(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 7, Special Issue 3, January 2025

Analysis of Temporary Preloading for Bridge Approach Embankment to Eliminate Secondary Compression Case Study: Probolinggo – Banyuwangi Toll Road Construction Project Section 3 STA 40+550

Muhammad Rizal Permadi[1,a)], **Indrasurya B. Mochtar**[2,b)], **Noor Endah Mochtar**[3,c)] **& Reza Kazhimi**[4,d)]

[1)]*Magister Student, Civil Engineering Dept, Institut Teknologi Sepuluh Nopember, Surabaya*
[2)]*Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya*
[3)]*Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya*
[4)]*PT Jasamarga Probolinggo Banyuwangi, Probolinggo*

Correspondent : [a)]mrizalpermadi@gmail.com, [b)]indrasurya@ce.its.ac.id, [c)]noor_endah@ce.its.ac.id & [d)]rezakazhimi@gmail.com

ABSTRACT

Probolinggo - Banyuwangi Toll Road is part of the National Strategic Project, has a length of 172 km which is divided into 7 sections. One of the challenges faced is soft soil, where information is obtained in section 3 precisely STA 40 + 550 there is soft soil, which has low bearing capacity and high compressibility. The depth of the soft soil itself reaches 10 meters, with the plan to build in the approach bridge area which has a 10 meter high embankment. Considering the high embankment, based on previous studies, it is estimated that the amount of primary and secondary compression generated is quite large. This study analyzes primary, and secondary compression in bridge approach embankments built on soft soil, focusing on eliminating secondary compression using the preloading method, while the primary compression time is accelerated using Prefabricated Vertical Drains (PVD). Primary consolidation results in a 1.35-meter settlement, and secondary settlements vary over 20 years. From the analysis, it is found that the annual rate of secondary settlements decreases after year 10, so it is considered that the year 10 settlements are eliminated. To eliminate these settlements at year 10 of the operational period, the required embankment height increases by up to 13.60 meters of granular backfill, preloading of 4.49 t/m^2 is equivalent to 2.26 m, and the height of the embankment to be demolished is 1.85 m.

Keyword : soft soil, secondary compression, preloading

INTRODUCTION

The Probolinggo – Banyuwangi Toll Road is a part of National Strategic Project (PSN) and is the easternmost toll road section of Trans Java. It spans approximately 172 km across three administrative areas: Probolinggo, Situbondo, dan Banyuwangi, divided into 7 sections as shown in Figure 1. The construction of this project is divided into two phases; the first phase covers sections 1 to 3, while the second phase covers sections 4 to 7.

One of the challenges faced in the construction of the Probolinggo - Banyuwangi toll road is soft soil. At STA 40+550, information was obtained that the subsoil has an N-SPT value of less than 10 to a depth of 10 meters. From the results of soil investigation, the soil includes *very soft to soft soil* with a 0.5 meter thick sand layer at a depth of 2 meters as shown in Figure 2. Soft soil is highly compressible and requires a long time to fully consolidate. Furthermore, its low bearing capacity limits the load it can support. It is a challenge in itself, because at that location a bridge structure is planned to be built with an embankment height of 10 m, as shown in Figure 3.

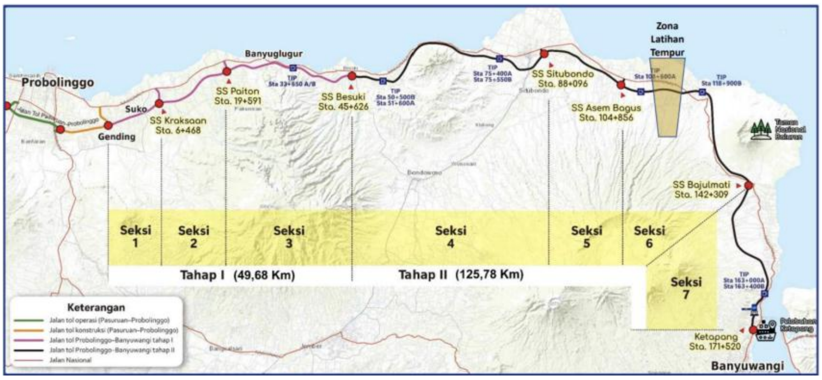

Figure 1. Toll Road Map of Probolinggo – Banyuwangi
(PT Jasamarga Probolinggo Banyuwangi)

