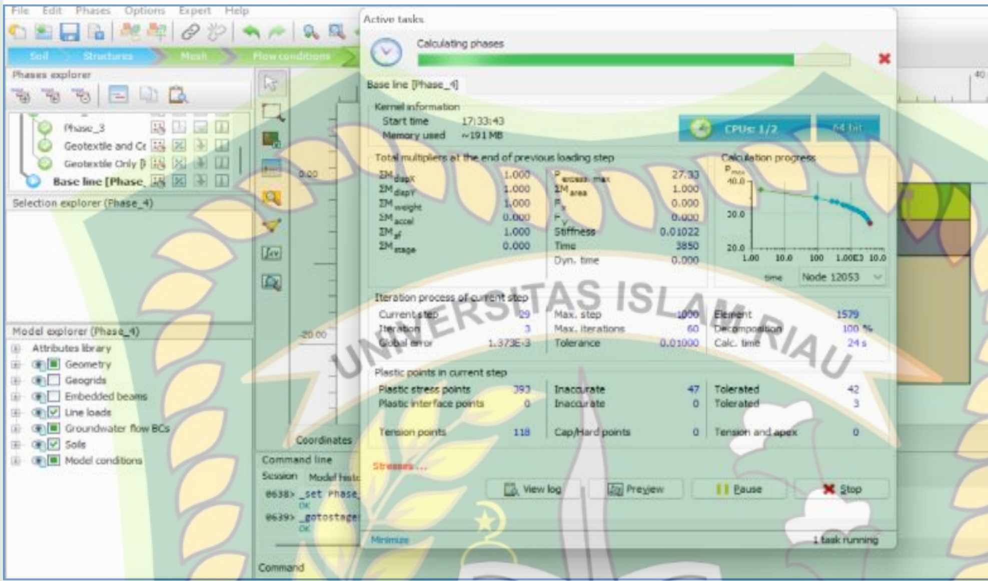


Figure 4.13 Calculation phase

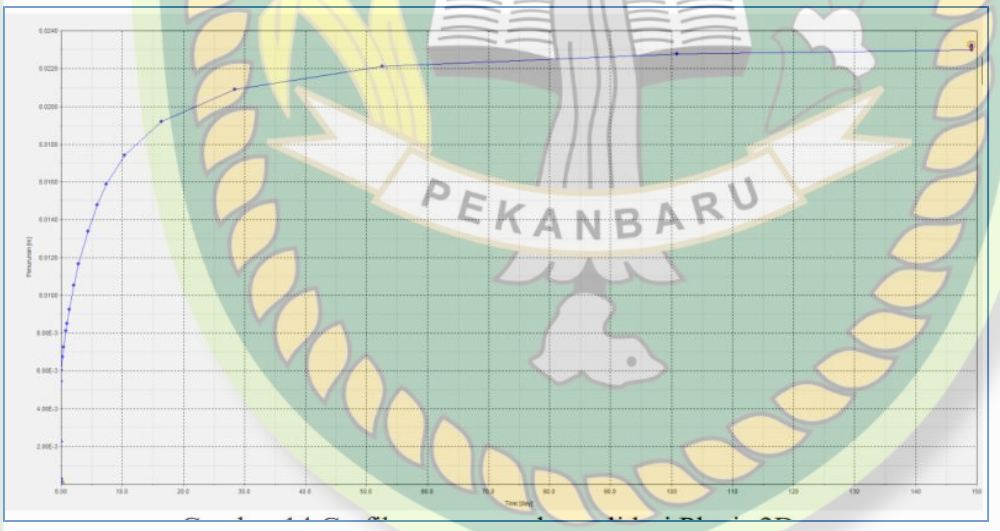


Figure 4.14 Analysis Output curve

After the mesh generation and staged construction specifications are met, the program calculates the deformation automatically, and the resulting curve is generated.

3. Compare the simulation results to previous studies and SNI code standards to assess the effectiveness of the peat soil improvement methods.
4. Results and Discussion
5. Conclusion and suggested recommendations

6. Report Writing

4.6 Validation

Simulation outputs will be compared with field observations and standards (e.g., SNI) to ensure reliability. Adjustments to input parameters will be made as necessary to improve model accuracy.

Thumb Rule: wood should be submerged about 30 cm below the lowest ground water table.

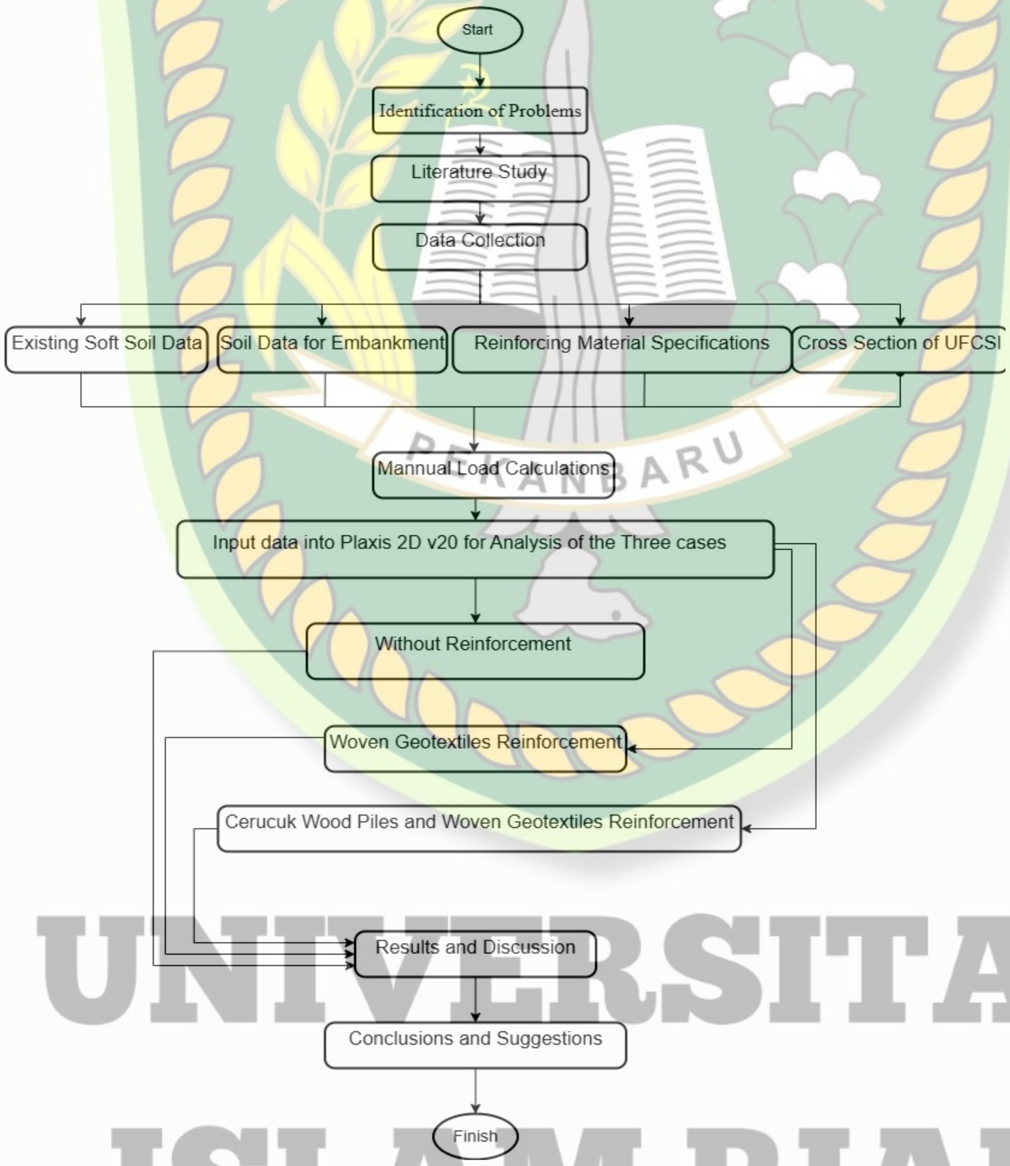


Figure 4.15 Research Flowchart

CHAPTER 5
RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter presents the findings from the settlement analysis performed for three reinforcement Cases: unreinforced peat soil, geotextile reinforcement, and the combined use of geotextile with cerucuk wood piles. The analysis was conducted using the finite element method to evaluate the effectiveness of these methods in improving peat soil conditions. The discussion focuses on the interaction between reinforcement materials and peat soil, improvements in soil reinforcement performance, and practical recommendations for construction applications.

5.2 Bearing Capacity of Wood Piles.

a) Design data

Table 5.1 Cerucuk wood pile Design data (UFCSI)

Parameter	Value
Diameter of wooden pile (D)	0.15 m
Length of pile (L)	4.00 m
Area of pile section (A)	$\frac{1}{4} \times \pi \times D^2 = 0.0177\ m^2$
Perimeter of pile (W_p)	$\pi \times D = 0.471$ m
SPT N-Value	2
Average N value (Ni)	2
Friction of soil (fi) = 0.20 × Ni = 0.2 X 2	0.4 t/m² = 3.92 kN/m²

b) Ultimate Vertical Bearing Capacity (q_u)

Table 5.2 Ultimate Vertical Bearing Capacity (UFCSI)

Formula	Calculation	Result
$Q_p = F_{max} = (40 \times N \times A)$	40 × 2.0 × 0.0177	1.416 ton/pile =14.16 kN
$Q_s = T_{skin} = (W_p \times fi \times li)$	(0.471 × 0.4 × 4.0)	0.751ton/pile = 7.51KN
$q_u = F_{max} + T_{skin}$	14.16 + 7.51	21.67 KN

c) Allowable Vertical Bearing Capacity (q_a)

$$qa = q_u/n \qquad (4)$$

n = safety factor of 3

Table 5.3 Allowable Vertical Bearing Capacity (UFCSI)

Calculation	Result
21.696/ 3	2.93 KN/pile

Cerucuk Wood Pile Interaction: The cerucuk piles have a diameter of 0.15 m and a length of 4.0 m, with an ultimate vertical bearing capacity of 21.69 kN and allowable vertical capacity of 2.94 kN. They penetrate deeper, transferring loads to more stable soil layers. Their frictional resistance with the peat enhances bearing capacity and limits excessive deformation.

5.3 Analysis of the Interaction Between Peat Soil, Geotextile, and Wood Piles

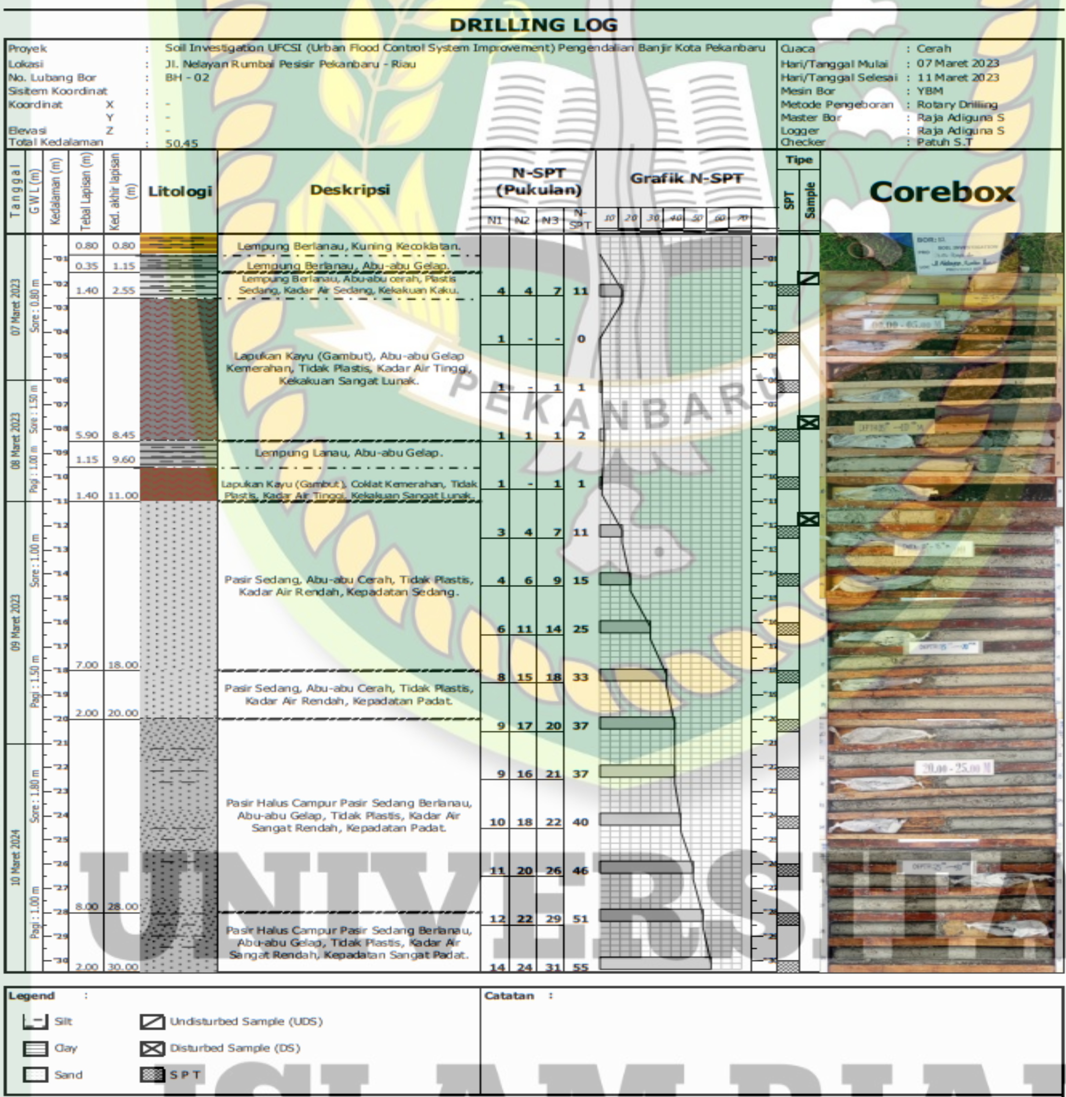
a) Borehole Drilling and N-SPT Testing Results

Soil investigations were conducted at BH-2, figure 5.1, through borehole drilling, Table 5.1, and the Standard Penetration Test (SPT), Table 5.2. The subsurface layers consisted of clayey silt, decayed wood (peat), and various sand layers at respective depths, as shown in Table 5.4.

