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# Design of Toll Road Embankment With Secondary Compression Mitigation After Pvd Installation and Solutions For The Probolinggo – Banyuwangi Toll Road Construction Project Package 2 Sta 16+300 – Sta 16+700

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**ABSTRACT**

In the Probolinggo-Banyuwangi Toll Road construction project package 2, there are several areas where the subgrade consists of soft soil, one of which is at STA 16+300 – STA 16+700. In this section, soft soil with a depth of up to 12 meters is found. The primary issue in constructing on soft soil is settlement. Settlement occurs due to the high compressibility of clay, where consolidation takes an extended period. This condition may pose problems during both the construction and operational phases of the toll road due to ongoing settlement.

Consolidation consists of primary consolidation and secondary compression. Primary consolidation occurs first, followed by secondary compression. The method used in this study to accelerate primary consolidation and secondary compression involves prefabricated vertical drains (PVD) combined with preloading. The study was conducted at STA 16+300 – STA 16+700, where compressible soil with a depth of 12 meters is present, but the embankment height varies. For this study, embankment heights of 4m, 6m, and 8m were analyzed. Once the magnitude of primary consolidation and secondary compression from year 2 to year 15 was determined, the results were evaluated based on the Binamarga standards. Specifically, the settlement requirements are as follows: during the 2nd and 3rd years, settlement must be less than 2 cm; during the 2nd and 12th years, it must be less than 10 cm with a construction period of 2 years and maintenance of 1 year; and during the 5th and 6th years, it must be less than 2 cm; while during the 5th and 15th years, it must be less than 10 cm with a construction period of 3 years and maintenance of 2 years. From these results, the required embankment heights for which preloading is necessary were identified.

Slope stability analysis for the embankment was also conducted to determine whether the stability meets the required standards. If the stability requirements were not met, reinforcement using geotextile material was applied. Therefore, for each embankment variation, the necessary amount of geotextile was determined.

The results of this study show that the settlement requirements of Binamarga were met during the 2nd and 3rd years, the 5th and 6th years, and the 5th and 15th years, but not during the 2nd and 12th years, indicating the need for preloading. Regarding embankment stability, the factor of safety for all embankment variations was found to be below the required standard, necessitating the use of geotextile reinforcement. Based on these results, this study serves as input for selecting the appropriate method and ensuring a faster implementation period for the toll road construction.

**Keywords** : soft soil, primary consolidation, secondary compression, prefabricated vertical drain (pvd), preloading, geotextile.

## INTRODUCTION

The construction of the Probolinggo–Banyuwangi toll road is part of the government's Trans Java Toll Road development program, which connects Merak to Banyuwangi. In the construction area of the Probolinggo–Banyuwangi toll road, package 2, several zones have been identified where the subgrade consists of soft soil, based on soil investigation results. Field tests indicate 12 points with soft soil, characterized by N-SPT values ranging from 2 to 10 and depths reaching up to 18 meters. One notable section is between STA 16+300 and STA 16+700, where the investigation results show soft soil up to a depth of 12 meters. Given these conditions, ground improvement is necessary to ensure sufficient bearing capacity and to prevent excessive settlement during the operational phase of the toll road.

Settlement issues arise primarily due to compressible clay soil. Compression, or consolidation, occurs over a prolonged period and can be categorized into two types: primary consolidation and secondary consolidation. Consolidation typically spans a long timeframe, possibly decades or even centuries. Therefore, it is crucial to accelerate the consolidation process.

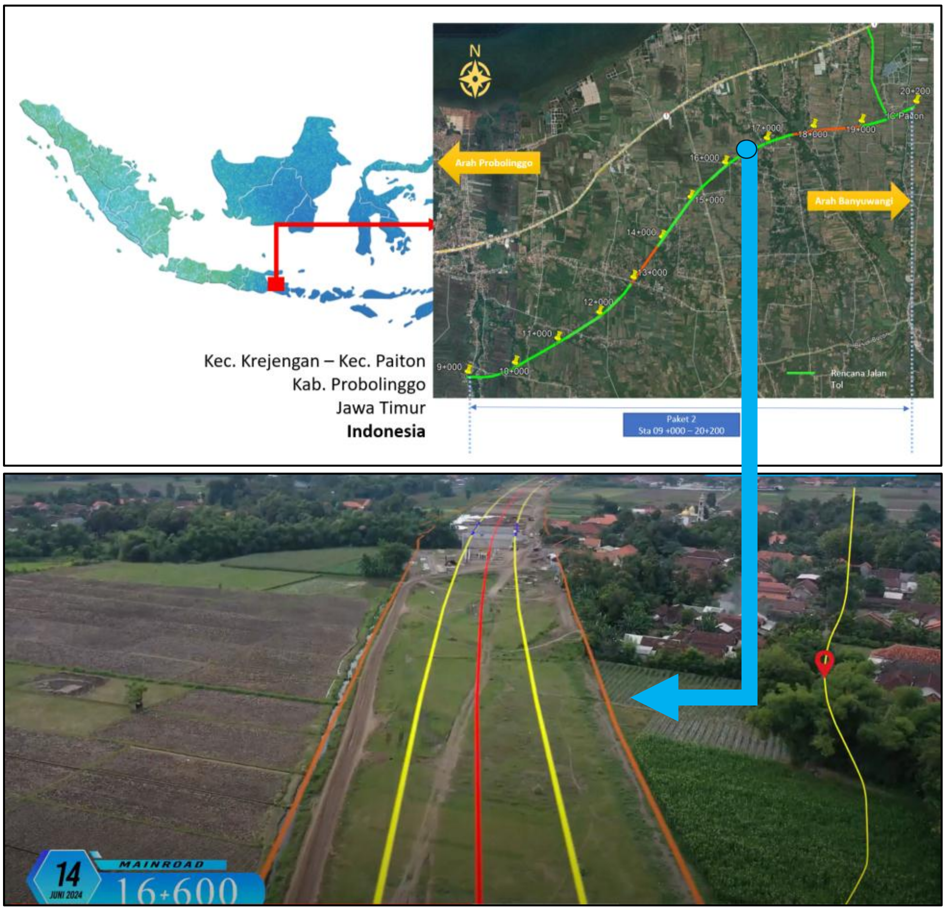


**Figure 1.** Location of the Probolinggo–Banyuwangi Toll Road Construction Package 2 at Station 16+600

One method to expedite consolidation is by using Prefabricated Vertical Drains (PVD) in combination with preloading, which helps induce secondary compression earlier. However, in practice, even after ground improvement and embankment placement over clay subgrade, significant settlement can still occur, despite the expected completion of primary consolidation.