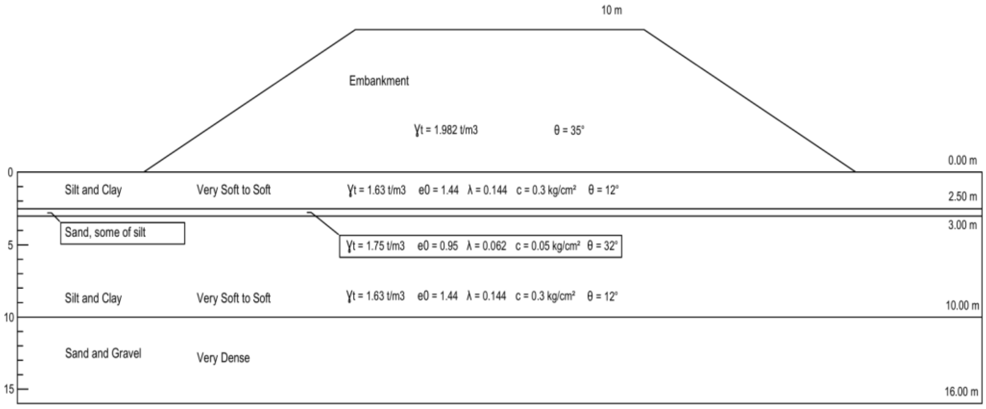

Figure 2. Soil Stratigraphy
(PT Jasamarga Probolinggo – Banyuwangi)

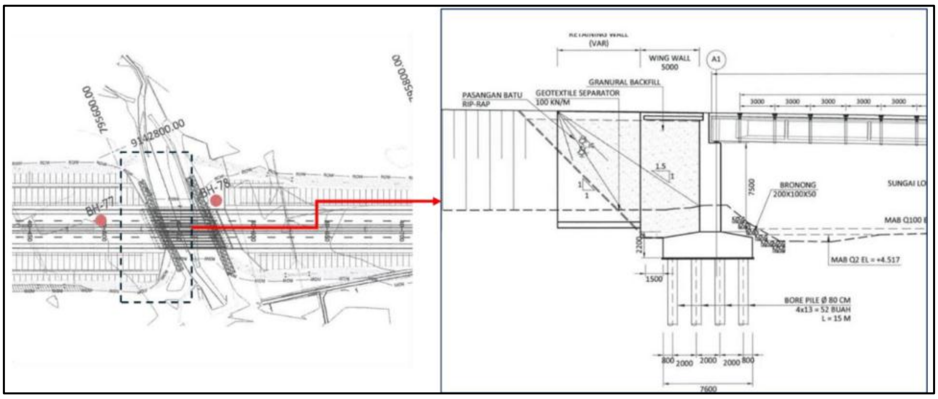

Figure 3. Bridge Location Plan at STA 40+550
(PT Jasamarga Probolinggo – Banyuwangi)

Compression in inorganic soils is generally classified into two types: immediate settlement and consolidation, which can be further divided into primary and secondary consolidation. Immediate settlement itself is completed in a fairly short time and during the construction period. Compression due to primary consolidation is dominant because it is very large and takes a long time. This makes primary settlement the main focus of settlement, so secondary settlement is often ignored or not taken into account. Currently, Prefabricated Vertical Drain (PVD) technology can accelerate the primary compression time, so that it can be resolved before the road is operated and leave the secondary compression to be monitored to meet the Bina Marga requirement of a maximum settlement of 2cm/year or 10cm in 10 years. Primary consolidation is the most dominant due to its significant magnitude and long duration, while secondary consolidation is often overlooked because of its relatively small magnitude and occurs after the primary consolidation has completed. Based on previous studies, secondary consolidation accounts for approximately 1/3 to 1/4 of the magnitude of primary consolidation, whereas primary consolidation results in settlement of about 1/3 to 1/4 of the height of the embankment or the applied load on the subsoil (Wahyu and Mochtar, 2019).