Figure 5.1 Soil Investigation at the UFCSI Location for BH-2

During the drilling process, in-situ tests were conducted, which included the Standard Penetration Test (SPT) and the collection of both Undisturbed Samples (UDS) and Disturbed Samples (DS). The SPT was performed at 2-meter intervals to evaluate soil resistance. UDS samples were collected from the clay and silt layers; however, the sandy and rocky layers did not yield suitable UDS samples. The results of the core drilling were carefully documented to identify the subsurface types and layering, providing valuable data for analyzing the soil conditions at the site.

Table 5.4 BH - 02 (Soil Investigation UFCSI,2024)

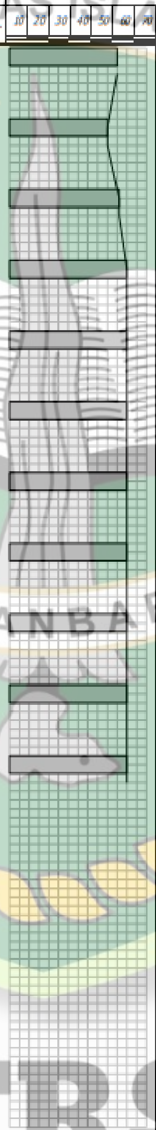


DRILLING LOG

Proyek	: Soil Investigation UFCSI (Urban Flood Control System Improvement) Pengendalian Banjir Kota Pekanbaru		Cuaca	:
Lokasi	: Jl. Nelayan Rumbai Pesisir Pekanbaru - Riau		Hari/Tanggal Mulai	: 07 Maret 2023
No. Lubang Bor	: BH - 02		Hari/Tanggal Selesai	: 11 Maret 2023
Sistem Koordinat	:		Mesin Bor	: YBM
Koordinat X	: -		Metode Pengeboran	: Rotary Drilling
Y	: -		Master Bor	: Raja Adiguna S
Elevasi Z	: -		Logger	: Raja Adiguna S
Total Kedalaman	: 50.45		Checker	: Patuh S.T

Tanggal	G W L (m)	Kedalaman (m)	Tebal Lapisan (m)	Ked. akhir lapisan (m)	Litologi	Deskripsi	N1	N2	N3	N-SPT
10 Maret 2024	Sore : 1.80 m; Pagi : 1.00 m	31–36					14	20	30	50
							12	24	32	56
							15	26	34	60
11 Maret 2023	Sore : 1.40 m; Pagi : 1.20 m	36–50					18	30	30/	≥60
						Pasir Halus, Abu-abu Gelap, Tidak Plastis, Kadar Air Sangat Rendah, Kepadatan Sangat Padat.	24	32	28/	≥60
							22	31	29/	≥60
							27	36	24/	≥60
							24	30	30/	≥60
							28	34	26/	≥60
			20.45	50.45			32	39	21/	≥60
		51–60				STOP BOR 50.45 Meter				

Grafik N-SPT



Tipe: SPT | Sample

Corebox

Legend :

- Silt
- Clay
- Sand
- Undisturbed Sample (UDS)
- Disturbed Sample (DS)
- S P T

Catatan :

Table 5.5 Standard Penetration Results (Soil Investigation UFCSI,2024)

SPT No.	Depth (m)	BH - 02			Σ N
		N1	N2	N3	blows
0	0	0	0	0	**0**
1	2	4	4	7	**11**
2	4	1	-	-	**0**
3	6	1	-	1	**1**
4	8	1	1	1	**2**
5	10	1	-	1	**1**
6	12	3	4	7	**11**
7	14	4	6	9	**15**
8	16	6	11	14	**25**
9	18	8	15	18	**33**
10	20	9	17	20	**37**
11	22	9	16	21	**37**
12	24	10	18	22	**40**
13	26	11	20	26	**46**
14	28	12	22	29	**51**
15	30	14	24	31	**55**
16	32	14	20	30	**50**
17	34	12	24	32	**56**
18	36	15	26	34	**60**
19	38	18	30	30/2 cm	**60**
20	40	24	32	28/4 cm	**60**
21	42	22	31	29/6 cm	**60**
22	44	27	36	24/5 cm	**60**
23	46	24	30	30/3 cm	**60**
24	48	28	34	26/5 cm	**60**
25	50	32	39	21/7 cm	**60**

Table 5.6 Summary of Drilling Results (Soil Investigation UFCSI,2024)

No.	Nomor Titik	Final Depth (m)	Kedalaman Dengan	
			N-SPT < 10	N-SPT ≥ 60
1.	BH - 01	50.45	08.00	42.00
2.	BH - 02	50.45	10.00	36.00

Table 5.7 Summary of Drilling Results at BH-02 (Soil Investigation UFCSI,2024)

Depth (m)	Layer Thickness (m)	Description
00.00 – 00.80	0.8	Clayey silt, yellowish-brown.
00.80 – 01.15	0.35	Clayey silt, dark grey.
01.15 – 02.55	1.4	Clayey silt, light grey, medium plasticity, medium water content, stiff consistency.
02.55 – 08.45	5.9	Decayed wood (peat), dark reddish-grey, non-plastic, high water content, very soft consistency.
08.45 – 09.60	1.15	Silty clay, dark grey.
09.60 – 11.00	1.4	Decayed wood (peat), reddish-brown, non-plastic, high water content, very soft consistency.
11.00 – 18.00	7.0	Medium sand, light grey, non-plastic, low water content, medium density.
18.00 – 20.00	2.0	Medium sand, light grey, non-plastic, low water content, dense.
20.00 – 28.00	8.0	Fine sand mixed with medium sand and silty silt, dark grey, non-plastic, very low water content, dense.
28.00 – 30.00	2.0	Fine sand mixed with medium sand and silty silt, dark gray, non-plastic, very low water content, very dense.
30.00 – 50.45	20.45	Fine sand, dark grey, non-plastic, very low water content, very dense.

The peat soil exhibited high water content, very soft consistency, and low bearing capacity, as described in Table 5.4, necessitating reinforcement solutions. BH-02 was chosen because of the availability of its data, which includes a comprehensive record of subsurface stratigraphy, SPT values, and borehole log details, making it the most suitable reference point for analyzing soil conditions in the study area. The borehole location provided consistent and reliable geotechnical data, allowing for a detailed evaluation of peat soil properties, bearing capacity, and the effectiveness of geotextile and cerucuk reinforcement. Additionally, BH-02's dataset covers a range of soil types, including clay, silt, and sand layers, enabling a thorough investigation of soil-structure interactions and load transfer mechanisms between the reinforcement materials and the underlying peat soil. This ensures that the findings from the FEM analysis and settlement predictions are well-supported.

a) Peat Soil Sampling and Laboratory Tests

Table 5.8 Properties of Existing Peat Soil (Soil Investigation UFCSI,2024)

Category	Parameter	Value
Index and physical properties	Specific gravity (gs)	2.51
	Moisture content (wn) (%)	161.77
	Saturated density (kn/m³)	8.99
	Dry density (kn/m³)	3.36
	Void ratio (e)	6.30
	Porosity (n)	0.86
	Degree of saturation (sr) (%)	64.35
Atterberg limits	Liquid limit (ll) (%)	NA
	Plastic limit (pl) (%)	NA
	Plasticity index (pi) (%)	NA
Soil classification	Type	Peat (Pt)
Grain size analysis	Gravel (%)	0.00
	Peat (%)	52.96
	Silt-clay (%)	47.04
Engineering properties	**Triaxial test uu**	
	Cohesion (c) (kn/m²)	NA
	Friction angle (ø) (°)	NA
	Direct shear test	
	Cohesion (cm) (kn/m²)	5.3
	Angle of internal friction (°)	1.174
	Consolidation test	
	Compression ratio (cc)	NA
	Coeff. Of consolidation (cv avrg)	NA
	Initial void ratio	NA

Unconfined compression test	Undisturbed compressive strength (quu) (kn/m²)	NA
	Remoulded compressive strength (q_{ur}) (kn/m²) and sensitivity (si) (kn/m²)	NA

Table 5.8 presents the Laboratory tests on collected samples confirming that peat soil has a high void ratio (6.297), low unit weight (8.99 kN/m³), and low Young's modulus (3000 kN/m²), making it highly compressible. Woven geotextile and Wood piles were introduced as reinforcements to enhance soil performance.

Table 5.9 Borehole Samples Soil (Soil Investigation UFCSI,2024)

Borehole	Sample Type	Depth (m)
BH-02	UDS	1.50 – 2.00
	DS	7.50 – 8.00
	DS	5.50– 12.00

b) Summary of the Laboratory Results for Plaxis 2D Input

Table 5.10 Soil Data Input in Plaxis 2D (Soil Investigation UFCSI,2024)

Parameter	Name	Embankment	Sand	Peat	Clay	Unit
Material model	-	Mohr Coulomb	Mohr Coulomb	Soft Soil	Soft Soil	-
Type of material behaviour	Type	Drained	Drained	Undr. (A)	Undr. (A)	-
Saturated Soil unit weight	γ_{sat}	16.20	15.81	8.99	16.32	kN/m³
Dry Soil unit weight	γ_{dry}	13.60	13.08	3.43	12.57	kN/m³
Initial void ratio	e_{init}	0.95	0.9	3.39	1.39	-
Cohesion	c	-	8.72	5.30	47.17	kN/m²
Friction angle	ϕ	-	5.25	1.174	0.00	°

Table 5.10 presents key material properties from the case study's laboratory tests, serving as input for finite element modelling. The soil's embankment fill, sand, peat, and clay are described using the Mohr-Coulomb model, with embankment and sand behaving as drained materials, while peat and clay are classified as Soft Soils undrained (A). Peat exhibits low density (γsat = 8.99 kN/m³) and high compressibility (einit = 3.39), indicating poor strength characteristics. Sand has moderate shear strength (c = 8.72 kN/m², ϕ = 37.4°), while clay shows high cohesion (47.17 kN/m²) but a negligible friction angle (0°). These values provide critical insight for assessing embankment stability and soil improvement strategies.

Table 5.11 Correlation Soil Data Input in Plaxis 2D

Parameters	Symbol	Embankment	Sand	Peat	Clay	Unit
Youngs Modulus	E_{ref}	43000.00	98070.00	3000.00	8825.00	kN/m²
Poison Ratio	v	0.30	0.20	0.35	0.45	-
Friction angle	ϕ	35.00	37.40	0.00	0.00	°
Dilatancy angle	ψ'	5.00	7.40	0.00	0.00	°
Horizontal permeability	k_x, k_y	7.12	3.12	0.01000 E-3	0.08640 E-3	m/day
Interface strength reduction factor	R_{inter}	0.60	0.60	0.6	0.6	-

The material properties in Table 5.11 are derived from correlations in Section 3.10. Young's modulus reflects stiffness variations, with sand being the most rigid and peat the weakest. Poisson's ratio indicates deformation behaviour, with clay exhibiting the highest lateral strain. Friction and dilatancy angles confirm strength differences, with sand offering superior shear resistance, while peat and clay remain negligible. Permeability values align with drainage behaviour, where sand facilitates rapid flow, unlike low-permeability peat and clay. A uniform interface strength reduction factor of 0.60 ensures consistency in numerical modelling.

c) Cerucuk Woodpile Properties

Table 5.11 Cerucuk Woodpile Parameters (UFCSI,2024)

Parameter	Symbol	Value	Unit
Diameter of pile	D	0.15	M
Length of pile	L	4.00	M
Young's modulus of timber	E	52.59 E10^6	kN/m²
Cross-sectional area	A	0.018	m²
The moment of inertia	I	0.02485E-3	m⁴
Soil friction factor	f_i	3.92	KN
End bearing resistance	F_{max}	14.16	KN
Skin friction resistance	$T_{skin, max, Min}$	1.85	KN

d) Woven geotextile properties

Table 5.12 Bima Woven Geotextile BW 250 Properties (UFCSI,2024)

Test	Method	Direction	Result (Strength)	Elongation (%)
Grab Breaking Load and Elongation	ASTM D4632, Gauge length: 75 mm, Speed 300 mm/min	Machine Direction (MD)	1687 N	26.80
		Cross Direction (CD)	1565 N	24.00
Static Puncture Strength	ASTM D6241, Speed: 50 mm/min	-	5810 N	-
Trapezoid Tearing Strength	ASTM D4533	Machine Direction (MD)	922 N	-
		Cross Direction (CD)	1850 N	-
Tensile Properties (Wide Width Strip)	ASTM D4595, Gauge length: 100 mm, Speed: 50 mm/min	Machine Direction (MD)	47.6 kN/m	40.00
		Cross Direction (CD)	50.9 kN/m	32.0%

i) Estimated vertical load (surcharge) for road inspection.

Table 5.13 Road inspection estimated vertical load (UFCSI,2024)

Load Type	Details	kg/m²	t/m²	kN/m²
Vertical Load	Vehicle load alongside the inspection road	400.00	0.40	4.00
	Live load in the inspection/landscape area	120.00	0.12	1.20
Total Vertical Load		520.00	0.52	5.20

5.4 Mechanisms of Interaction Between Reinforcement and Peat Soil

i) Woven Geotextile Interaction: The woven geotextile of tensile strength of 47.6 kN/m (MD) and 50.9 kN/m (CD), acts as a separator and load distributor, reducing lateral displacement and providing tensile strength to limit differential settlement.

ii) Cerucuk Wood Pile Interaction: The cerucuk piles have a diameter of 0.15 m and a length of 4.0 m, with an ultimate vertical bearing capacity of 21.69 kN and allowable vertical capacity of 7.23 kN. Penetrate deeper, transferring loads to more stable soil layers. Their frictional resistance with the peat enhances bearing capacity and limits excessive deformation.

iii) Combined System: The combination of geotextile and cerucuk wood piles stabilizes the embankment more effectively by controlling settlement and enhancing overall soil strength.

5.5 Evaluation of Soil Reinforcement Performance

5.5.1 Finite Element Total displacement analysis results.

The results are grouped into three cases based on the research objectives

a) Case 1 Embankment on natural peat soil without reinforcement

The water table is set at ground level, reflecting the conditions at the Urban Flood Control System Improvement (UFCSI) project site. During heavy rains and flooding, water consistently accumulates on the surface, leading to high soil moisture content. This excessive moisture contributes to the softness and low strength of the soil. A PLAXIS 2D model setup illustrating the Ground water table (GWT) conditions is shown in Figure 5.2 and Figure 5.3.