In road construction, guidelines from the Directorate General of Highways, particularly Pavement Design Standard No. 02/M/BM/2017, stipulate that the rate of settlement should be less than 20 mm per year. Additionally, Geotechnical Design and Construction Guide 4 requires that settlement should not exceed 10 cm over a 10-year period. These regulations serve as standard criteria for settlement limits in embankment construction, including toll roads. However, the current provisions have certain ambiguities in their application, specifically:

1. The Bina Marga regulations do not explicitly clarify whether the settlement criteria refer to total settlement, which includes both primary and secondary consolidation. Consequently, in practice, focus is often placed solely on primary consolidation, with less attention given to secondary compression.
2. The Bina Marga regulations do not specify whether the settlement criteria apply upon the completion of the construction phase or after the maintenance period ends.

In toll road construction, the focus is often limited to settlement during the construction phase, addressing only primary consolidation, while the period following primary consolidation—during which secondary compression occurs—is frequently overlooked. Consequently, during the maintenance and operational phases of the toll road, surface unevenness and excessive settlement are commonly observed. This can compromise road safety and driving comfort, while also incurring significant maintenance costs.

In the construction of the Probolinggo–Banyuwangi Toll Road Package 2, numerous areas with soft soil have been identified. Based on these conditions, an initial study is being conducted to assess the Bina Marga settlement criteria regarding secondary compression after reinforcement using PVD combined with embankment loads of varying heights but with consistent compressible soil depth. The aim is to establish an appropriate method and efficient implementation timeframe for constructing the Probolinggo–Banyuwangi Toll Road.

This study aims to determine the magnitude of primary and secondary consolidation occurring under the criteria of $Sc < 2$ cm per year and $Sc < 10$ cm over a 10-year period. It also seeks to identify embankment heights where secondary consolidation exceeds the Bina Marga standards and to propose appropriate measures for mitigating secondary compression, which is often overlooked after the maintenance period and during the operational phase of toll roads. The goal is to prevent significant settlement during the operational phase.

## LITERATURE REVIEW

In civil engineering, soft soil can be said to be a soil that has many problems and becomes a big challenge when there is civil building construction on it. In Geotechnical Manual 4 (2001), soft soils are defined as soils with low shear strength and high compressibility which, if not carefully recognized and investigated, can lead to intolerable long-term instability and settlement problems. In addition, soft soils are characterized by high moisture content, high compressibility, and low bearing capacity when compared to other clay soils. In other words, the presence of soft soils in a civil construction project is not desirable due to the many possible problems arising from the weakness of soft soils.

In geotechnical engineering, the terms soft and very soft are specifically defined for clays. When related to the results of field investigations such as Cone Penetrometer Test

(CPT), Standard Penetration Test (SPT), and Vane Shear Test (VST), the relationship between soft soil consistency and the range of test values shown in Table 1 can be obtained.

**Table 1.** Correlation for Clay Parameters

| Consistency | Cohesion not undrained, cu (kPa) | Conus resistance qc (kPa) | N SPT | Su (kPa) | Free compressive strength, qu (kPa) |
|---|---|---|---|---|---|
| Very soft | < 12,5 | 0 – 180 | < 2 | < 12 | < 25 |
| Soft | 12,5 – 25 | 180 – 375 | 2 – 4 | 12 – 25 | 25 – 50 |
| Firm | 25 – 50 | 375 – 750 | 4 – 8 | 25 – 50 | 50 – 100 |
| Stiff | 50 – 100 | 750 – 1500 | 8 – 15 | 50 – 100 | 100 – 200 |
| Very stiff | 100 – 200 | 1500 – 3000 | 15 – 30 | 100 – 200 | 200 – 400 |
| Hard | > 200 | > 3000 | > 30 | > 200 | > 400 |

Source : Ministry of Public Works, 2024

## Soft Soil Parameters

1. Cohesion

Cohesion is the force of attraction between particles in rock constituents expressed in units of weight per unit area. If the higher the shear strength of a soil, the higher the cohesive force value of the rock. Conversely, if the shear strength decreases, the cohesive value of the soil will also decrease. It can be said that the cohesive force is directly proportional to the density of the object. Therefore, the higher the density of the soil, the higher the value of the cohesive force obtained.

**Table 2.** Relationship between Cohesion, N-SPT, and Volume Weight Values

| Cohesive Soil | | | | | |
|---|---|---|---|---|---|
| N-SPT | < 4 | 4 – 6 | 6 - 15 | 16 – 30 | 31 – 50 |
| State | Very soft | Soft | Medium | Stiff | Hard |
| Cohesion | 0 – 10 | 10i – 25 | 25 –i 45 | 45 –i 95 | > 100 |
| Unit Weight | 14 – 18 | 16 – 18 | 16 –i 18 | 16 –i 20 | 20 –i 23 |

Source : Lambe dan Whitman, 1969

In this research, analysis of the subgrade data to obtain the undrained cohesion value (Cu) uses the formula of Ardana and Mochtar (1999), which is a correlation based on the Plasticity Index value as shown in Figure 2 below.

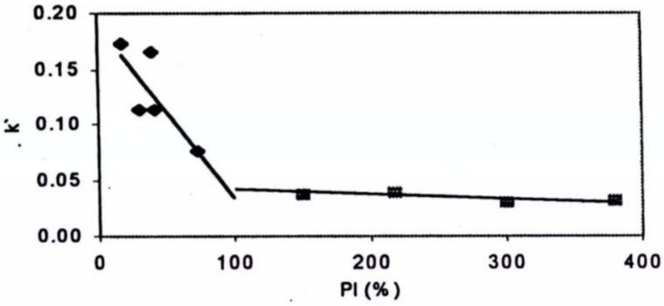


**Figure 2.** Correlation of Plasticity Index Values

Source : Ardana and Mochtar, 1999

The Cu value increase of the soil can be obtained using correlations such as the following:

1. For Plasticity Index (PI) value < 100%
   Cu (kg/cm$^2$) = 0.0737 + (0.1899 – 0.0016 PI) x σ′(kg/cm$^2$) …(1)
   Cu (kPa) = 7.37 + (0.1899 – 0.0016 PI) x σ′ (kPa) …(2)
2. For the value of Plasticity Index (PI) > 100%
   Cu (kg/cm$^2$) = 0.0737 + (0.0454 – 0.00004 PI) x σ′(kg/cm$^2$) …(3)
   Cu (kPa) = 7.37 + (0.0454 – 0.00004 PI) x σ′ (kPa) …(4)
   where :
   Cu = bearing capacity (kg/cm$^2$)
   PI = soil plasticity index
   σ′ = stress occurring in the soil layer (kg/cm$^2$) or (kPa)

**Primary Consolidation**

There are two types of consolidation based on the applied stress: Normally Consolidated Soil (NC Soil): Soil in which the current effective overburden stress is the maximum stress the soil has ever experienced. Or Overconsolidated Soil (OC Soil): Soil in which the current effective overburden stress is less than the maximum stress the soil has previously experienced.