Referring to previous studies on estimating secondary compression, with the embankment at the site being 10 meters high, the secondary compression was estimated at 0.625 meters. With such a large value, it is considered that secondary compression can be eliminated. This study aims to determine the amount of secondary compression at the study site and eliminate it with the preloading method, so as to obtain information on the required height of the embankment required, as well as the height of the embankment that must be dismantled to eliminate secondary compression with the review time of secondary compression in the 5th, 10th, 15th and 20th years. By eliminating secondary compression, it is expected that the location will not experience a decline in the future until the planned year.

LITERATURE REVIEW

Soil Compression

Compression generally occurs due to the addition of load on the soil surface, causing a natural or artificial reduction in soil volume as soil particles become more tightly packed, thereby reducing the pore volume between the particles. Compression can be caused by the expulsion of pore water or air, particle deformation or size change, particle repositioning, and other factors.

In the field, there are two types of consolidation based on stress:

1. Normally Consolidated (OCR $\leq$ 1), refers to a condition where the effective overburden stress is equal to the maximum stress the soil has ever experienced. In this state, the soil has not been subjected to any previous higher effective stresses and is currently at its maximum consolidation level.
2. Over Consolidated (OCR > 1), refers to a condition where the current effective overburden stress is less than the maximum stress the soil has experienced in the past. In this state, the soil has undergone a higher effective stress in the past, leading to greater consolidation than the current condition.

The value of the Over Consolidated Ratio (OCR) is determined using the following formula.

$$OCR = \frac{\sigma'_c}{\sigma'_o} \quad \dots (1)$$

Where:

σ'_c = Pre-consolidation stress (kN/m^2)
σ'_o = Effective overburden stress (kN/m^2)

Settlement is divided into three types, namely immediate settlement, primary consolidation, and secondary settlement as shown in Figure 4 below.

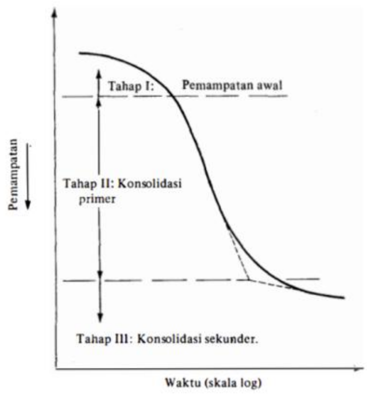

Figure 4. Time-Settlement Relationship Chart

1. Primary Consolidation

Primary consolidation is the compression that occurs due to the expulsion of water from the soil pores because of increased load on the soil surface. Primary compression is typically dominant in clayey soils, with a relatively large magnitude of settlement and a prolonged duration. Primary compression is denoted as Sc and can be calculated using the Terzaghi (1942) equation as follows:

1. OCR ≤ 1 or Normally Consolidated

$$Sc = \left[\frac{Cc}{1+e_o}\log\frac{\sigma'_o+\Delta\sigma}{\sigma'_o}\right]H \quad \ldots (2)$$

2. OCR > 1 or Over Consolidated

$$Sc = \left[\frac{Cs}{1+e_o}\log\frac{\sigma'_o+\Delta\sigma}{\sigma'_o}\right]H \quad \ldots (3)$$

3. If $(\sigma'_o + \Delta\sigma) \leq \sigma'_c$

$$Sc = \left[\frac{Cs}{1+e_o}\log\frac{\sigma'_o+\Delta\sigma}{\sigma'_o} + \frac{Cc}{1+e_o}\log\frac{\sigma'_o+\Delta\sigma}{\sigma'_o}\right]H \quad \ldots (4)$$