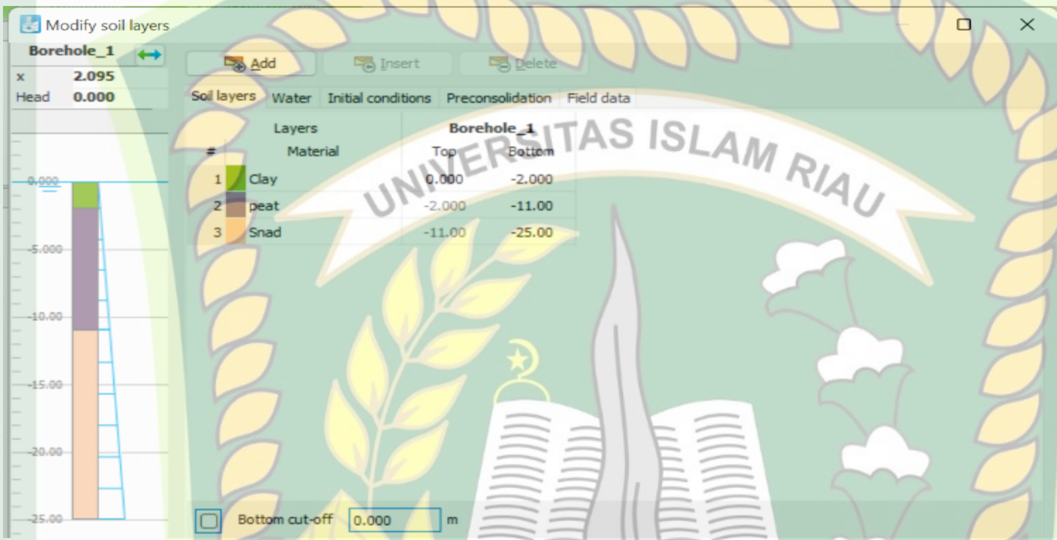


Figure 5.2 Borehole showing the Water Table and Soil Interfaces

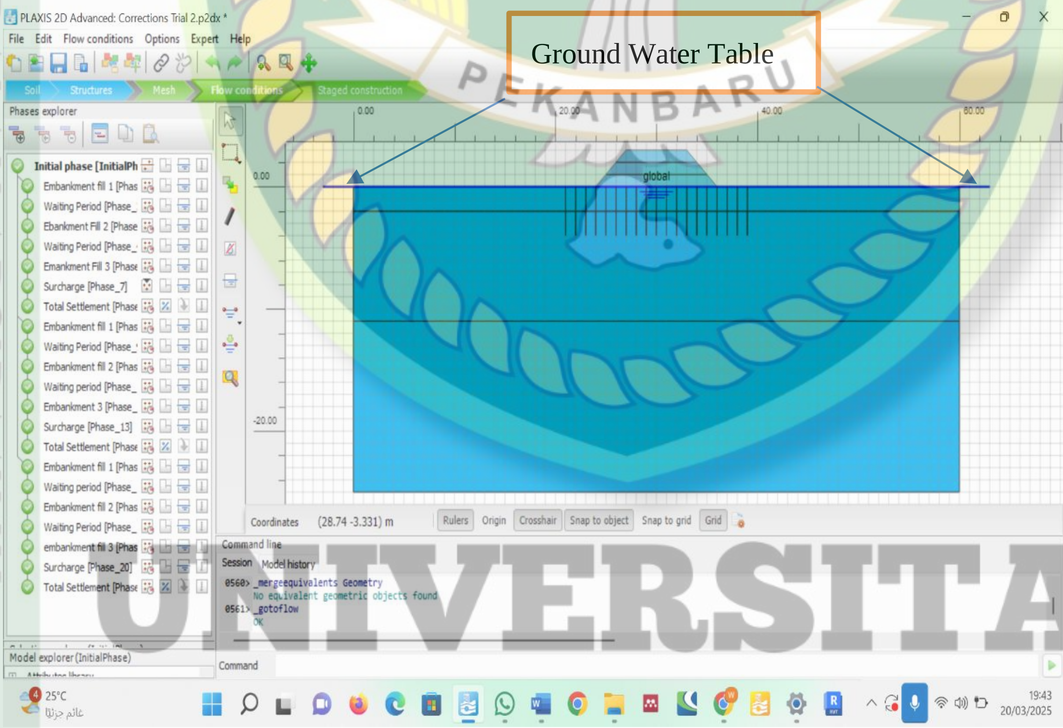


Figure 5.3 Staged Construction Water Table

Table 5.14 Total Displacement (U) for Unreinforced Peat Soil

Phase	Consolidation Settlement	Consolidation Time
	Meters (mm)	(Days)
Initial	0.00	0
1st step of the embankment fill	22.28	2
Waiting period before adding 2nd step	22.97	3
2nd step of the embankment fill	58.77	2
Waiting period before adding 3rd step	59.55	1
3rd step of the embankment fill	106.90	2
Surcharge	130.60	2
Degree of consolidation 90%	1022.00	5067

Table 5.14 presents the total consolidation settlement of an unreinforced embankment. The lowest settlement in the 1st fill stage was 22.28 mm after two days, while the highest during the two-day surcharge phase reached 130.6 mm. Waiting times before the 2nd and 3rd fills resulted in additional settlements of 0.69 mm and 0.78 mm, respectively. The total consolidation settlement at U = 90% was 1022 mm over 5076 days (13.9 years), This highlights the high compressibility and low shear strength of the soil, necessitating reinforcement.

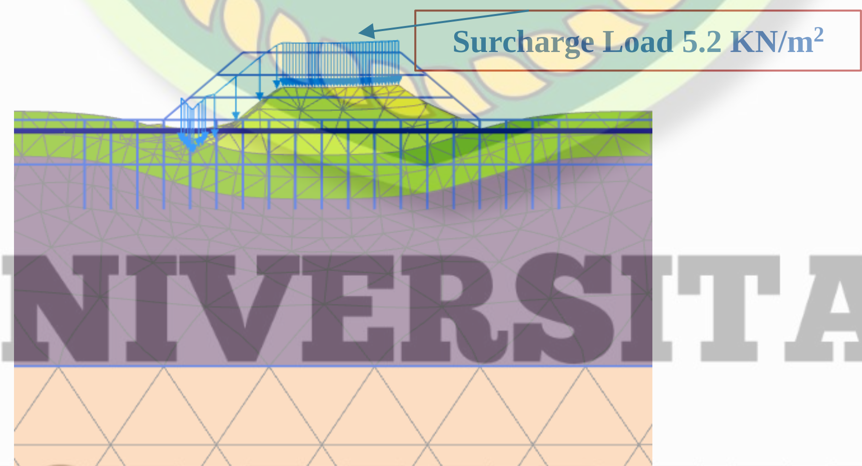


Figure 5.4 Plaxis 2D Output for Deformed Shape for Unreinforced Peat Soil

Figure 5.4 shows that the embankment experiences excessive vertical settlement and lateral soil displacement due to low shear strength and high compressibility.

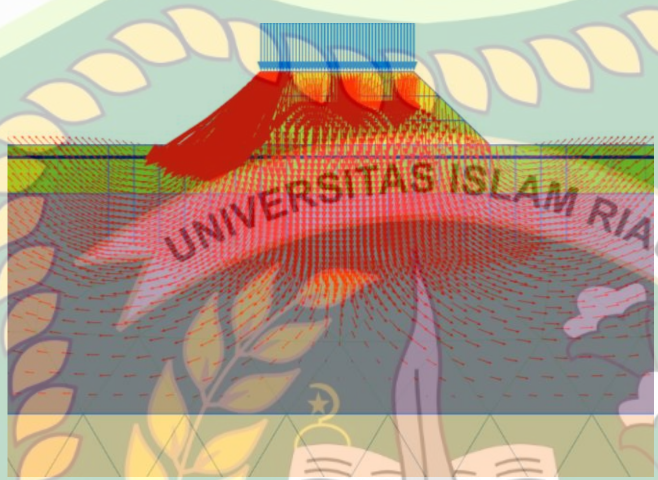


Figure 5.5 Plaxis 2D Output for Soil Movement Direction for Unreinforced Peat Soil

Figure 5.5 shows that the arrows indicate significant outward lateral movement, demonstrating insufficient resistance to deformation.

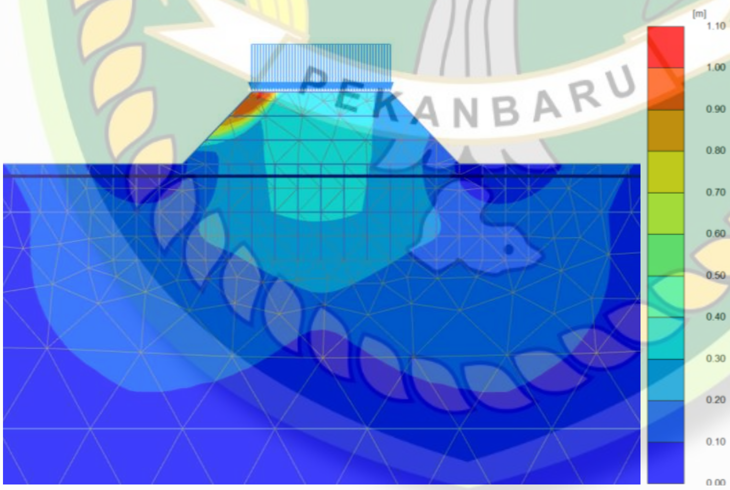


Figure 5.6 Plaxis 2D Output for Total Displacement U for Unreinforced Peat Soil

Figure 5.6 and Figure 5.13 show that the total stress is concentrated at the left slope of the embankment, leading to the highest observed settlement of 1022 mm, requiring 5076 days (13.9 years) to reach 90% consolidation. This confirms that unreinforced natural peat soil lacks sufficient stability to support infrastructure.

b) Case 2: Embankment construction on peat soil reinforced with Woven Geotextiles only.

Table 5.15 Summary of Total Displacement (U) for Peat Reinforced with Woven Geotextile

Phase	Consolidation settlement	Consolidation Time
	Meters (mm)	(Days)
Initial	0.00	0
1st step of the embankment fill	22.26	2
Waiting period before adding second step	22.94	3
2nd step of the embankment fill	58.65	2
Waiting period before adding 3rd step	59.43	1
3rd step of the embankment fill	106.60	2
Surcharge	138.30	2
Consolidation settlement u = 90%(m)	315.00	5418

Table 5.15 illustrates the consolidation settlement of peat soil reinforced with woven geotextiles. The lowest settlement of 22.26 mm occurred in the 1st fill stage in 2 days, while the highest, 138.30 mm, was recorded during the two-day surcharge phase. Waiting times before the 2nd and 3rd fills reduced settlements by 0.68 mm and 0.78 mm, respectively. The total settlement decreased to 315 mm, achieving 90% consolidation in 5418 days (14.84 years).

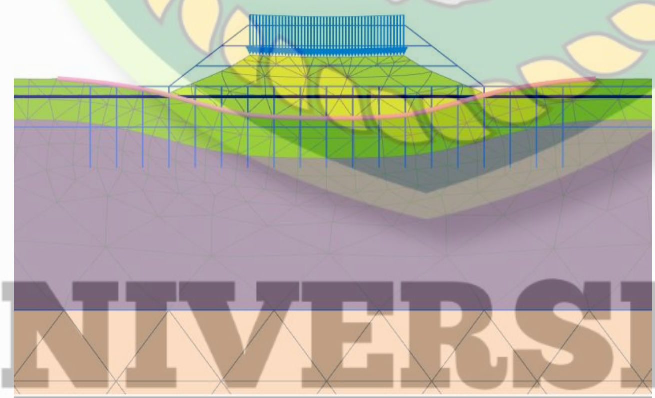


Figure 5.7 Plaxis 2D Output for Deformed Shape of Peat Reinforced with Woven Geotextile

Figure 5.7 shows that woven geotextile reduced settlement by approximately 69.18% and provided lateral restraint.

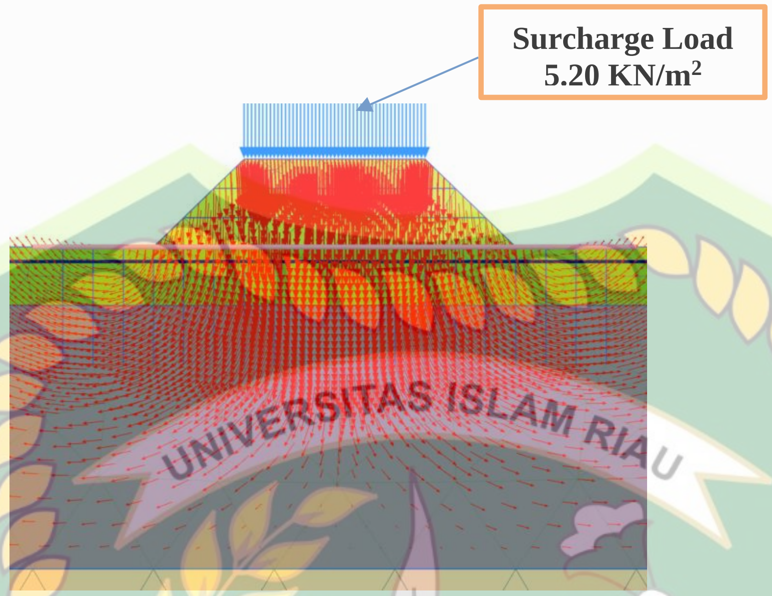


Figure 5.8 Plaxis 2D Output for Soil Movement Direction of Peat Reinforced with Woven Geotextile

Figure 5.8 shows that the lateral displacement is reduced but remains notable, showing that geotextiles alone cannot completely restrain movement.

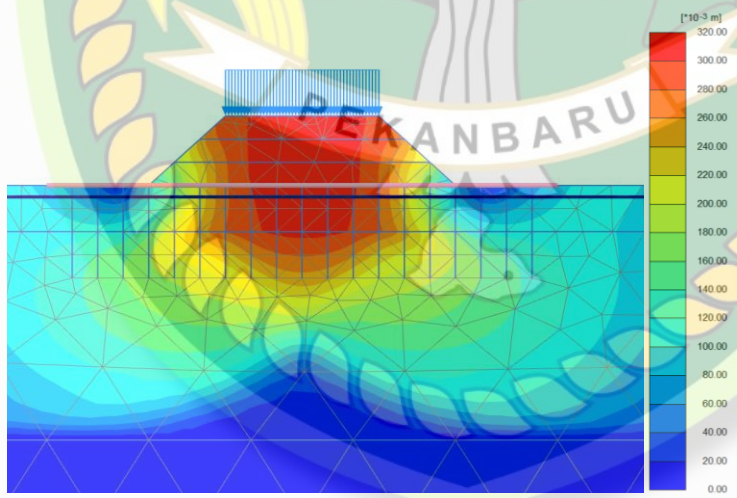


Figure 5.9 Plaxis 2D Output for Total Displacement U of Peat Reinforced with Woven Geotextile

Figure 5.9 and figure 5.13 illustrate a maximum settlement reduction of 315 mm, achieving 90% consolidation in 5418 days (14.84 years). While the geotextile effectively restrains lateral deformation, it does not fully mitigate excessive settlement, indicating the need for additional reinforcement.

c) Case 3: Embankment on peat soil reinforced with wood piles and woven geotextile.