In general, the amount of consolidation settlement for a clay layer with thickness H can be calculated using the following equation (Das, 1985):.

1. NC – Soil

$$Sc_i = \frac{Cc \times H_i}{1+e_0} \log \frac{\sigma'_0 + \Delta\sigma}{\sigma'_0} \quad \dots(5)$$

2. OC – Soil

Jika, Δσ + σ'o ≤ σ'p :

$$Sc_i = \frac{Cs \times H_i}{1+e_0} \times \log \frac{\sigma'_0 + \Delta\sigma}{\sigma'_0} \quad \dots(6)$$

Jika, Δσ + σ'o > σ'p :

$$Sc_i = \frac{Cs \times H_i}{1+e_0} \log \frac{\sigma'_p}{\sigma'_0} + \frac{Cc \times H_i}{1+e_0} \log \frac{\sigma'_0 + \Delta\sigma}{\sigma'_c} \quad \dots(7)$$

Where :

| | |
|---|---|
| Cc | : compression index |
| Cs | : swelling index |
| σ’o | : Effective overburden stress |
| σ'p | : Pre-consolidation stress |
| Δσ | : Additional vertical load |
| Q | : Effective vertical stress at the ground surface due to embankment |
| eo | : Initial void ratio |

The values of Cc (Compression Index) and Cs (Swelling Index) are obtained from the correlation of soft soil parameters by Kosasih and Mochtar (2007). This correlation depends on the void ratio (e) as presented in graphical form in Figure 3 and Figure 4.

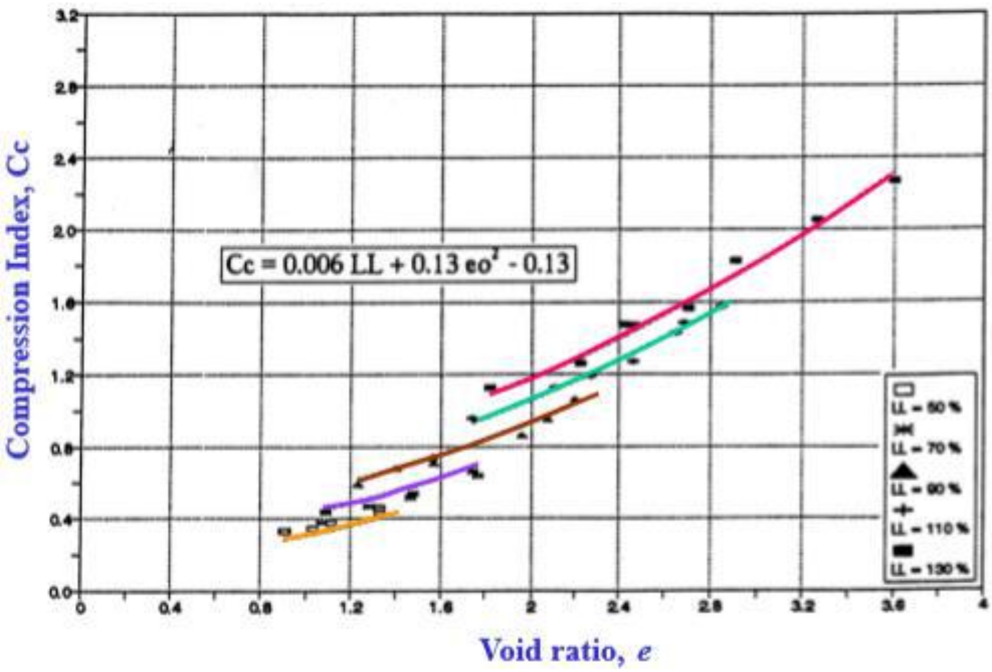


**Figure 3**. Correlation Graph of Void Ratio (**e**) vs Compression Index (**Cc**) (Kosasih and Mochtar, 2007)

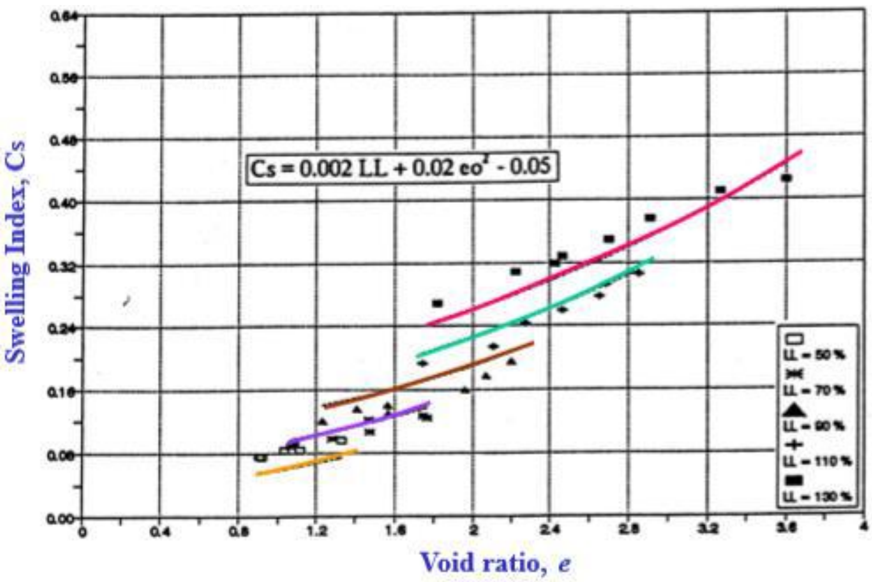


**Figure 4**. Correlation Graph of Void Ratio (**e**) vs Swelling Index (**Cs**) (Kosasih and Mochtar, 2007)

**Secondary Compression**

Secondary compression is the compression that occurs after primary compression is completed. This is caused by the rearrangement of soil particles, leading to further compaction of the soil. Secondary compression plays a more significant role compared to primary consolidation in organic soils and inorganic soils with very high compressibility (Das, 2010). The settlement due to secondary consolidation is calculated using the formula (Mesri and Ajlouni, 2007) as follows:

$$Ss = C\alpha' \, H \, log \, (t_2/t_1) \quad \ldots(8)$$

Meanwhile, the secondary compression index (Cα) is calculated using the following equation, based on the curve of the relationship between e and log t as shown in Figure 5:

$$C\alpha' = C\alpha / (1 + e_p) \quad \ldots(9)$$

$$C_\alpha = \frac{\Delta e}{\Delta \log t} \quad \text{...(10)}$$

Where :
Ss = Secondary consolidation settlement
Cα' = Secondary compression index
H = Thickness of the soil layer
Cα = Secondary compression coefficient
ep = Void ratio at the end of primary consolidation = (eo - Δep)
Δe = Change in void ratio, calculated from Δe = Cc {log(σ'o + Δσ) - log σo}
t2 = Time under consideration
t1 = Time at the end of primary consolidation