Where:

Cc = Compression index
Cs = Swelling index
σ'_c = Pre-consolidation stress (kN/m^2)
σ'_o = Effective overburden stress (kN/m^2)
$\Delta\sigma$ = Vertical load increment (kN/m^2)
Q = Effective vertical stress at the ground surface (kN/m^2)
e_o = Initial void ratio

2. Secondary Compression

Secondary consolidation is the compression caused by the plastic adjustment of soil particles, occurring after the completion of primary consolidation. According to Mesri (1973), the magnitude of settlement due to secondary consolidation can be calculated using the following formulation:

$$Ss = C'_\alpha H \log\left(\frac{t_2}{t_1}\right) \#(5) \quad \ldots (5)$$

To obtain the value of secondary settlement, the secondary compression index must be determined first using the following formula:

$$C'_\alpha = \frac{C_\alpha}{1+e_p} \quad \ldots (6)$$

$$C_\alpha = \frac{\Delta e}{\log\left(\frac{t_2}{t_1}\right)} \quad \ldots (7)$$

Where:

Ss = Secondary Compression
C'_α = Secondary compression index
C_α = Secondary compression coefficient
e_p = Void ratio at the end of primary consolidation
Δe = Change of void ratio, which is obtained from $\Delta e = Cc\ [\log(\sigma'_o + \Delta\sigma) - \log\sigma_o]$
t_1 = Primary consolidation completion time (s)
t_2 = Planned secondary consolidation time (s)

Dhianty and Mochtar (2018) formulated the secondary compression index as follows:

$$C'_\alpha = (0{,}0072e_0 - 0{,}0067)\sigma' \quad \ldots (8)$$

$$C'_\alpha = (0{,}0077e_p - 0{,}0060)\sigma' \quad \ldots (9)$$

Preloading Embankment Method

One of the soil improvement methods related to compression is *preloading.* Basically, the embankment preloading method has a general purpose, which is to increase the bearing capacity and shear strength of the soil and resolve the soil compression that occurs before the infrastructure is built on it, so that when the infrastructure has been completed and used for a period according to the planned life, it does not experience soil compression again. Embankment preloading is a method of improving soft clay soils by placing soil piles at the location of soil improvement. When the desired soil compression has been achieved, part of the embankment can be removed.

According to Mesri (1973), Koutsoftas et al. (1987), Ladd (1994), and Yu and Frizzy (1944) in Dhianty and Mochtar (2018), secondary compression deformation is significantly reduced when the soil is overconsolidated to a moderate degree, suggesting that the use of preload greater than the final embankment/structure load is an effective method of reducing secondary compression.

The stages of determining *preloading,* and the initial embankment height to eliminate secondary compression are as follows:

1. Calculate the amount of primary (Sc) and secondary (Ss) compression in a given year due to a predetermined load variation (q).
2. Creating a relationship curve between load (q) and primary compression (Sc) and a relationship curve between load (q) and primary compression plus secondary compression (Sc+Ss) in one graph.
3. To determine the need for *preloading* (Δq), by plotting the primary and secondary compression values (Sc+Ss) on the axis and drawing a perpendicular line until it intersects the q vs Sc and q vs Sc+Ss curves.
4. From the intersection result, draw a horizontal line to the left until the load value is obtained. The q value from the intersection of the q vs Sc curve is called $q_{final-2}$, and the q value from the intersection of the q vs Sc+Ss curve is called $q_{final-1}$ as shown in Figure 5. Or to obtain the values of $q_{final-2}$ and $q_{final-1}$ by using the regression equation generated from the curve in Figure 5.