Table 5.16 Summary of Total Displacement (U) For Peat Reinforced with Both Woven Geotextile and Cerucuk Wood Piles

Phase	Consolidation settlement (mm)	Consolidation Time (Days)
Initial	0.00	1
1st step of the embankment fill	20.67	3
Waiting period before adding 2nd step	21.12	2
2nd step of the embankment fill	55.44	2
Waiting period before adding 3rd step	56.25	1
3rd step of the embankment fill	100.80	2
Surcharge	129.80	2
Consolidation settlement u = 90%(m)	286.70	5524

Table 5.16 presents the consolidation settlement of peat soil reinforced with woven geotextile and wood piles. The lowest settlement of 20.67 mm occurred in the 1st fill stage in 2 days, while the highest, 129.8 mm, was recorded during the two-day surcharge phase. Settlement reductions of 0.45 mm and 0.81 mm were observed before the 2nd and 3rd fills, respectively. The total settlement decreased to 286.7 mm, achieving 90% consolidation in 5524 days (15.52 years).

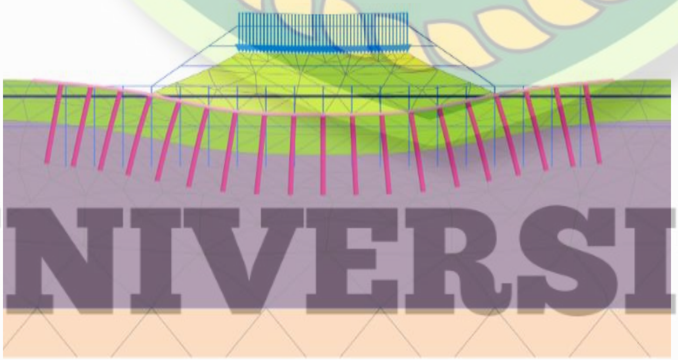


Figure 5.10 Plaxis 2D Output for Deformed Shape of Peat Reinforced with Both Woven Geotextile and Cerucuk Wood Piles

Figure 5.10 shows that the combination of geotextile and cerucuk wood piles significantly reduces settlement by 72% compared to the unreinforced case while also restricting lateral movement and enhancing overall stability.

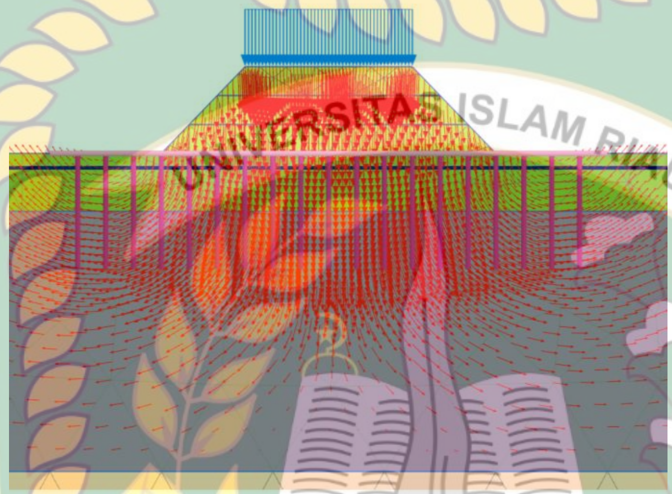


Figure 5.11 Plaxis 2D Output for Soil Movement Direction of Peat Reinforced with Both Woven Geotextile and Cerucuk Wood Piles

Figure 5.11 shows that the arrows indicate improved stability with reduced lateral displacement compared to previous cases.

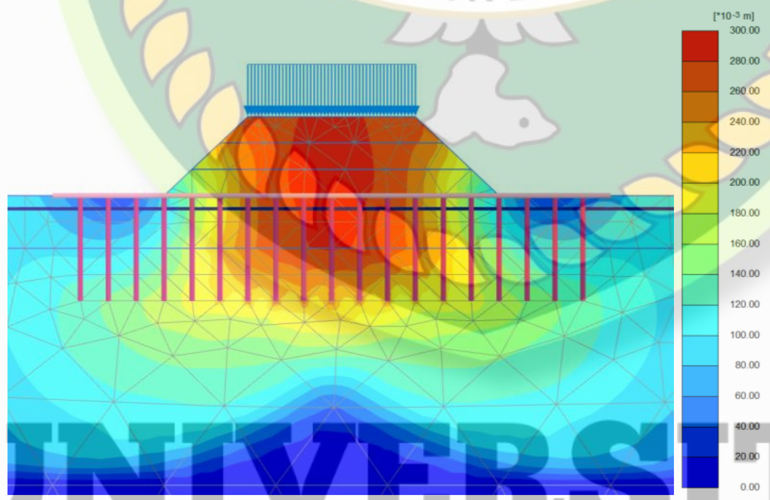


Figure 5.12 Plaxis 2D Output for Total Displacement U of Peat Reinforced with Both Woven Geotextile and Cerucuk Wood Piles

Figure 5.12 above and Figure 5.11 showed a maximum settlement of 286.7 mm, achieving 90% consolidation in 5524 days (15.52 years). The geotextile provided lateral restraint while the wood piles transferred loads to a deeper, more stable layer.

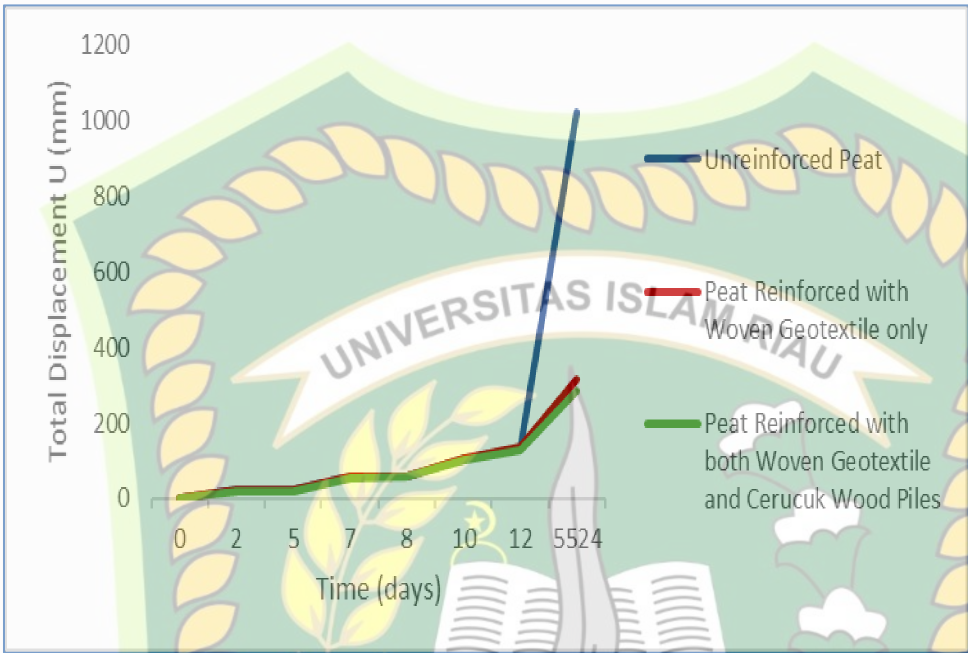


Figure 5.13 Total Displacement of Peat Soil Under Three Reinforcement Cases

Figure 5.13 Summarizes the total settlements of peat soil for all three reinforcement cases at all stages explained in the previous discussions and only the total displacements at 90^0 are further discussed here highlighting that the unreinforced case experienced the highest settlement of approximately 1022 mm. In contrast, the reinforced cases significantly reduced settlement, with the woven geotextile reinforcement experiencing a total settlement of 315 mm, while the combined woven geotextile and cerucuk wood piles reinforcement resulted in the lowest settlement at 286.7 mm. These findings highlight the effectiveness of reinforcement in minimizing settlement, with the combined method providing the greatest improvement.

Table 5.17 Summary of Settlement Reduction for Both Cases

Case	Maximum Degree of consolidation U= 90% (mm)	Settlement Reduction (%)
Unreinforced	1022.00	–
Geotextile Only	315.00	69.18
Combined Reinforcement	286.70	72.00

Table 5.17 presents the settlement reduction percentages for three reinforcement cases. The combination of woven geotextile and cerucuk wood piles achieved the highest reduction at 72%, while woven geotextile alone reduced settlement by 69.19% compared to the unreinforced case. This demonstrates that woven geotextile effectively restrained horizontal deformation, while cerucuk wood piles, modelled as embedded beams in PLAXIS 2D, efficiently transferred loads to deeper, more stable layers. However, 28% of the total settlement (1022 mm), approximately 286.16 mm, remains, indicating that complete settlement mitigation was not achieved. This is due to limitations in the embedded beam modelling approach, which is more suitable for medium to hard soils rather than highly compressible peat. Peat soils have low shear strength, high water content, and significant long-term consolidation behaviour, reducing the effectiveness of embedded beams in fully capturing the true soil-pile interaction. Consequently, while the reinforcement improved stability, the model's constraints limit the full representation of settlement behaviour in peatland conditions.

5.5.2 Settlement Comparison with Total Settlement Limits (MDPJ 2024)

The embankment settlement was assessed against the allowable settlement criteria outlined in the Manual Desain Perkerasan Jalan 2024 (MDPJ 2024) by Kementerian Pekerjaan Umum dan Perumahan Rakyat (2024). While MDPJ 2024 focuses on pavement design, its settlement guidelines are crucial for embankments to ensure long-term pavement durability and serviceability. According to Table 6.2 of MDPJ 2024, with a summary part of it illustrated by Table 5.21 below, the maximum allowable total settlement after pavement construction is 100 mm, preventing excessive deformation that could compromise pavement performance. This study compares the measured embankment settlement against this threshold to evaluate the effectiveness of the soil reinforcement techniques used. Maintaining settlement within this limit enhances embankment stability, minimizes surface deformation, and reduces long-term maintenance needs.

Table 5.21 Settlement Limits for Construction (*Table 6.2* 2024)

Settlement Type	Road Status/Class	Description	Allowable Limit	Typical Prevention Measures
Total Settlement	All national, provincial, city/regional, and local roads	Absolute settlement after pavement construction (same for structures nearby)	**100 mm (maximum)**. For rigid pavements, it must comply with safe design calculations	a) **Preloading** before pavement construction to allow for primary consolidation.

Table 5.18 Settlement Reduction Behavior Comparison

Case	Maximum Settlement (mm)	Total Settlement limit 100 mm	Settlement Reduction (%)
Unreinforced Peat Soil	1022.00	Not in Limit	0.00
Geotextile Reinforcement	315.00	Not in Limit	69.18
Combined Reinforcement	286.70	Not in Limit	72.00

Table 5.18 comparison results illustrate that woven geotextile reinforcement alone reduced settlement by 69.18%, lowering the maximum settlement from 1022 mm to 315 mm. However, this still exceeds the 100 mm allowable limit, suggesting that additional reinforcement was necessary. The combined reinforcement system (woven geotextile and cerucuk wood piles) further improved performance, achieving a 72% settlement reduction and lowering settlement to 286.70 mm. Despite these improvements, the remaining 286.16 mm settlement indicates that full compliance with Manual Desain Perkerasan Jalan 2024 (MDPJ 2024) was not achieved. This limitation is primarily attributed to the embedded beam modelling approach, which, while effective for medium to hard soils, does not fully capture the long-term consolidation behaviour of highly compressible peat. Peat soils' low shear strength, high water content, and significant long-term deformation reduce the effectiveness of embedded beams in accurately modelling load transfer mechanisms.

To further reduce settlement below the 100 mm limit, it is suggested to employ a double-layered Bima Woven Geotextile system to improve tensile resistance and minimize lateral deformation, ensuring better load distribution. Additionally, an Optimized Cerucuk Configuration with increased pile density and deeper penetration into firmer soil layers can enhance vertical load transfer. A grid close-spaced arrangement of cerucuk piles may further improve overall reinforcement efficiency, contributing to greater stability and reduced long-term settlement.

5.6 Practical Recommendations for Construction

Based on the findings of this research, the following recommendations are proposed to improve the effectiveness of cerucuk wood piles and woven geotextiles in peat soil reinforcement.

5.6.1 Cerucuk Wood Pile Design

1. Use Cerucuk wood piles with a diameter of 0.1 to 0.15 m and a close spacing of 0.5 to 1.0 m for effective load distribution.
2. The optimal pile length should range from 4.0 to 6.0 m to transfer loads to deeper, stable soil layers.
3. Ensure that the pile tops are submerged at least 30 cm beneath the embankment base to prevent decay and maintain long-term effectiveness.
4. Further research should explore the effects of pile spacing and depth variations on settlement reduction.

5.6.2 Geotextile Placement and Additional Techniques

1. A double-layered Bima Woven Geotextile system should be employed and placed at the pile top tip, at least 30 cm beneath the embankment base.
2. Combining preloading and surcharging techniques is recommended to accelerate consolidation and improve the long-term performance of peat soil reinforcement.
3. Future research should analyze the long-term durability of woven geotextiles under continuous load conditions.

5.6.3 Addressing Limitations of Embedded Beam Modeling in PLAXIS 2D

1) The study revealed that embedded beam elements in PLAXIS 2D are more suitable for medium to hard soils and may not fully capture the complex interaction between cerucuk wood piles and highly compressible peat.
2) Future numerical modelling should consider using plate elements or soil elements with interface properties to better simulate realistic pile-soil interaction.
3) Field validation studies should be conducted to compare numerical predictions with actual settlement behaviour in peatland environments.

5.6.4 Sustainability and Maintenance

i. Use locally sourced cerucuk wood to reduce costs and promote eco-friendly construction.

ii. Conduct regular monitoring of settlement behaviour to assess the long-term effectiveness of reinforcement techniques.

iii. Implement a maintenance framework to address potential pile degradation and geotextile performance over time.

5.6.5 Long-Term Performance and Maintenance Considerations

1) Further research should explore the effects of pile spacing and depth variations on settlement reduction.
2) Future studies should analyze the long-term durability of woven geotextiles under continuous load conditions.
3) Implement a maintenance framework to address potential pile degradation and geotextile performance over time.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study evaluated the effectiveness of combining woven geotextiles and cerucuk wood piles for peat soil reinforcement at the Urban Flood Control System Improvement (UFCSI) project site in Rumbai, Pekanbaru City, Indonesia. The following key conclusions are drawn based on the findings.