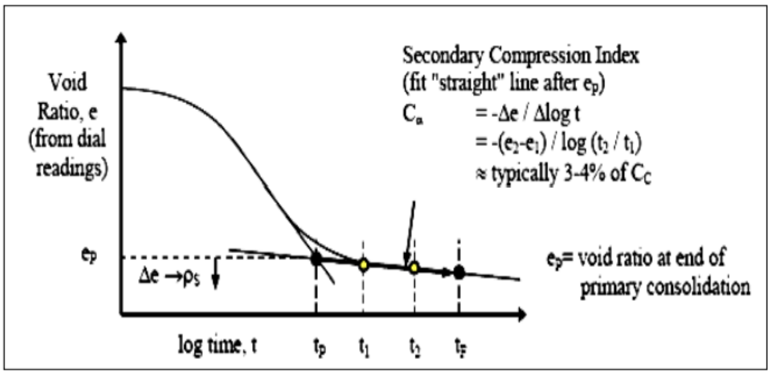


**Figure 5.** Relationship between e and Log t (Das, 2010)

According to Dhianty and Mochtar (2018), the correlation of the secondary compression index with the initial void ratio and effective pre-consolidation stress is formulatedasfollows:

$C\alpha' = (0{,}0072\ eo - 0{,}0067)\ P'$ ...(11)

and

$C\alpha' = (0{,}0077\ ep - 0{,}0060)\ P'$ ...(12)

Where :
eo = Initial void ratio
ep = Void ratio at the end of primary consolidation
P' = Effective consolidation stress, which represents the magnitude of the increase in stress due to external load

Terzaghi in Das (1985) defines the consolidation time period (t) using the following equation:

$t = T_v (Hdr)^2 / Cv$ ...(13)

Where:
Tv = Time factor, depending on the degree of consolidation U
Hdr = Thickness of the compressing layer (length of the path traveled by pore water flow)
Cv = Coefficient of consolidation for vertical pore water flow
t = Duration of consolidation completion

**Prefabricated Vertical Drain (PVD)**

To improve the condition of the soil, soil improvement techniques need to be applied. Vertical drain is an artificial drainage system installed vertically within soft soil layers (Hidayati et al., 2008). This method aims to accelerate the consolidation process, allowing construction work to begin sooner on the land. The vertical drain method was initially implemented using the sand drain method. However, with technological advancements, Prefabricated Vertical Drains (PVD) have started to replace sand drains as the drainage system.

**Preloading**

To accelerate the compression of the underlying soil, in this study, secondary compression is eliminated when primary consolidation is removed by applying a surcharge load, also known as preloading. Its function is to act as a load to accelerate compression, fill the voids caused by compression, and increase the bearing capacity of the soil beneath.

After the compression of the underlying soil occurs, the initial embankment height (Hawal) that was planned should match the final embankment height (Hakhir) as intended. The determination of the initial height during implementation must consider the settlement that will occur.

To calculate the initial embankment height (Hinitial) and final embankment height (Hfinal) due to primary consolidation compression, Hinitial represents the embankment height before primary consolidation occurs.

$$H_{initial} = (q + Sc - \gamma\ w) / \gamma_{\ timb} \quad \ldots(14)$$

Meanwhile, Hfinal represents the final embankment height after primary consolidation compression has occurred.

$$H_{final} = Hinitial - Sc \quad \ldots(15)$$

Where:

Hinitia = Initial embankment height
Hfinal = Final embankment height
Sc = Total soil compression due to the embankment load (H)
γtimb = Effective unit weight of the embankment material
γw = Unit weight of water

**Slope Stability Analysis**

After determining the amount of compression and the increase in Cu (undrained shear strength), the stability analysis of the embankment in the transverse direction can be calculated using the aid of supporting software.

Soil reinforcement with Geotextile, Geotextile functions as a filter and barrier for fine soil particles to prevent them from being carried away by the seepage flow, as a separator between two layers (soil to soil or soil to liquid), as well as for erosion and scour prevention. Geotextile is used as a reinforcing material to stabilize the embankment and prevent landslides.

According to the Directorate General of Highways Guideline Number 003/BM/2009 on Planning and Implementation of Soil Reinforcement with Geosynthetics, geosynthetics is defined as a general term for sheet-shaped products made of flexible polymeric materials, used with soil, rock, or other geotechnical materials, as an integral part of man-made works, structures, or systems (ASTM D 4439).

Geosynthetics is a type of sheet-shaped geosynthetic made from polymeric textile materials, which are water-repellent, which can take the form of non-woven, knitted or woven materials used in contact with soil or other materials in civil engineering applications. According to the Guidelines of the Directorate General of Highways No. 003/BM/2009 concerning Planning and Implementation of Soil Reinforcement with Geosynthetics, the definition of geotextile is any textile material that generally passes water which is installed with foundations, soil, rock or other geotechnical materials as an integral part of the structural system, or a man-made product. The guidelines also explain that the basis of the reinforced embankment planning approach is planning to prevent collapse.

$$\text{Tijin} = \text{Tult}\left(\frac{1}{\text{FSID}+\text{FSCR}+1\text{FSCD}+\text{FSBD}}\right) \quad \ldots(16)$$

Where :
FSID = safety numbers due to damage during installation
FSCR = safety numbers due to termite
FSCD = safety numbers due to chemical degradation
FSBD = safety numbers due to biological degradation

**Table 3.** Recommended Partial Safety Factor

| **Application Area** | **Safety Factors** | | | |
|---|---|---|---|---|
| | **Installation (FSID)** | **Termite (FSCR)** | **Chemical Degradation (*FSCD*)** | **Biological Degradation (FSBD)** |
| Separator | 1,1 – 2,5 | 1,5 – 2,5 | 1,0 – 1,5 | 1,0 – 1,2 |
| Cushioning | 1,1 – 2,0 | 1,2 – 1,5 | 1,1 – 2,0 | 1,0 – 1,2 |
| Road without | 1,1 – 2,0 | 1,5 – 2,5 | 1,0 – 1,5 | 1,0 – 1,2 |
| pavement | 1,1 – 2,0 | 2,5 – 4,0 | 1,0 – 1,5 | 1,0 – 1,3 |
| Wall | 1,1 – 2,0 | 2,0 – 3,5 | 1,0 – 1,5 | 1,0 – 1,3 |
| Embankment | 1,1 – 2,0 | 2,0 – 4,0 | 1,0 – 1,5 | 1,0 – 1,3 |
| Bearing capacity | 1,1 – 1,5 | 2,0 – 3,0 | 1,0 – 1,5 | 1,0 – 1,3 |
| Slope stability | 1,1 – 1,5 | 1,0 – 2,0 | 1,0 – 1,5 | 1,0 – 1,1 |
| Overlay | 1,1 – 3,0 | 1,0 – 1,5 | 1,5 – 2,0 | 1,0 – 1,2 |
| Railroad | 1,1 – 1,5 | 1,5 – 3,0 | 1,0 – 1,5 | 1,0 – 1,1 |
| Form flexibility | 1,1 – 1,5 | 1,5 – 2,5 | 1,0 – 1,5 | 1,0 – 1,1 |