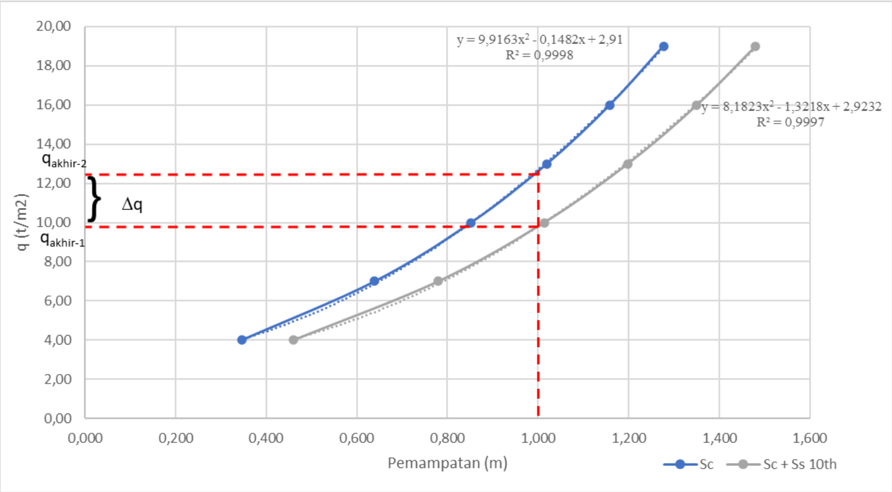

Figure 5. Position of the Embankment during Settlement

a. The preloading load (Δq) is obtained by the following formula:

$$\Delta q = q_{final-2} - q_{final-1} \qquad \ldots (10)$$

b. To determine the initial embankment height ($H_{initial}$) and final embankment height (H_{final}) after compression, the following formula can be used:

$$H_{initial} = \frac{q_{(i)} + Sc_{(i)}.\gamma_w}{\gamma_{embankment}} \qquad \ldots (11)$$

$$H_{final} = H_{initial(i)} - Sc_{(i)} \qquad \ldots (12)$$

c. Meanwhile, the following formula is used to determine the final embankment height of the field (H_{field}):

$$H_{field} = H_{final(i)} - \frac{\Delta q}{\gamma_{embankment}} \qquad \ldots (13)$$

d. For the height of the eliminated embankment (Heliminated) to the height of the field design embankment ($_{Hdesign}$), the following formula can be used:

$$H_{eliminated} = H_{final} - H_{design} \qquad \ldots (14)$$

METHOD OF ANALYSIS

This study was conducted to determine the amount of secondary compression after primary compression was completed with the use of PVD, and the amount preloading to complete the amount of secondary compression in years 5; 10; 15 and 20. The object of this research is STA 40+550 with a 10-meter embankment height and a soft soil depth of up to 10m. The analysis method used stages as in the previous study by Dhianty and Mochtar (2018). The stages of analysis are as follows:

1. Calculation of primary and secondary compression caused by the specified load variations of 4, 7, 10, 13, 16, and 19 t/m2 using formulas (4) and (5). The amount of secondary compression was reviewed in the 5th; 10th; 15th and 20th years;
2. In addition to primary and secondary compression, the initial height of the embankment and the final height of the embankment due to load variations and primary compression were also calculated using formulas (11) and (12).

The calculation results of points 1 and 2 due to load variation are recapitulated in Table 1.

Table 1. Recapitulation of Primary and Secondary Compression, Initial and Final Embankment Height due to Load Variation

Load (q)	Sc	Hinitial	Hfinal	Ss at year (m)			
(t/m2)	(m)	(m)	(m)	5	10	15	20
4,00	0,345	2,192	1,846	0,069	0,114	0,148	0,175
7,00	0,639	3,853	3,214	0,085	0,140	0,182	0,214
10,00	0,852	5,474	4,622	0,097	0,161	0,208	0,246
13,00	1,020	7,072	6,052	0,108	0,178	0,230	0,272
16,00	1,159	8,655	7,497	0,116	0,192	0,248	0,293
19,00	1,277	10,228	8,951	0,123	0,203	0,263	0,310

3. From Table 1, the relationship curves between load and primary compression (q vs Sc) and load and primary compression plus secondary compression (q vs Sc+Ss) were constructed. The graphs are shown in Figure 6 and the regression equations of the curves are shown in Table 2.