1. **Interaction Between Peat Soil, Geotextiles, and Cerucuk Wood Piles**
   1. Woven geotextiles provided lateral restraint, reducing horizontal deformation.
   2. Cerucuk wood piles transferred loads to deeper, more stable soil layers, improving settlement.
2. **Improvements in Soil Reinforcement Performance**
   1) The combination of woven geotextiles and cerucuk wood piles achieved the highest settlement reduction (72%), while geotextiles alone reduced settlement by 69.19%.
   2) Despite these improvements, 28% of the total settlement (1022 mm), approximately 286.16 mm, remains due to the peat's high compressibility and limitations in the embedded beam modelling approach.
   3) Embedded beams in PLAXIS 2D were effective but more suitable for medium to hard soils, not fully capturing the peat soil's complex deformation and consolidation behaviour.
3. **Comparison with Manual Desain Perkerasan Jalan (MDPJ 2024) Settlement Limits**
   a) The final recorded settlement for the combined reinforced case was 286.70 mm, exceeding the Manual Desain Perkerasan Jalan 2024 (MDPJ 2024) allowable total settlement limit of 100 mm. This indicates that additional reinforcement or alternative modelling techniques may be required for full compliance

6.2 Recommendations

1) Optimize the cerucuk wood pile design by using a diameter of 0.1–0.15 m, spacing of 0.5–1.0 m, and pile length of 4.0–6.0 m to enhance load transfer and reach stable soil layers. Additionally, increasing pile density and considering a staggered or grid arrangement may further improve vertical load transfer and stability.
2) Ensure pile tops and woven geotextiles are embedded at least 30 cm beneath the embankment base to prevent decay and improve load distribution.
3) Implement a Double-Layered Woven Geotextile system to enhance tensile resistance, minimize lateral deformation, and improve overall reinforcement efficiency
4) Apply preloading and surcharging to accelerate peat soil consolidation and minimize post-construction settlement.
5) Improve numerical modelling by considering plate elements or soil elements with interface properties for better representation of peat-cerucuk interaction in PLAXIS 2D.
6) Conduct field validation studies to compare numerical predictions with actual settlement behaviour in peatland conditions.
7) Investigate the effects of pile spacing and depth variations on settlement reduction and assess the long-term durability of woven geotextiles under continuous loading.
8) Establish a monitoring and maintenance framework to track pile degradation and geotextile performance over time, ensuring long-term effectiveness and preventing excessive deformation.
9) Promote sustainability by using locally sourced cerucuk wood and implementing regular settlement monitoring to ensure long-term effectiveness and prevent excessive deformation.

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APPENDICES

Appendix A The Urban Flood Control System Improvement (UFCSI)

Figure. 7.1 Study Site Location and Its conditions at Jl Neleyan Rumbai

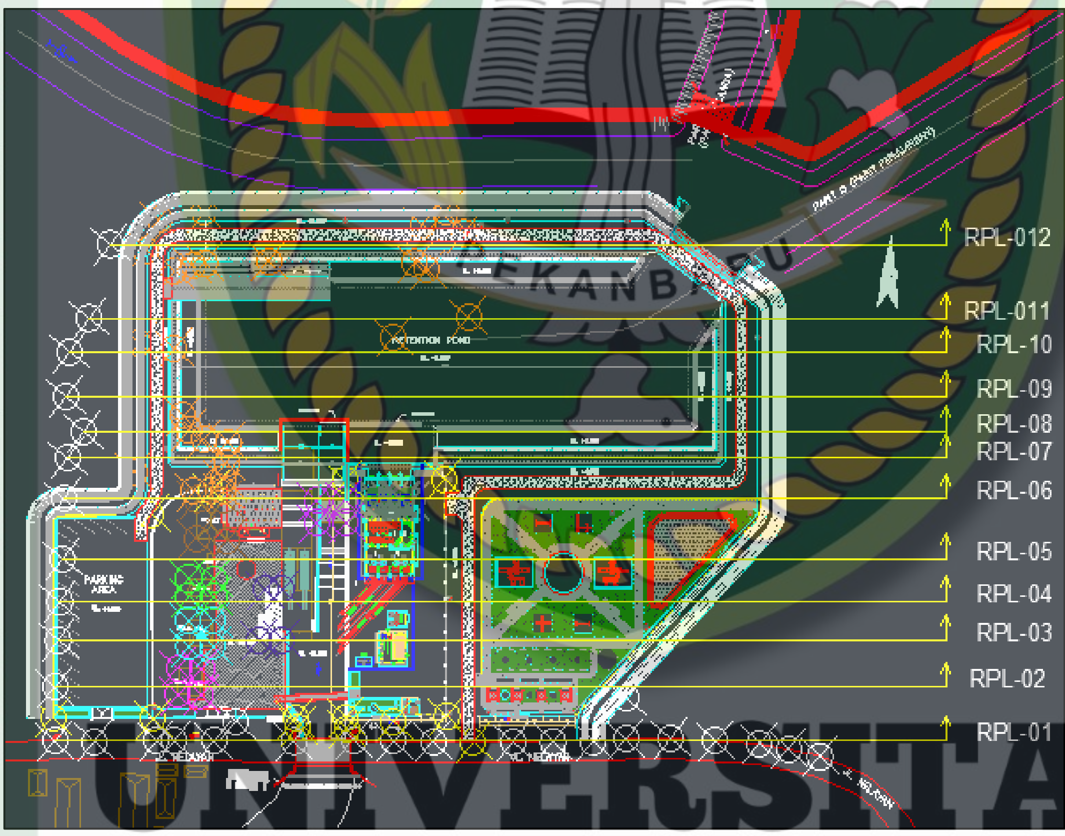

Figure 7.2 UFCSI Drawing

Appendix B Laboratory Soil Tests for Embankment

Figure 7.3 Embankment Soil Laboratory Test Report (UFCSI)

No. Hole	Deskripsi Tanah	Kepadatan		CBR	Analisa Distribusi Ukuran Butiran						Atterberg Limit			Angka Pori	Kadar Air	Berat isi Tanah	Berat isi Tanah Kering
		MDD	OMC	%	Kerikil	Pasir	Lanau	Lempung	Cu	Cc	LL	PL	PI	e	Wn	γ_{wet}	γ_{dry}
		gr/cm^3	%		%	%	%	%			%	%	%		%	gr/cm^3	gr/cm^3
01	Pasir gradasi buruk, pasir berkerikil atau sedikit mengandung butiran halus (SP)	1,67	18,56	13,67	0,00	97,24	1,50	1,26	4,17	1,30	27,66%	25,87%	1,79%	0,97	19,42%	1,62	1,36

Figure 7.4 Embankment Soil laboratory test results (UFCSI)

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UNIVERSITAS ABDURRAB

PEMERIKSAAN KADAR AIR (ASTM D 2216)

Pengirim Sampel : PT. Minarta Dutahutama — Tanggal Uji : 12 Juni 2024

Pekerjaan : Konstruksi UFCSI — Diuji Oleh : MWP

Lokasi : Kelurahan Palas, Muara Fajar — Diperiksa Oleh : PN

Deskripsi Tanah : Tanah kuning — Koordinat Sampel : 0°36'59.0"N 101°26'01.5"E

1	No. Cawan	Unit		1	2	3
2	Massa Cawan	M_1	gram	5,20	5,40	5,20
3	Massa Cawan + tanah basah	M_2	gram	86,10	85,20	75,70
4	Massa Cawan + tanah kering	M_3	gram	72,90	72,20	64,30
5	Massa air tanah	M_2-M_3	gram	13,20	13,00	11,40
6	Massa tanah kering	M_3-M_1	gram	67,70	66,80	59,10
7	Kadar air	$\frac{M_2 - M_3}{M_3 - M_1} \times 100\%$		19,50%	19,46%	19,29%
8	Kadar air rata-rata				19,42%	

Figure 7.5 Soil Moisture Content (UFCSI)

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ANALISA SARINGAN (ASTM D 2487) & ANALISA HIDROMETER (ASTM D 422)

Pengirim Sampel	: PT. Minarta Dutahutama	Tanggal Uji	: 13 Juni 2024
Pekerjaan	: Konstruksi UFCSI	Diuji Oleh	: MWP
Lokasi	: Kelurahan Palas, Muara Fajar	Diperiksa Oleh	: PN
Deskripsi Tanah	: Tanah kuning		

Tipe Hidrometer	=	152 H	Specific gravity (Gs)	=	2,68
Koreksi Meniskus (F_m)	=	1	Berat Kering Sampel (Ms)	=	500 gram
Faktor Koreksi Air (F_z)	=	-2	Larutan dispersi (*Reagent*)	=	Sodium silikat (Na_2SiO_3)
Faktor Koreksi Gs (a)	=	0,99	Konstanta yang bergantung suhu (A)	=	0,01206
Faktor Koreksi Suhu (F_T)	=	2,65			

No. Ayakan	Diameter (mm)	Berat Tertahan (gram)	% Tertahan	% Lolos saringan
3/8"	9,520	0,00	0,00	100,00
No. 4	4,750	0,00	0,00	100,00
No. 10	2,000	2,10	0,42	99,58
No. 20	0,850	136,20	27,24	72,34
No. 40	0,425	201,30	40,26	32,08
No. 60	0,250	73,10	14,62	17,46
No. 100	0,150	46,60	9,32	8,14
No. 200	0,075	26,90	5,38	2,76

Waktu (min)	Bacaan Hidrometer R	Temperature T (°C)	R_{cp}	Percent finer $\frac{a \times R_{cp}}{M_s} \times 100\%$	R_{cL}	L* (cm)	D (mm)
2	22	30	18	3,56	23	12,7	0,0304
4	20	30	16	3,17	21	13,0	0,0217
8	19	30	15	2,97	20	13,2	0,0155
15	14	30	10	1,98	15	14,0	0,0117
30	13	29	9	1,78	14	14,2	0,0083
60	11	29	7	1,39	12	14,5	0,0059
240	9	29	5	0,99	10	14,8	0,0030
1440	8	29	4	0,79	9	15,0	0,0012

Diperiksa Oleh	Disetujui Oleh
Koordinator Lab.Mekanika Tanah	Kepala Laboratorium Univ.Abdurrab
Puspa Ningrum, MT	**Doni Rinaldi Basri, MT**

Figure 7.6 Plastic Index (UFCSI)

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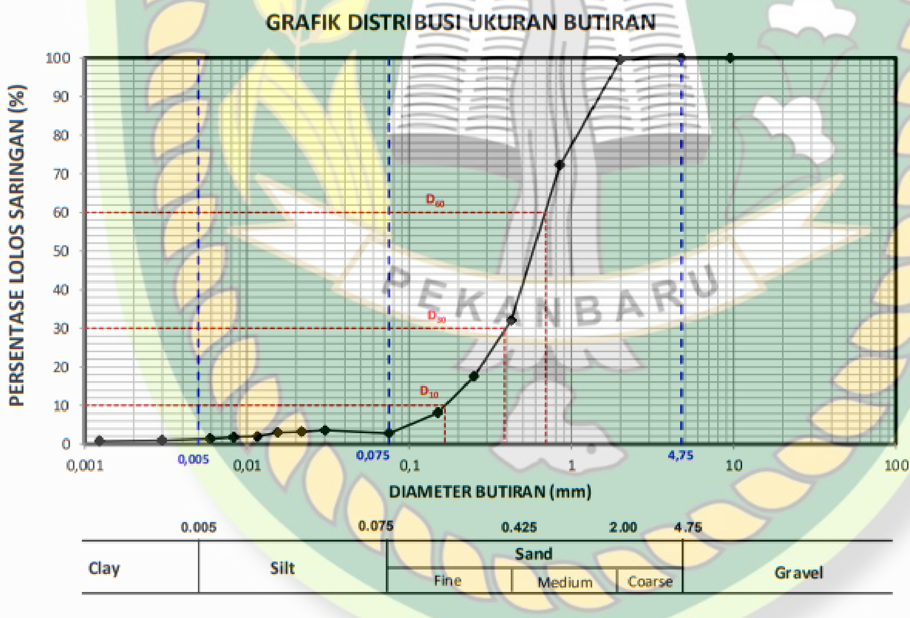
ANALISA SARINGAN (ASTM D 2487) & ANALISA HIDROMETER (ASTM D 422)

Pengirim Sampel	: PT. Minarta Dutahutama	Tanggal Uji	: 13 Juni 2024
Pekerjaan	: Konstruksi UFCSI	Diuji Oleh	: MWP
Lokasi	: Kelurahan Palas, Muara Fajar	Diperiksa Oleh	: PN
Deskripsi Tanah	: Tanah kuning		

Tipe Hidrometer	= 152 H	Specific gravity (Gs)	= 2,68
Koreksi Meniskus (F_m)	= 1	Berat Kering Sampel (Ms)	= 500 gram
Faktor Koreksi Air (F_z)	= -2	Larutan dispersi (*Reagent*)	= Sodium silikat (Na_2SiO_3)
Faktor Koreksi Gs (a)	= 0,99	Konstanta yang bergantung suhu (A)	= 0,01206
Faktor Koreksi Suhu (F_T)	= 2,65		



Kerikil (%) =	0,00	D_{10} =	0,166 mm
Pasir (%) =	97,24	D_{30} =	0,386 mm
Lanau (%) =	1,50	D_{60} =	0,693 mm
Lempung (%) =	1,26		

Cu = 4,17 **Cc = 1,30**

Diperiksa Oleh	Disetujui Oleh
Koordinator Lab.Mekanika Tanah	Kepala Laboratorium Univ.Abdurrab
Puspa Ningrum, MT	**Doni Rinaldi Basri, MT**

Figure 7.7 Hydrometer analysis (UFCSI)

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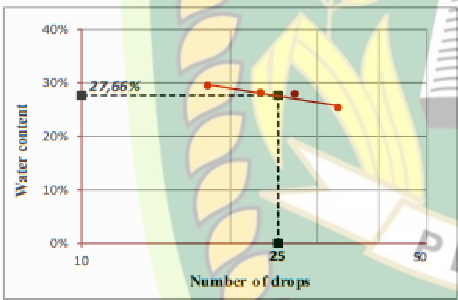
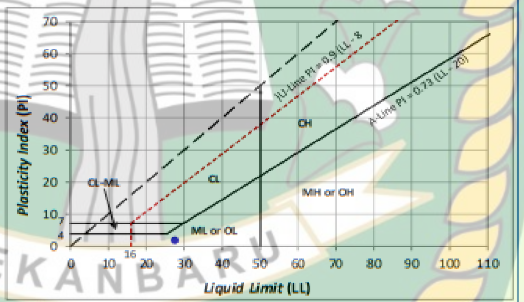
PENENTUAN BATAS ATTERBERG (ASTM D 4318)

Pengirim Sampel	: PT. Minarta Dutahutama	Tanggal Uji	: 13 Juni 2024
Pekerjaan	: Konstruksi UFCSI	Diuji Oleh	: MWP
Lokasi	: Kelurahan Palas, Muara Fajar	Diperiksa Oleh	: PN
Deskripsi Tanah	: Tanah kuning	Koordinat Sampel	: 0°36'59.0"N 101°26'01.5"