Source : Hatmoko, 2020

## RESEARCH METHODE

This research method begins with a literature study to collect references related to soft soil improvement for road design, which facilitates the planning process. Secondary data is obtained from soil investigations carried out by PT Jasamarga Probolinggo Banyuwangi and related stakeholders in the Probolinggo–Banyuwangi Toll Road Development Project. Primary data is collected through field drilling and testing of undisturbed soil samples at specific depths to determine the soil characteristics. Laboratory tests are then conducted to obtain physical parameters and compression index values. Primary and secondary consolidation settlements are calculated using a combination of embankment and PVD to accelerate consolidation, ensuring the settlements meet the Bina Marga requirements. Preloading is planned to further speed up consolidation. The stability of the embankment is checked using stability analysis software, and if it does not meet the required safety factors, reinforcement with geotextile is performed. Finally, conclusions and recommendations are drawn based on the analysis results.

## DATA COLLECTION

Primary data testing was conducted because the secondary data only included N-SPT values and did not contain results from physical tests, mechanical tests, or consolidation tests at the research site. The primary data testing was carried out through borehole logging at Sta 16+550 with a drilling depth of up to 15 meters.

Based on the borehole logging and N-SPT results obtained in the field, corrections were applied to the N-SPT values using the appropriate equation, and soil classification was determined as presented in the Table 4.

**Table 4.** Data N-SPT Sta 16+550

| Depth | | | Description | N-SPT | N1(60) | Consistency |
|---|---|---|---|---|---|---|
| 0 | - | 2 | Silty clay, brown | 4 | 4,28 | Soft |
| 2 | - | 4 | Fine sandy silt | <1 | 1,69 | Very soft |
| 4 | - | 6 | Fine sandy silt | 5 | 4,92 | Soft |
| 6 | - | 8 | Silty clay, brown | 6 | 5,79 | Soft |
| 8 | - | 10 | Stiff silt, brown | 9 | 7,02 | Medium |
| 10 | - | 12 | Stiff silt, gray | 5 | 3,97 | Soft |
| 12 | - | 14 | Sandy hardpan, brown | 27 | 21,61 | Dense |
| 14 | - | 16 | Sandy hardpan, brown | 14 | 10,72 | Medium |

Laboratory testing was conducted to determine soil classification and soil parameters. For primary data, undisturbed soil samples were taken at depths of 2 meters, 6 meters, and 8 meters from the ground surface. The tested parameters include physical, mechanical, and consolidation parameters. A summary of the laboratory test results is presented in Table 5.

**Table 5a.** The results of the laboratory tests

| No | Parameter | Symbol | Unit | Test Results | | |
|---|---|---|---|---|---|---|
| | | | | **UDS-1 2 - 2.5 m** | **UDS-2 6 - 6.5 m** | **UDS-3 8 - 8.5 m** |
| I | Indeks Properties | | | | | |
| 1 | Water Content | Wn | % | 40,00 | 35,00 | 33,00 |
| 2 | Unit Weight | γt | t/m3 | 1,68 | 1,70 | 1,71 |
| 3 | Dry Unit Weight | γd | t/m3 | 1,20 | 1,26 | 1,29 |
| 4 | Liquid Limit | LL | % | 48 | 36 | 34,00 |
| 5 | Plastic Limit | PL | % | 28 | 25 | 25,00 |
| 6 | Liquidity Index | Li | | 0,6 | 0,91 | 0,89 |
| 7 | Spesific Gravity | Gs | | 2,54 | 2,68 | 2,63 |
| 8 | Void Ratio | eo | | 1,12 | 1,13 | 1,05 |
| 9 | Porosity | n | | 0,53 | 0,53 | 0,51 |
| 10 | Degree of Saturation | SR | % | 91 | 83 | 83,00 |
| II | Grain Size | | | | | |
| - | Gravel | | % | 0,00 | 0,00 | 0,00 |
| - | Sand | | % | 9,98 | 38,67 | 47,19 |
| - | Silt and Clay | | % | 90,02 | 61,332 | 52,81 |
| III | Strength Test | | | | | |
| - | TX-UU Cohesion | c | kg/cm2 | 0,15 | | |
| | Fricton angle | ϕ | º | 11 | | |
| - | QT Cohesion | c | kg/cm2 | | 0,12 | 0,15 |
| | Fricton angle | ϕ | º | | 27 | 29 |
| IV | Moduli | | | | | |

**Table 5b.** The results of the laboratory tests

| No | Parameter | Symbol | Unit | Test Results | | |
|---|---|---|---|---|---|---|
| | | | | **UDS-1 2 - 2.5 m** | **UDS-2 6 - 6.5 m** | **UDS-3 8 - 8.5 m** |
| - | Undrained moduli | Eu | kg/cm2 | 40 | - | - |
| - | Secant moduli | E50 | kg/cm2 | 10 | - | - |
| - | Oedometer moduli | Eoed | kg/cm2 | 38 | 44 | 120 |
| **V** | **Consolidation Test** | | | | | |
| 1 | Compression index | Cc | | 0,26 | 0,29 | 0,20 |
| 2 | Swelling index | Cs | | 0,02 | 0,01 | 0,01 |
| 3 | Eff. Over burden pressure | p0' | kg/cm2 | 0,34 | 0,79 | 0,94 |
| 4 | Preconsolidation Pressure | pc' | kg/cm2 | 2,20 | 2,4 | 3,30 |
| 5 | Over Consolidation Ratio | OCR | | 6,47 | 3,04 | 3,51 |
| 6 | Modified Compression Index | | | 0,091 | 0,106 | 0,07 |
| 7 | Modified Swelling Index | k | | 0,007 | 0,004 | 0,01 |
| 8 | Coef of Consolidation | CV | (cm2/dt) | 0,0028 | 0,0021 | 0,0023 |
| | | | (m2/thn) | 8,88 | 6,67 | 7,16 |

The groundwater table is located at a depth of -3.5 meters, meaning the soil layer below consists of saturated clay, making it necessary to determine the undrained shear strength (Cu) as an indicator of soil strength. Laboratory test results have provided Cu values for each soil layer; however, these tests were conducted at 6-meter depth intervals, while the soil reinforcement analysis requires data at 1-meter intervals. Therefore, empirical calculations of Cu using the Ardana & Mochtar formula are conducted. The results are then compared, and the larger Cu value is selected for use in the analysis.