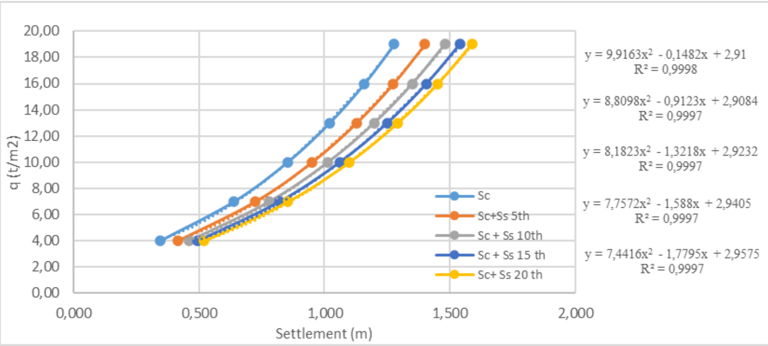

Figure 6. Relationship Curve between Compression (Sc) (Sc+Ss) and Load (q)

Table 2. Regression Equation of the Curve between Compression and Load

Parameter	Regression Equation	R^2
Sc	$q = 9{,}9163.\ Sc^2 – 0{,}01482.\ Sc + 2{,}91$	0,9998
Sc + Ss 5yr	$q = 8{,}8098.(Sc+Ss)^2 – 0{,}9123.(Sc+Ss) + 2{,}9084$	0,9997
Sc + Ss 10yr	$q = 8{,}1823.\ (Sc+Ss)^2 – 1{,}3218.(Sc+Ss) + 2{,}9232$	0,9997
Sc + Ss 15yr	$q = 7{,}7572.\ (Sc+Ss)^2 – 1{,}588.(Sc+Ss) + 2{,}9405$	0,9997
Sc + Ss 20yr	$q = 7{,}4416.\ (Sc+Ss)^2 – 1{,}7795.(Sc+Ss) + 2{,}9575$	0,9997

4. In addition, the curves of the relationship between load and $H_{initial}$ and H_{final} and $H_{initial}$ due to primary compression were made as Figures 7 and 8.