A. Uji Batas Cair (*Liquid Limit*, LL)

1	No. Cawan	Unit		1	2	3	4
2	Massa Cawan Kosong	M_1	gram	10,10	11,60	8,50	9,60
3	Massa Cawan + tanah basah	M_2	gram	43,20	45,50	42,60	49,10
4	Massa Cawan + tanah kering	M_3	gram	36,50	38,10	35,10	40,10
5	Massa air tanah	M_2-M_3	gram	6,70	7,40	7,50	9,00
6	Massa tanah kering	M_3-M_1	gram	26,40	26,50	26,60	30,50
7	Kadar Air	$\frac{M_2 - M_3}{M_3 - M_1} \times 100\%$		25,38%	27,92%	28,20%	29,51%
8	Jumlah Ketukan	N	blows	33	27	23	18





B. Uji Batas Plastis (*Plastic Limit*, PL)

1	No. Cawan	Unit		1	2
2	Massa Cawan Kosong	M_1	gram	11,30	8,70
3	Massa Cawan + tanah basah	M_2	gram	14,70	12,60
4	Massa Cawan + tanah kering	M_3	gram	14,00	11,80
5	Massa air tanah	M_2-M_3	gram	0,70	0,80
6	Massa tanah kering	M_3-M_1	gram	2,70	3,10
7	Kadar Air	$\frac{M_2 - M_3}{M_3 - M_1} \times 100\%$		25,93%	25,81%
8	Kadar Air rata-rata			25,87%	

Liquid Limit (LL)	=	27,66%
Plastic Limit (PL)	=	25,87%
Plasticity Index (PI)	=	1,79%
Unified Soil Classification System (USCS)	=	SP

Diperiksa Oleh	Disetujui Oleh
Koordinator Lab.Mekanika Tanah	Kepala Laboratorium Univ.Abdurrab
Puspa Ningrum, MT	Doni Rinaldi Basri, MT

Figure 7.8 Atterberg Limits *(UFCSI)*

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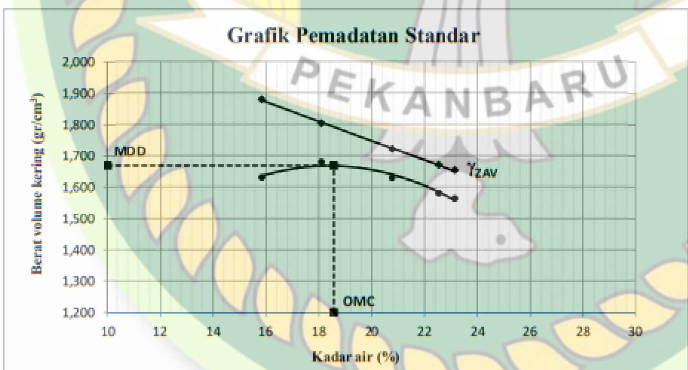
PEMERIKSAAN PEMADATAN (ASTM D 698)

Pengirim Sampel	: PT. Minarta Dutahutama	Tanggal Uji	: 18 Juni 2024
Pekerjaan	: Konstruksi UFCSI, Kelurahan Palas, Muara Fajar, Pekanbaru	Diuji Oleh	: MWP
Deskripsi Tanah	: Tanah Kuning	Diperiksa Oleh	: PN
Diameter Mould	: 10,11 cm	Tipe Pemadatan	: Standar
Tinggi Mould	: 11,55 cm	Berat Penumbuk	: 2,5 kg
Berat Mould	: 1706,50 gr	Jumlah Lapisan	: 3 lapis
Volume Mould	: 927,202 cm^3	Jumlah Pukulan/lapis	: 25 tumbukan

Percobaan No	Unit	1			2			3			4			5		
Berat *mould*	gram	1706,5			1706,5			1706,5			1706,5			1706,5		
Berat *mould* + tanah padat	gram	3458,1			3545,6			3531,4			3502,7			3492,3		
Berat tanah padat	gram	1751,6			1839,1			1824,9			1796,2			1785,8		
Berat volume basah	gr/cm^3	1,889			1,983			1,968			1,937			1,926		
No. Cawan timbangan		atas	tengah	bawah	atas	tengah	bawah	atas	tengah	bawah	atas	tengah	bawah	atas	tengah	bawah
Berat cawan kosong	gram	5,5	5,4	5,3	6,0	5,5	5,3	5,1	5,2	5,1	5,4	5,0	5,2	5,6	5,6	5,1
Berat cawan + tanah basah	gram	87,4	86,9	86,2	90,0	91,6	90,4	99,9	80,7	96,9	99,0	96,8	98,1	92,5	95,7	99,1
Berat cawan + tanah kering	gram	76,3	75,4	75,4	77,1	78,6	77,2	83,7	67,8	80,9	81,5	79,9	81,3	79,9	78,2	78,3
Berat air	gram	11,1	11,5	10,8	12,9	13,0	13,2	16,2	12,9	16,0	17,5	16,9	16,8	12,6	17,5	20,8
Berat tanah kering	gram	70,8	70,0	70,1	71,1	73,1	71,9	78,6	62,6	75,8	76,1	74,9	76,1	74,3	72,6	73,2
Kadar air	%	15,7	16,4	15,4	18,1	17,8	18,4	20,6	20,6	21,1	23,0	22,6	22,1	17,0	24,1	28,4
Kadar air rata-rata	%	15,84			18,10			20,78			22,54			23,16		
Berat volume kering	gr/cm^3	1,631			1,680			1,630			1,581			1,564		
γ_{ZAV}	gr/cm^3	1,881			1,805			1,722			1,671			1,654		



Maximum Dry Density, $\gamma_{d\,max}$ (MDD) = 1,668 gr/cm^3
Optimum Moisture Content, w_{opt} (OMC) = 18,56 %

Diperiksa oleh	Disetujui oleh
Koordinator Lab.Mekanika Tanah	Kepala Laboratorium Univ.Abdurrab
Puspa Ningrum, MT	**Doni Rinaldi Basri, MT**

Figure 7.9 **Optimum Moisture Content *(UFCSI)***

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PENGUJIAN CBR (ASTM D 1883)

Pengirim Sampel : PT. Minarta Dutahutama
Pekerjaan : Konstruksi UFCSI, Kelurahan Palas, Muara Fajar, Pekanb.
Deskripsi Tanah : Tanah Kuning

Tanggal Uji : 19 Juni 2024
Diuji Oleh : MWP
Diperiksa Oleh : PN

Ukuran mould
Diameter mould : 15,24 cm
Tinggi mould : 11,64 cm
Volume : 2123,31 cm^3
Berat mould : 6783 gr

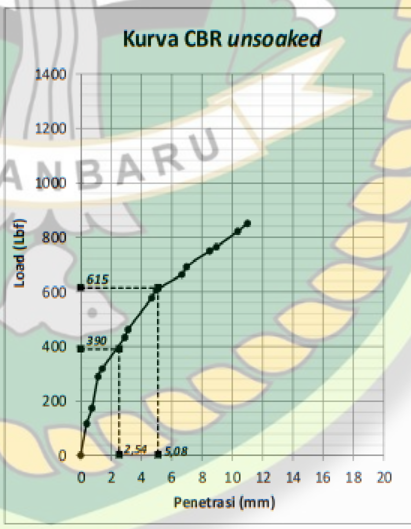
Jenis pemadatan
Tipe pemadatan : Standar
Jumlah pukulan : 56
Jumlah lapisan : 3

kalibrasi proving ring
Penetrasi : 0,01 mm/div
Load : 28,85 Lbf/div

Deskripsi	Unit	Nilai					
Berat mould + tanah padat	gram	10865					
Berat volume basah	gr/cm^3	1,922					
No. Cawan timbangan		atas (1)	atas (2)	tengah (2)	tengah (2)	bawah (1)	bawah (2)
Massa cawan kosong	gram	2,70	2,70	2,60	5,30	2,60	2,70
Massa cawan + tanah basah	gram	58,70	43,80	46,70	55,00	57,70	46,20
Massa cawan + tanah kering	gram	47,90	35,90	38,30	45,50	47,20	37,90
Kadar air	%	23,89	23,80	23,53	23,63	23,54	23,58
Kadar air rata-rata	%	23,66					
Berat volume kering	gr/cm^3	1,555					

Data CBR non rendaman (unsoaked)

Time (Minute)	Penetrasi		Load	
	Dial Gauge	mm	Dial Gauge	Lbf
0,00	0	0,00	0	0,00
0,50	40	0,40	4	115,40
1,00	75	0,75	6	173,10
1,50	115	1,15	10	288,50
2,00	142	1,42	11	317,35
2,50	290	2,90	15	432,75
3,00	312	3,12	16	461,60
3,50	467	4,67	20	577,00
4,00	498	4,98	21	605,85
4,50	665	6,65	23	663,55
5,00	697	6,97	24	692,40
5,50	852	8,52	26	750,10
6,00	895	8,95	26,5	764,53
6,50	1035	10,35	28,5	822,23
7,00	1100	11,00	29,5	851,08



Penetrasi (mm)	Load (Lbf)		CBR (%)	Nilai CBR (%)
Standar	Standar	Hasil Uji		
2,54	3000	390	13,00	13,67
5,08	4500	615	13,67	

Diperiksa oleh
Koordinator Lab.Mekanika Tanah

Puspa Ningrum, MT

Disetujui oleh
Kepala Laboratorium Univ.Abdurrab

Doni Rinaldi Basri, MT

Figure 7.10 CBR Test (UFCSI)

UNIVERSITAS ABDURRAB	**DOKUMENTASI**
	Klien : PT. Minarta Dutahutama
	Pekerjaan : Konstruksi UFCSI Pengendalian Banjir
	Lokasi : Kelurahan Palas, Muara Fajar, Kota Pekanbaru

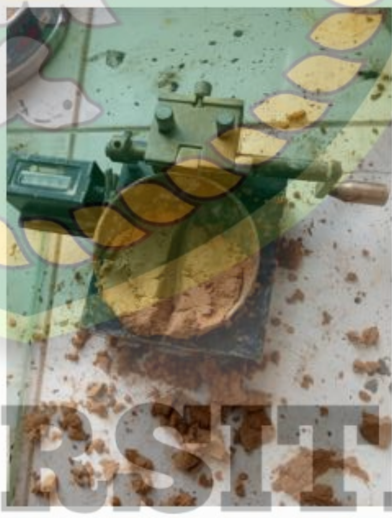
Pengujian kadar air sampel tanah kuning	Pengujian Hidrometer
	
Pengujian analisa saringan	Pengujian batas cair (LL)
	

Figure 7.11 Laboratory Soil Investigation Equipment (UFCSI)

Appendix C Laboratory Tests for Subsoil (UFCSI)

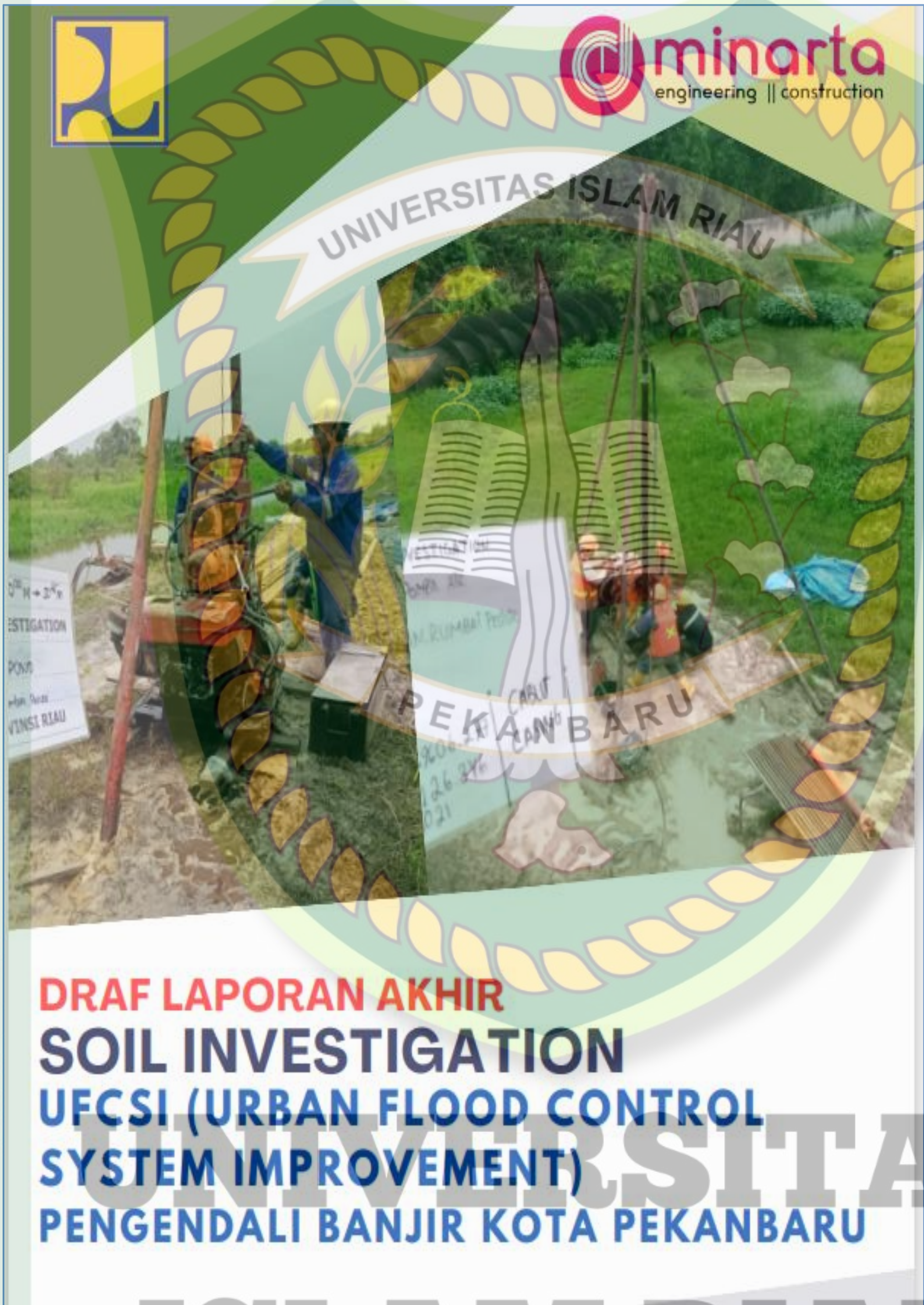


Figure 7.11 Soil Investigation Report for Subsoil Laboratory Tests

Table 7.1 BH-2 Subsoil Layers (UFCSI)