## RESEARCH ANALYSIS

Based on the cross-sectional profile obtained from the project, the height of the existing embankment with treatments varies between 4.00 meters and 8.00 meters. In this analysis, embankment heights of 4 m, 6 m, and 8 m are considered. The initial embankment height will be greater than the planned embankment height, taking into account the settlement of the original soil caused by the embankment load. The magnitude of the settlement is calculated based on the compression of compressible soil layers up to a depth of 12 m.

The method used involves assuming several initial embankment heights and determining the physical implementation height graphically. This is done by plotting the relationship curves for Sc vs $H_{final}$, q vs $H_{final}$ dan $H_{initial}$ vs $H_{final}$ from the calculated results for each assumed embankment load. The settlement considered is based on the load applied during the embankment construction.

The calculation of consolidation settlement is carried out due to the embankment load. The settlement caused by the embankment load (qo) is determined using various embankment load values of 4 t/m², 7 t/m², 10 t/m², 13 t/m², and 16 t/m².

Due to the settlement of soft/compressible soil caused by embankment, the embankment height during construction (Hinitial) will not be the same as the design embankment height (Hfinal). Therefore, the initial embankment height during construction must be higher than the design embankment height so that, as the soil undergoes settlement, the construction embankment height can reach the design embankment height.

After determining the initial embankment height (Hinitial), the final embankment height (Hfinal) for each embankment load can be calculated. Hfinal = Hinitial – Sc cumulative

The results of the calculation for the embankment load (qo) can be found in Table 7.

**Table 6.** Recapitulation of the Hfinal Calculation for Each qo Variation.

| No | Load q ($t/m^2$) | Sc (m) | $H_{initial}$ (m) | $H_{final}$ (m) |
|---|---|---|---|---|
| 1 | 4 | 0,32 | 2,40 | 2,08 |
| 2 | 7 | 0,56 | 4,20 | 3,64 |
| 3 | 10 | 0,73 | 5,96 | 5,23 |
| 4 | 13 | 0,87 | 7,71 | 6,84 |
| 5 | 16 | 0,98 | 9,44 | 8,45 |

After the calculations, a relationship between Hfinal vs Hinitial and Hinitial vs q final is obtained. Based on the recap of the results in Table 6, the following equation graph is generated.

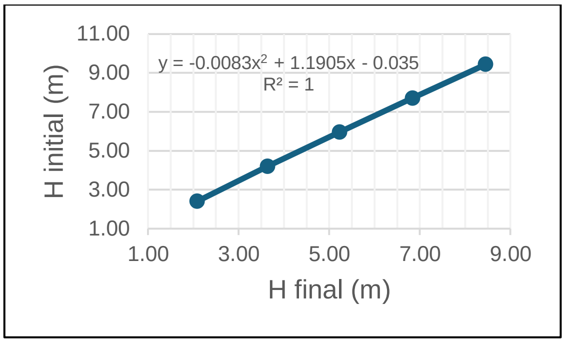


**Figure 6.** Relationship between Hfinal vs Hinitial

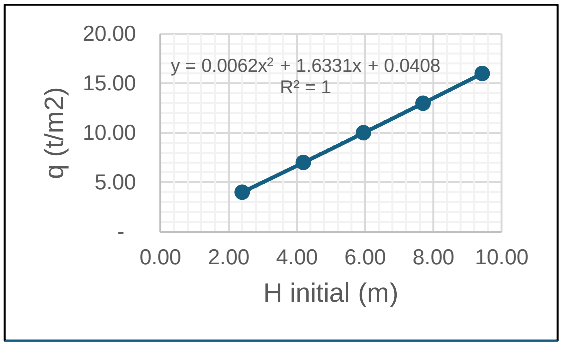


**Figure 7.** Relationship between Hinitial vs q final

The time required for consolidation = 90% with two-way drainage is

$$t = \frac{T_v * H_{dr}^2}{C_v} = \frac{0,848 * 6^2}{2,49} = 3,89\ tahun \qquad \ldots(17)$$

The compression time for a 90% consolidation degree is found to be 3.89 years. Therefore, a graph showing the relationship between consolidation degree and compression time can be plotted.

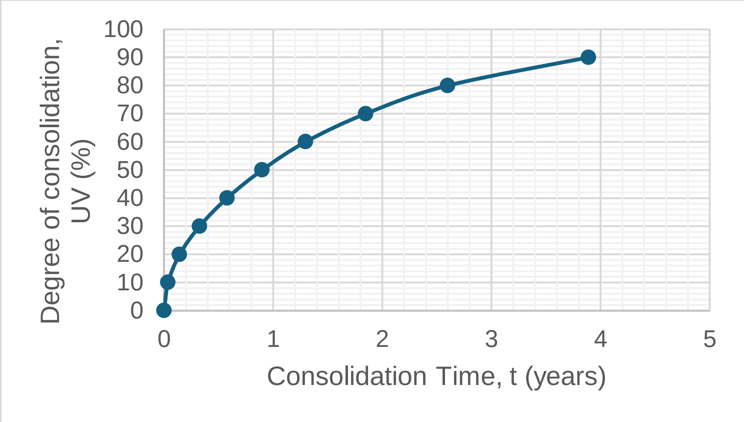


**Figure 8.** Consolidation Time and Degree of Consolidation

Since the time to complete the compaction is 3.89 years, an acceleration of the consolidation process is required by using Prefabricated Vertical Drains (PVD). In the PVD design, the installation pattern is calculated by comparing triangular and rectangular installation patterns with variations in the spacing between PVDs. The spacing variations between PVDs that are calculated are 0.75, 1.00, 1.25, 1.50, 1.75, and 2.00 meters. The planned depth of the PVD is as deep as the depth of the soft soil, which is 12 meters.

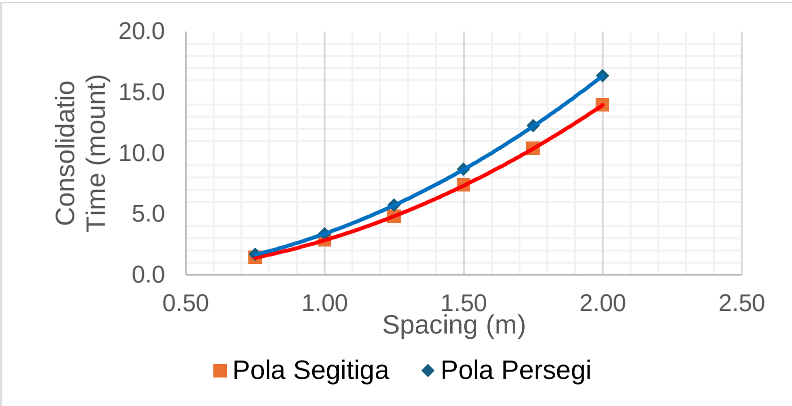


**Figure 9.** PVD Spacing vs. Consolidation Time at 99% Degree of Consolidation

Based on the PVD calculation, it was determined that for the design data with a consolidation time of 4 months, a consolidation degree of 99% was achieved with both triangular and rectangular patterns at a spacing of 1.00 meter. If we calculate the required PVDs for a road section with a length of 1 km and a width of 62 meters, according to the road cross-section, a comparison of the required volume based on the variation of spacing with the same installation pattern (rectangular pattern) shows that the PVD requirement for a 1.00-meter spacing is 43.76% more efficient than the PVD requirement for a 0.75-meter spacing. Furthermore, when comparing the costs, with a unit price of Rp. 4,500.00 per meter for DG 6581-type PVDs, and a consolidation time of ≤ 4 months, the rectangular pattern is 15.48% more cost-efficient than the triangular pattern for all installation spacings of 1.00 meter.

After the primary consolidation process is completed, secondary consolidation occurs during the operational phase. The calculation of secondary settlement (Ss) in this design assumes that the time for secondary settlement to occur is 2 years, 5 years, and 10 years after the road or structure is established, and after the completion of primary consolidation. The results of the Ss calculation can be seen in Table 7.

**Table 7.** Secondary Settlement on Embankment Variations per Year

| H Akhir (H) (m) | Load q (t/m2) | Ss in years- 1 (cm) | 2 | 3 | 5 | 6 | 10 | 12 | 15 |
|---|---|---|---|---|---|---|---|---|---|
| 4,0 | 7,67 | 2,32 | 4,20 | 5,79 | 8,38 | 9,46 | 12,90 | 14,26 | 16,01 |
| 6,0 | 11,45 | 2,57 | 4,67 | 6,43 | 9,30 | 10,50 | 14,32 | 15,83 | 17,77 |
| 7,0 | 13,32 | 2,66 | 4,82 | 6,65 | 9,61 | 10,85 | 14,80 | 16,36 | 18,37 |
| 8,0 | 15,17 | 2,72 | 4,94 | 6,80 | 9,84 | 11,11 | 15,15 | 16,75 | 18,81 |

After obtaining the secondary settlement at various reviewed years, the rate of settlement is calculated for the period between year 2 and year 3, with a requirement that the settlement must be less than 2 cm/year, and for the period between year 2 and year 12, with a requirement of less than 10 cm/year (assuming a construction period of 2 years and a maintenance period of 1 year). Additionally, the rate of settlement is evaluated for the period between year 5 and year 6, with a requirement of less than 2 cm/year, and for the period between year 5 and year 15, with a requirement of less than 10 cm/year (assuming a construction period of 2 years and a maintenance period of 3 years)

**Table 8.** Settlement in Year 2 & Year 3, and Year 2 & Year 12

| Final Elevation (m) | Binamarga Requirements 2 to 3 | < 2 cm / yrs | 2 to 12 | < 10 cm / 10 yrs |
|---|---|---|---|---|
| 4,00 | 1,59 cm | Compliant | 10,06 cm | Non-compliant |
| 6,00 | 1,76 cm | Compliant | 11,16 cm | Non-compliant |
| 7,00 | 1,82 cm | Compliant | 11,54 cm | Non-compliant |
| 8,00 | 1,87 cm | Compliant | 11,81 cm | Non-compliant |

**Table 9.** Settlement in Year 5 & Year 6, and Year 5 & Year 15

| Final Elevation (m) | Binamarga Requirements 5 to 6 | < 2 cm / yrs | 5 to 15 | < 10 cm / 10 yrs |
|---|---|---|---|---|
| 4,00 | 1,08 cm | Compliant | 7,64 cm | Compliant |
| 6,00 | 1,20 cm | Compliant | 8,48 cm | Compliant |
| 7,00 | 1,24 cm | Compliant | 8,76 cm | Compliant |
| 8,00 | 1,27 cm | Compliant | 8,97 cm | Compliant |

The results of the rate of settlement calculation indicate that the settlement between Year 2 and Year 12 exceeds 10 cm per 10 years at all final field elevations (H), necessitating preloading. The following are the results of the preloading requirements needed to achieve the planned final elevation (H).

**Table 10.** The value of preloading and the dismantling elevation (H).

| Secondari Time | Final Elevation | Sc | Ss | Sc+Ss | q | Initial Elevation p+s | Final Elevation p+s | H Unloding |
|---|---|---|---|---|---|---|---|---|
| | (m) | (m) | (m) | (m) | (t/m2) | (m) | (m) | (m) |
| 5 tahun | 4,00 | 0,60 | 0,08 | 0,69 | 8,48 | 5,08 | 4,39 | 0,39 |
| | 6,00 | 0,80 | 0,09 | 0,90 | 12,84 | 7,63 | 6,73 | 0,73 |
| | 7,00 | 0,88 | 0,10 | 0,98 | 14,91 | 8,82 | 7,84 | 0,84 |
| | 8,00 | 0,96 | 0,10 | 1,05 | 16,86 | 9,96 | 8,90 | 0,90 |
| 10 tahun | 4,00 | 0,60 | 0,13 | 0,73 | 9,32 | 5,57 | 4,84 | 0,84 |
| | 6,00 | 0,80 | 0,14 | 0,95 | 14,06 | 8,33 | 7,38 | 1,38 |
| | 7,00 | 0,88 | 0,15 | 1,03 | 16,29 | 9,61 | 8,58 | 1,58 |
| | 8,00 | 0,96 | 0,15 | 1,11 | 18,41 | 10,82 | 9,71 | 1,71 |

The next step is to calculate the soil stability after consolidation. Once the stability value is obtained, reinforcement is then carried out using geotextile. The results of the geotextile requirements calculation can be seen in Table 10, along with the graph showing the relationship between the required amount of geotextile and the final embankment height in Figure 10.

**Table 11.** Geotextile Requirements for Embankment Variations

| Final Elevation | Amount of Geotextile Reinforcement, Sf 1,25 | |
|---|---|---|
| (m) | (Layer) | (m) |
| 4,00 | 2 | 94,80 |
| 6,00 | 7 | 370,30 |
| 7,00 | 10 | 554,19 |
| 8,00 | 14 | 804,12 |

Based on the geotextile reinforcement calculations, a graph showing the relationship between the final embankment height and the required amount of geotextile reinforcement has been obtained.