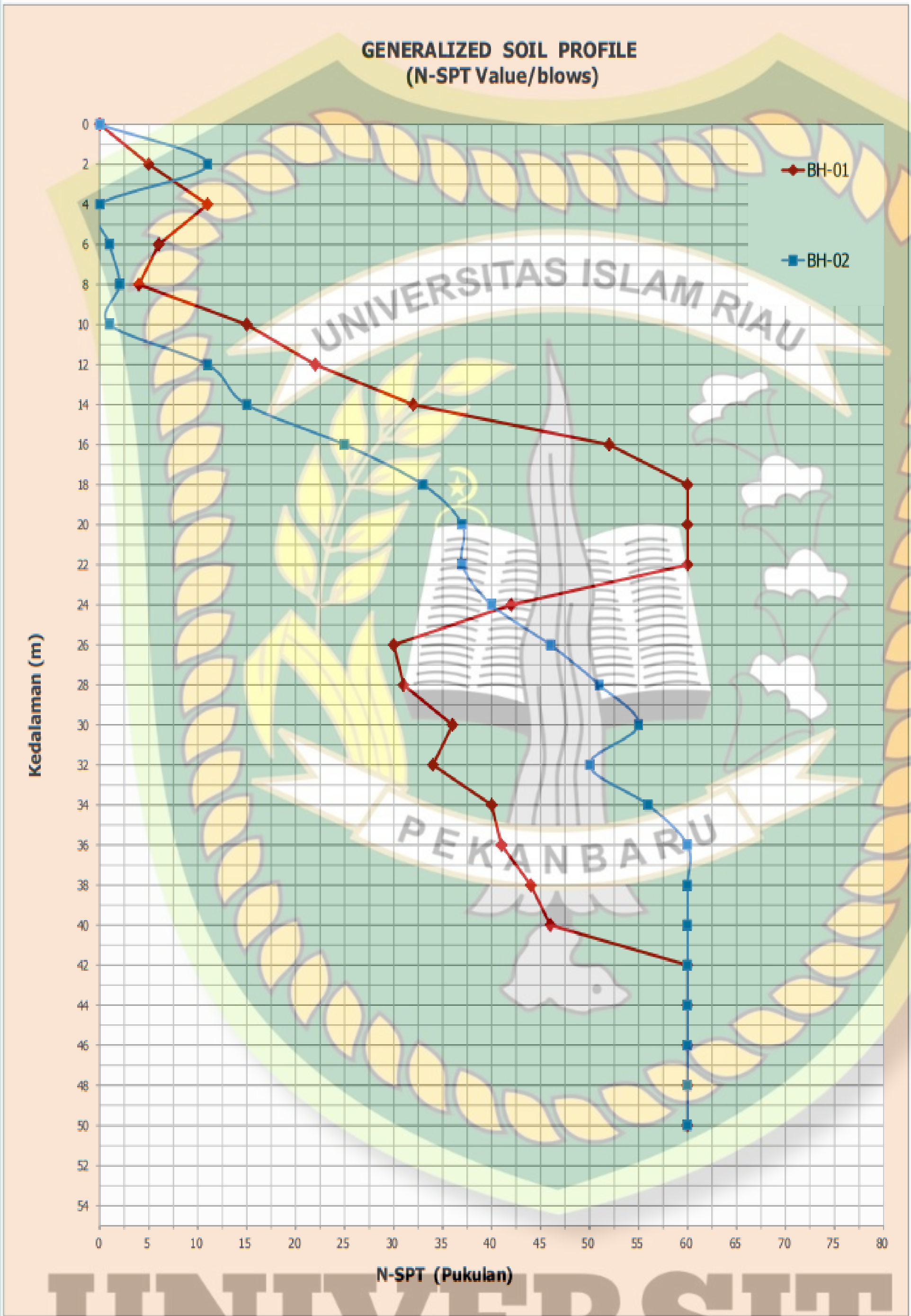
Tabel 4.2 Ringkasan Hasil pengeboran di titik BH – 02.

Test No.	:	**BH - 02**	**Koordinat**	:	**-**
Date	:	**07 – 11 Maret 2024**	**Final Depth**	:	**50.45 meter**
GWL (m)	:	**-**	**Bor Master**	:	**Raja Adiguna S**

Depth (m)	Tebal Lapisan (m)	Deskripsi
00.00 – 00.80	00.80	Lempung Berlanau, Kuning Kecoklatan.
00.80 – 01.15	00.35	Lempung Berlanau, Abu-abu Gelap.
01.15 – 02.55	01.40	Lempung Berlanau, Abu-abu cerah, Plastis Sedang, Kadar Air Sedang, Kekakuan Kaku.
02.55 – 08.45	05.90	Lapukan Kayu (Gambut), Abu-abu Gelap Kemerahan, Tidak Plastis, Kadar Air Tinggi, Kekakuan Sangat Lunak.
08.45 – 09.60	01.15	Lempung Lanau, Abu-abu Gelap.
09.60 – 11.00	01.40	Lapukan Kayu (Gambut), Coklat Kemerahan, Tidak Plastis, Kadar Air Tinggi, Kekakuan Sangat Lunak.
11.00 – 18.00	07.00	Pasir Sedang, Abu-abu Cerah, Tidak Plastis, Kadar Air Rendah, Kepadatan Sedang.
18.00 – 20.00	02.00	Pasir Sedang, Abu-abu Cerah, Tidak Plastis, Kadar Air Rendah, Kepadatan Padat.
20.00 – 28.00	08.00	Pasir Halus Campur Pasir Sedang Berlanau, Abu-abu Gelap, Tidak Plastis, Kadar Air Sangat Rendah, Kepadatan Padat.
28.00 – 30.00	02.00	Pasir Halus Campur Pasir Sedang Berlanau, Abu-abu Gelap, Tidak Plastis, Kadar Air Sangat Rendah, Kepadatan Sangat Padat.
30.00 – 50.45	20.45	Pasir Halus, Abu-abu Gelap, Tidak Plastis, Kadar Air Sangat Rendah, Kepadatan Sangat Padat.

Table 7.2 BH-2 Laboratory Tests for Peat Soil (UFCSI)

Parameter	01.50 – 02.00 m	07.50 – 08.00 m	11.50 – 12.00 m
Sample Type	UDS	DS	DS
Water Content (W, %)	29.78	161.77	20.87
Specific Gravity (GS)	2.661	2.505	2.686
Wet Unit Weight (γ wet, kg/cm³)	1.632	0.899	1.581
Dry Unit Weight (γ dry, kg/cm³)	1.257	0.343	1.308
Direct Shear Test - Cohesion (Cm, kg/cm²)	0.378	0.054	0.089
Direct Shear Test - Friction Angle (Fm, °)	6.678	1.174	5.248
Atterberg Limits - Liquid Limit (LL, %)	63.56	NP	NP
Atterberg Limits - Plastic Limit (PL, %)	24.60	NP	NP
Atterberg Limits - Plasticity Index (PI, %)	38.96	NP	NP
Triaxial UU Test - Cohesion (C, kg/cm²)	0.481	NP	NP
Triaxial UU Test - Friction Angle (Ø, °)	7.477	NP	NP
Consolidation - Compression Index (CC)	0.349	-	-
Consolidation - Coefficient of Consolidation (Cv, cm²/s)	0.0000403	-	-
Unconfined Compressive Strength (UCS, Quu, kg/cm²)	1.636	-	-



Proyek :	Lokasi :
Soil Investigation UFCSI (Urban Flood Control System Improvement) Pengendalian Banjir Kota Pekanbaru	Jl. Nelayan Rumbai Pesisir Pekanbaru - Riau

Figure 7.12 General Soil Profile (UFCSI)

Table 7.3 BH-2 (UFCSI)

minarta engineering || construction

DRILLING LOG

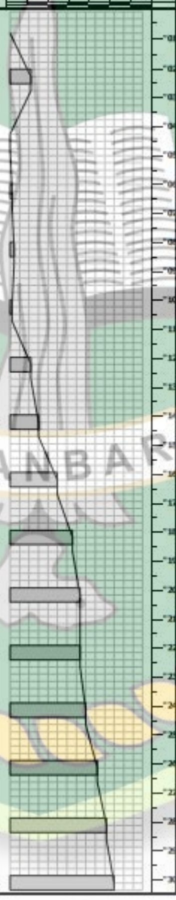
Proyek	: Soil Investigation UFCSI (Urban Flood Control System Improvement) Pengendalian Banjir Kota Pekanbaru	Cuaca	: Cerah
Lokasi	: Jl. Nelayan Rumbai Pesisir Pekanbaru - Riau	Hari/Tanggal Mulai	: 07 Maret 2023
No. Lubang Bor	: BH - 02	Hari/Tanggal Selesai	: 11 Maret 2023
Sisitem Koordinat	:	Mesin Bor	: YBM
Koordinat X	: -	Metode Pengeboran	: Rotary Drilling
Y	: -	Master Bor	: Raja Adiguna S
Elevasi Z	: -	Logger	: Raja Adiguna S
Total Kedalaman	: 50.45	Checker	: Patuh S.T

Tanggal	GWL (m)	Tebal Lapisan (m)	Ked. akhir lapisan (m)	Deskripsi
07 Maret 2023	Sore : 0.80 m	0.80	0.80	Lempung Berlanau, Kuning Kecoklatan.
		0.35	1.15	Lempung Berlanau, Abu-abu Gelap.
		1.40	2.55	Lempung Berlanau, Abu-abu cerah, Plastis Sedang, Kadar Air Sedang, Kekakuan Kaku.
08 Maret 2023	Sore : 1.50 m	5.90	8.45	Lapukan Kayu (Gambut), Abu-abu Gelap Kemerahan, Tidak Plastis, Kadar Air Tinggi, Kekakuan Sangat Lunak.
	Pagi : 1.00 m	1.15	9.60	Lempung Lanau, Abu-abu Gelap.
		1.40	11.00	Lapukan Kayu (Gambut), Coklat Kemerahan, Tidak Plastis, Kadar Air Tinggi, Kekakuan Sangat Lunak.
09 Maret 2023	Sore : 1.00 m	7.00	18.00	Pasir Sedang, Abu-abu Cerah, Tidak Plastis, Kadar Air Rendah, Kepadatan Sedang.
	Pagi : 1.50 m	2.00	20.00	Pasir Sedang, Abu-abu Cerah, Tidak Plastis, Kadar Air Rendah, Kepadatan Padat.
10 Maret 2024	Sore : 1.80 m	8.00	28.00	Pasir Halus Campur Pasir Sedang Berlanau, Abu-abu Gelap, Tidak Plastis, Kadar Air Sangat Rendah, Kepadatan Padat.
	Pagi : 1.00 m	2.00	30.00	Pasir Halus Campur Pasir Sedang Berlanau, Abu-abu Gelap, Tidak Plastis, Kadar Air Sangat Rendah, Kepadatan Sangat Padat.

N-SPT (Pukulan)

N1	N2	N3	N-SPT
4	4	7	11
1	-	-	0
1	-	1	1
1	1	1	2
1	-	1	1
3	4	7	11
4	6	9	15
6	11	14	25
8	15	18	33
9	17	20	37
9	16	21	37
10	18	22	40
11	20	26	46
12	22	29	51
14	24	31	55

Grafik N-SPT



Corebox

Legend :
- Silt
- Clay
- Sand
- Undisturbed Sample (UDS)
- Disturbed Sample (DS)
- S P T

Catatan :

DRILLING LOG

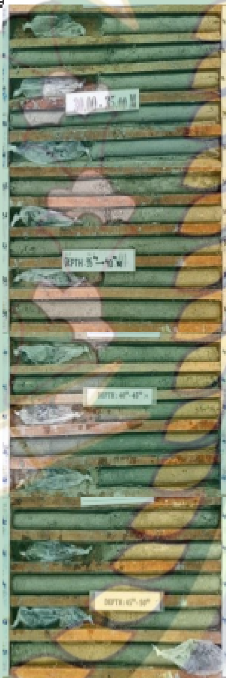
Proyek	: Soil Investigation UFCSI (Urban Flood Control System Improvement) Pengendalian Banjir Kota Pekanbaru	Cuaca	:
Lokasi	: Jl. Nelayan Rumbai Pesisir Pekanbaru - Riau	Hari/Tanggal Mulai	: 07 Maret 2023
No. Lubang Bor	: BH - 02	Hari/Tanggal Selesai	: 11 Maret 2023
Sistem Koordinat	:	Mesin Bor	: YBM
Koordinat X	: -	Metode Pengeboran	: Rotary Drilling
Y	: -	Master Bor	: Raja Adiguna S
Elevasi Z	: -	Logger	: Raja Adiguna S
Total Kedalaman	: 50.45	Checker	: Patuh S.T

Tanggal	G W L (m)	Kedalaman (m)	Tebal Lapisan (m)	Ked. akhir lapisan (m)	Litologi	Deskripsi	N1	N2	N3	N-SPT
10 Maret 2024	Sore : 1.80 m; Pagi : 1.00 m	31–35								
		32					14	20	30	50
		34					12	24	32	56
11 Maret 2023	Sore : 1.40 m; Pagi : 1.20 m	36					15	26	34	60
		38					18	30	30/	≥60
		40				Pasir Halus, Abu-abu Gelap, Tidak Plastis, Kadar Air Sangat Rendah, Kepadatan Sangat Padat.	24	32	28/	≥60
		42					22	31	29/	≥60
		44					27	36	24/	≥60
		46					24	30	30/	≥60
		48					28	34	26/	≥60
		50	20.45	50.45			32	39	21/	≥60
		51–60				STOP BOR 50.45 Meter				

Grafik N-SPT: 10 20 30 40 50 60 70

Tipe: SPT, Sample

Corebox



Legend :

- Silt
- Clay
- Sand
- Undisturbed Sample (UDS)
- Disturbed Sample (DS)
- S P T

Catatan :