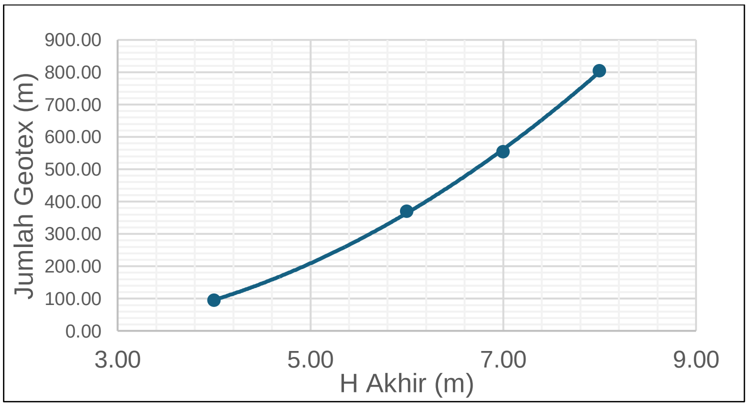


**Figure 10.** Relationship Between Final Elevation (H) and Geotextile Quantity

From this graph, it is observed that as the embankment height increases, the amount of geotextile reinforcement required to achieve the planned embankment stability also increases.

## CONCLUSIONS

Based on the results of the analysis and calculations presented in the previous chapter, the following points can be concluded:

1. The primary and secondary settlement after the application of PVD with variations in embankment height (final H) of 4 m, 6 m, 7 m, and 8 m shows settlement results that meet Binamarga requirements in the 5th and 6th years, with settlement less than 2 cm per year and in the 5th to 15th years with settlement less than 10 cm per 10 years.
2. In the 2nd and 3rd years, primary and secondary settlements still meet the Binamarga requirements, but in the 2nd to 12th years, the settlement exceeds 10 cm per 10 years, which does not meet the established requirements.
3. The variation in embankment height shows that settlements in the 2nd and 12th years exceed 10 cm per 10 years, which does not meet Binamarga standards. However, in the 5th and 15th years, the settlement remains below 10 cm per 10 years, thus meeting the requirements and being more suitable for field implementation.
4. According to the study, secondary settlement in the 2nd and 12th years exceeds 10 cm per 10 years for all embankment height variations of 4 m, 6 m, 7 m, and 8 m, which does not comply with Binamarga requirements.
5. Considering the settlement exceeding 10 cm per 10 years in the 2nd and 12th years, additional treatment is required in the form of preloading. Using preloading, the initial embankment height required to meet Binamarga requirements is 5.57 m for a final height of 4 m, 8.33 m for a final height of 6 m, 9.61 m for a final height of 7 m, and 10.82 m for a final height of 8 m.

## REFERENCES

[1] Beatrix, M., Fatmawati, L. E. & Widhiarto, H. (2018). "Pengaruh PVD (Prefabricated Vertical Drain) Dalam Mempercepat Proses Konsolidasi Pada Konstruksi Taxiway Di Bandara Juanda Surabaya". *Jurnal Hasil Penelitian LPPM Universitas 17 Agustus 1945 Surabaya*. Surabaya.

[2] Das, Braja M. (1988). *Mekanika Tanah : Prinsip - Prinsip Rekayasa Geoteknik jilid 1*. Diterjemahkan oleh Noor Endah dan Indrasurya B.M. Erlangga. Surabaya.

[3] Das, Braja M. (1988). *Mekanika Tanah: Prinsip-Prinsip Rekayasa Geoteknik jilid 2*. Diterjemahkan oleh Noor Endah dan Indrasurya B.M. Erlangga. Surabaya.

[4] Das, Braja M. dan Sobhan, K. (2010). *Principles of Geotechnical Engineering Eighth Edition, SI*. Cengage Learning. USA.

[5] Departemen Permukiman dan Prasarana Wilayah. (2002). *Panduan Geoteknik – 4 Desain dan Konstruksi Timbunan Jalan pada Tanah Lunak Edisi Pertama*.

[6] Direktorat Jenderal Bina Marga. (2017). *Manual Desain Perkerasan Jalan Revisi 2017. Kementrian PUPR*. Jakarta.

[7] Dhianty, Ega. dan Mochtar, I. B. (2018). Perumusan Indeks Pemampatan Sekunder dan Metode Menghilangkan Pemampatan Sekunder pada Tanah Lempung. *Tesis*. Institut Teknologi Sepuluh Nopember. Surabaya.

[8] Endah, Noor. (2012). *Modul Ajar Metode Perbaikan Tanah*. Jurusan Teknik Sipil FTSP ITS. Surabaya.

[9] Haris, Achmad (2023). Penggunaan PVD dan Preloading pada Oprit Jembatan untuk Menghilangkan Pemampatan Jangka Panjang (Konsolidasi Primer dan Sekunder) Studi kasus : Oprit Jembatan ruas Jalan Nasional Palembang – Pelabuhan Tanjung Api – Api Sta 20+200. *Master Thesis*. Program Pasca Sarjana, teknik Sipil ITS.

[10] Kosasih, A. Mochtar, I.B. (2007). Pengaruh Kadar Air, Angka Pori, dan Batas Cair Tanah Lempung Terhadap Indeks Pemampatan Konsolidasi Cc dan Indeks Pengembangan Cs. *Master Thesis*. Program Pasca Sarjana, teknik Sipil ITS.

[11] Mesri, G. (1974). *Coefficient of Secondary Compression, J. Soil Mech. Found*. Div., ASCE 99, No. 1, 123 – 137.

[12] Mochtar. B, Indrasurya. (2000). *Teknologi Perbaikan Tanah dan Alternatif Pada Tanah Bermasalah (Problematic Soils)*. Jurusan Teknik Sipil – FTSP ITS. Surabaya.

[13] PT Jasamarga Probolinggo Banyuwangi (2023). *Laporan Hasil Penyelidikan Tanah Proyek Pembangunan Jalan Tol Probolinggo – Banyuwangi Paket 2*.

[14] PT Jasamarga Probolinggo Banyuwangi (2023). *Review Rencana Teknik Akhir Proyek Pembangunan Jalan Tol Probolinggo – Banyuwangi*.

[15] Rusdiansyah (2008). *Penggunaan PVD dan Preloading untuk Mempercepat Waktu Konsolidasi Di Lahan Penumpukan Peti Kemas Pelabuhan Trisakti Banjarmasin. Vol. 9 No. 2.*

[16] Septiandri, R.A. (2021). Metode Cepat Untuk Menentukan Besar Pemampatan Konsolidasi (Sc) Pada Timbunan Di Atas Tanah Lunak Dan Perencanaan Perkuatannya Untuk Kondisi Dengan Dan Tanpa Pemasangan Prefabricated Vertical Drain (Pvd). *Master Thesis*. Program Pasca Sarjana, teknik Sipil ITS.