FOTO DOKUMENTASI KEGIATAN

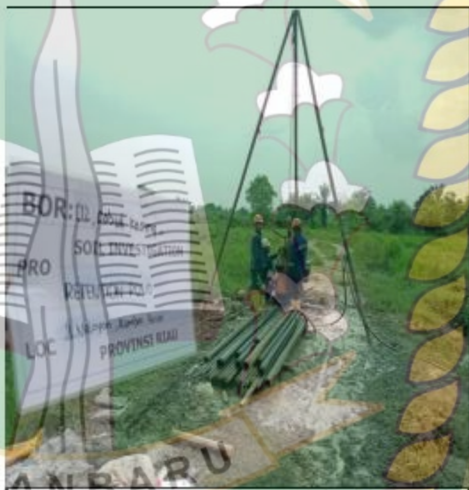
PENGUJIAN BORING

SOIL INVESTIGATION UFCSI (URBAN FLOOD CONTROL SYSTEM IMPROVEMENT)
PENGENDALIAN BANJIR KOTA PEKANBARU

Lokasi : Jl. Nelayan Rumbai Pesisir Pekanbaru - Riau

minarta engineering | construction | **BH-02**

Kegiatan Boring



Kegiatan Boring

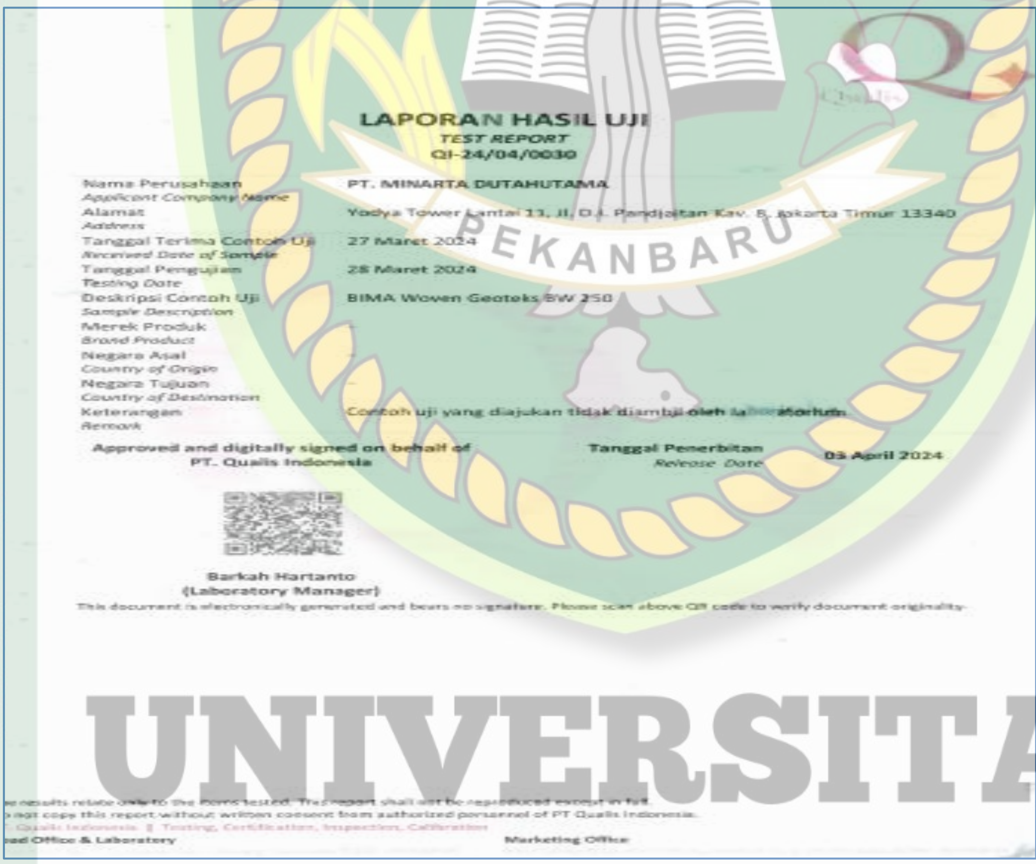
Pukulan SPT

Pukulan SPT

Figure 7.13 BH-2 Drilling Location (UFCSI)

Figure 7.14 Natural ground for both Peat and Clay (UFCSI)

Appendix D Laboratory Report Tests for Woven Geotextiles properties



LAPORAN HASIL UJI
TEST REPORT
QI-24/04/0030

Nama Perusahaan *Applicant Company Name*	PT. MINARTA DUTAHUTAMA
Alamat *Address*	Yodya Tower Lantai 11, Jl. D.I. Pandjaitan Kav. 8, Jakarta Timur 13340
Tanggal Terima Contoh Uji *Received Date of Sample*	27 Maret 2024
Tanggal Pengujian *Testing Date*	28 Maret 2024
Deskripsi Contoh Uji *Sample Description*	BIMA Woven Geoteks BW 250
Merek Produk *Brand Product*	-
Negara Asal *Country of Origin*	-
Negara Tujuan *Country of Destination*	-
Keterangan *Remark*	Contoh uji yang diajukan tidak diambil oleh laboratorium

Approved and digitally signed on behalf of PT. Qualis Indonesia

Tanggal Penerbitan *Release Date* 03 April 2024

Barkah Hartanto
(Laboratory Manager)

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...ead Office & Laboratory   Marketing Office

Figure 7.15 Woven Geotextile Test Report (UFCSI)

KEMENTERIAN PEKERJAAN UMUM DAN PERUMAHAN RAKYAT
DIREKTORAT JENDERAL BINA MARGA
DIREKTORAT BINA TEKNIK JALAN DAN JEMBATAN
BALAI GEOTEKNIK, TEROWONGAN DAN STRUKTUR
Jalan A.H. Nasution No. 264 Kec. Arcamanik Kota Bandung, Jawa Barat 40294, Telp. (022) 7834487

KAN
LP-1838-IDN

TEST REPORT

Report Number	LB 0701-Bb36/GS/29/23
Sample Code	29/GS/VIII/2023
Type of Sample	Woven Geotextile BIMA Geoteks BW 250
Request From	PT. Panca Tetrasa
Letter Number	123359/LOO/HN/HN / 13 Juli 2023
Adress	Jl. Musi No. 5 Jakarta 10150
Contact Number	021-3810589
Project Name	-
Sample Description	Sample size 4 x 4 m (3 samples) and received rolled up
Received	August 8th, 2023

Properties Test Request :

No	Properties	Test Method
1	a) Wide Width Tensile Test	ISO 10319
	b) Thickness at Specified Pressures	ISO 9863
	c) Static Puncture Test (CBR Test)	ISO 12236
	d) Mass per Unit Area	ISO 9864
	e) Water Permeability Characteristics Normal to the Plane, Without Load	ISO 11058
	f) Index Puncture Resistance	ASTM D4833
	g) Grab Breaking Load and Elongation of Geotextiles	ASTM D4632
	h) Trapezoid Tearing Strength	ASTM D4533

Notes:

1) Testing only applies to test samples and test specimens received according to the test application letter.
2) The Test Certificate and its Attachments are an integral part of the Test Report.
3) Test Reports are not used for commercial purposes and if Test Reports are misused, it is not the responsibility of the Implementation Unit for Geotechnics, Tunnels, and Structures.
4) This test report is prohibited from being republished and reproduced in part or in whole without the approval of the Implementation Unit for Geotechnics, Tunnels, and Structures

Bandung, October 24th 2023

Head of Implementation Unit
for Geotechnics, Tunnels, and Structures

Dr. Fahmi Aldiamar, ST., MT.
NIP. 19790330 200502 1 001

TERKENDALI

INITIALS
Service Support/Head of Administrative Sub-Division

Figure 7.16 Laboratory Woven Geotextile Test Report (UFCSI)

QI-24/04/0030

Qualis

Test Results :

1. **Grab Breaking Load & Elongation of Geotextiles**
Test Method: ASTM D4632, Gauge length : 75 mm, Speed: 300 mm/minuets

Machine Direction (MD)	Result	
	Strength (N)	Elongation (%)
Average	1687	36.8

Cross Direction (CD)	Result	
	Strength (N)	Elongation (%)
Average	1565	24.0

2. **Static Puncture Strength of Geotextiles and Geotextiles-Related Products**
Test Method: ASTM D6241, Speed : 50 mm/minuets

	Result (N)
Average	5830

3. **Trapezoid Tearing Strength of Geotextiles**
Test Method: ASTM D4533

Machine Direction (MD)	Result (N)
Average	922

Cross Direction (CD)	Result (N)
Average	1850

4. **Tensile Properties of Geotextiles by the Wide Width Strip Method**
Test Method: ASTM D4595, gauge length: 100 mm, speed : 50 mm/minuets

Machine Direction (MD)	Result	
	Strength (kN/m)	Elongation (%)
Average	47.6	40.0

Cross Direction (CD)	Result	
	Strength (kN/m)	Elongation (%)
Average	50.8	32.0

Page 3 of 4

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TSQ-LAB-CIAF-087

Figure 7.17 Woven geotextile laboratory Results (UFCSI)

	KONTRAKTOR	PEMBERI TUGAS	KONSULTAN
SURAT IJIN PELAKSANAAN PEKERJAAN			
UFCSI (URBAN FLOOD CONTROL SYSTEM IMPROVEMENT) PENGENDALIAN BANJIR KOTA PEKAN BARU	PT.MINARTA DUTAHUTAMA	SNVT PJSA SUMATERA III PROVINSI RIAU	YACHIYO ENGINEERING CO., LTD NIPPON KOEI CO.,LTD , PT.INDRA KARYA(Persero) PT.DUTA CIPTA MANDIRI ENGINEERING CONSULTANT

PERSETUJUAN PELAKSANAAN PEKERJAAN

NOMOR DOKUMEN :
HARI : Jum'at
TANGGAL : 19 April 2024
JENIS PEKERJAAN : Pengadaan Geotextile, tebal Sedang (400 - 800 gr\/m2) manual
LOKASI DIKERJAKAN : Jalan Inspeksi Retention Pond dan Penataan Lingkungan
POSISI AS :

Dengan hormat,
Dengan ini mohon diijikan untuk mulai melaksanakan pekerjaan, sebagai berikut.

I. Bagian Pekerjaan yang akan dilaksanakan dengan lampiran :
   1. Nomor gambar kerja/ Shop drawing
   2. Judul gambar

II. Dasar Pertimbangan :
   1. Shop Drawing : Telah / Belum disetujui
   2. RKS : Bab Pasal Hal.
   3. Persetujuan Pemakaian Material : No Tanggal
   4. Persetujuan Pemakaian Tenaga Kerja : No Tanggal

III. BAHAN & ALAT KERJA YANG DIGUNAKAN

BAHAN		ALAT KERJA	
NAMA BAHAN	JUMLAH	NAMA ALAT KERJA	JUMLAH
1. Geo-texstile Matress Tipe Woven - Volume dalam (m2) :	7200 m2 (15 ROLL)		

IV. TENAGA KERJA YANG DIPAKAI

KEAHLIAN	JUMLAH	KEAHLIAN	JUMLAH

V. JADWAL PELAKSANAAN
Pekerjaan akan dilaksanakan Mulai tgl 29 April s/d tgl 5 Mei 2024

VI. MEMUTUSKAN
Menyetujui/Tidak menyetujui pekerjaan yang diusulkan (Coret yang tidak perlu)

VII. CATATAN :
- Perhatikan stockpile untuk geotek. Pastikan terlindungi dari hujan dan panas
- Segera lakukan pengujian lab air
- Apabila barang yg datang berbeda dg yg diuji, spv silahkan reject

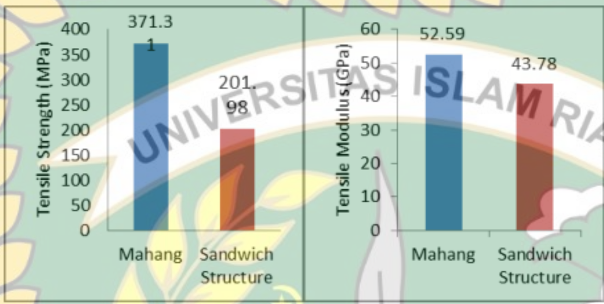
Mengetahui	Menyetujui	Diajukan oleh :
DIREKSI KONSTRUKSI PPK SUNGAI DAN PANTAI I SNVT PJSA SUMATERA III PROV. RIAU	Konsultan Supervisi YACHIYO ENGINEERING CO.,LTD NIPPON KOEI CO,LTD , PT.INDRA KARYA(Persero) PT.DUTA CIPTA MANDIRI ENGINEERING CONSULTANT	Kontraktor PT.MINARTA DUTAHUTAMA
MAHELGA LEVINA AMRAN, ST., MT. NIP. 19960315 201802 2 002	DELSY SIUKRI Construction Supervision Engineer	DIDI ISMANTO, ST Kepala Proyek

Figure 7.18 Laboratory Tests for woven Geotextile validation (UFCSI)

Appendix E Mechanical Properties of Cerucuk Mahang Wood

3. RESULTS AND DISCUSSIONS

Tensile test assessed the strength and stiffness of mahang wood and sandwich composite in breaking under tension. The results of tensile strength and tensile modulus for mahang wood and sandwich composite consisting mahang core and fibreglass face skins are shown in Fig. 2.



(a) (b)

Fig. 2 Results of (a) tensile strength and (b) young's modulus comparison for mahang wood and sandwich structure.

The ultimate tensile strength (UTS) corresponds to the maximum tensile stress a material can sustain prior to failure is often referred as tensile strength. Tensile strength and young's modulus of mahang wood obtained in this study are 371.31 MPa and 52.59 GPa respectively. Tensile properties of mahang wood in this experimental work is significantly higher than tensile properties of balsa wood as reported by Soden and McLeish [10]. They reported the value of 31.5 MPa for tensile strength and 5.17 GPa for tensile modulus. Mahang wood exhibited ten times stronger than balsa wood. Both tensile strength and tensile modulus of wood are slightly higher than sandwich structure. Although sandwich structure incorporating fibreglass face skins, the grain alignment in sandwich structure is perpendicular to the direction of tensile loading which make it weaker as it easily tearing apart the wood fibres. As for wood tensile tests, the grain aligned parallel to the direction of tensile loading. As a results, the wood cells working together in axial direction and act

as tiny column or tubes to resist tensile loads. The load-elongation curve obtained from tensile test is presented in Fig. 3. The first part of the graph shows slightly linear elastic behavior before plastic deformation occurs which transform the linear graph to curvature. Finally, a sudden drop occurs to signify an almost brittle rupture [11].

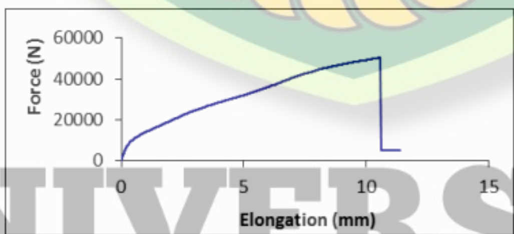


Fig. 3 Load-elongation curve for mahang wood specimen in tension

Figure 7.19 Young's modulus of cerucuk Mahang(Zakari et al., 2018)

Appendix F Installation of Cerucuk Mahang wood (UFCSI) Pekanbaru

Figure 7.20 Cerucuk wood installation at UFCSI Jl Nelayan Rumbai Pekanbaru Indonesia

Appendix G Woven Geotextile Installation

Figure 7.21 Woven Geotextile Installation at (UFCSI)