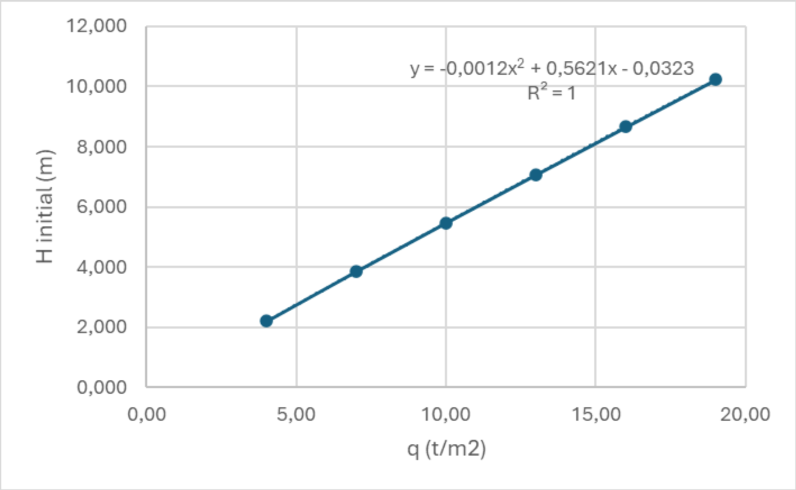

Figure 7. Relationship Curve between Load and H_{intial}

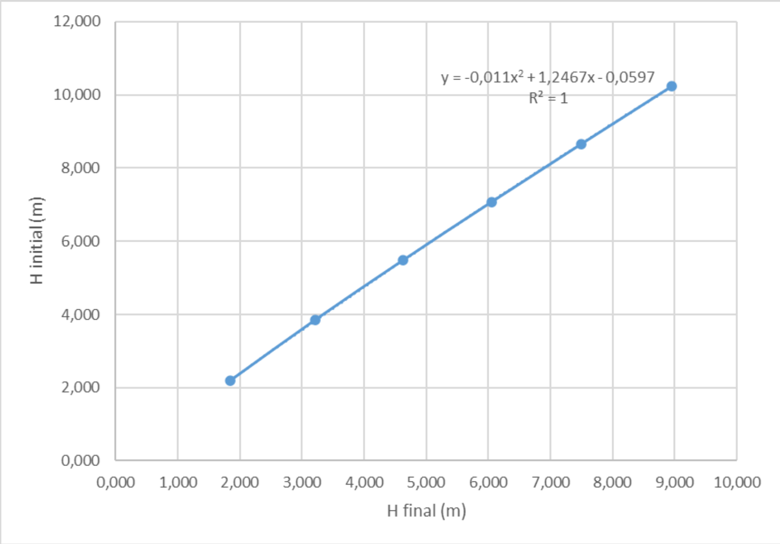

Figure 8. Relationship Curve between H_{final} and $H_{initial}$

5. Calculations were performed to obtain the final backfill load to complete primary and secondary compression with the regression equation in Table 2. Meanwhile, to obtain the initial backfill height to complete primary and secondary compression ($H_{initial(p+s)}$) simultaneously, the regression equation in Figure 7 was used.
6. The final field height (H_{field}) was also calculated using formula (13). A recapitulation of the calculation can be seen in Table 3.
7. From Table 3, the relationship between the final height of the field embankment (H_{field}) and the initial height of the embankment to remove primary and secondary compression ($H_{initial(p+s)}$) was graphed, as shown in Figure 9 and the regression equation of the curve as shown in Table 4.
8. In addition, from Table 3, the relationship between the initial height of the embankment to remove primary and secondary compression ($H_{initial(p+s)}$) and the total compression (Sc+Ss) as shown in Figure 10 and the regression equation of the curve as shown in Table 5 were graphed.

Table 3. Recapitulation of Calculation Results of initial embankment height ($H_{intial(p+s)}$); preloading load (Δq) and final field height (H_{field})

Year	$q_{final-2}$	$q_{final-1}$	Δq	Sc+Ss	$H_{initial(p+s)}$	$Hf_{inal(p+s)}$	H_{field}
	t/m2	t/m2	t/m2	m	m	m	m
5	4,553	4,044	0,509	0,41	2,502	2,088	1,831
	7,999	6,864	1,135	0,64	4,388	3,664	3,091
	11,707	9,983	1,724	0,85	6,384	5,435	4,565
	15,346	13,077	2,269	1,02	8,312	7,184	6,040
	18,826	16,053	2,772	1,16	10,125	8,850	7,452
	22,121	18,883	3,238	1,28	11,815	10,416	8,783
10	4,938	4,180	0,759	0,46	2,715	2,255	1,872
	8,818	7,249	1,568	0,78	4,831	4,052	3,261
	12,937	10,635	2,303	1,01	7,040	6,026	4,865
	16,960	13,992	2,968	1,20	9,156	7,958	6,461
	20,790	17,216	3,573	1,35	11,135	9,785	7,983
	24,402	20,274	4,128	1,48	12,970	11,490	9,408
15	5,252	4,046	1,206	0,49	2,887	2,394	1,786
	9,468	6,862	2,605	0,82	5,182	4,362	3,047
	13,907	9,982	3,925	1,06	7,553	6,492	4,513
	18,226	13,081	5,145	1,25	9,814	8,564	5,969
	22,327	16,059	6,268	1,41	11,920	10,513	7,351
	26,184	18,881	7,303	1,54	13,864	12,324	8,640
20	5,519	4,047	1,472	0,52	3,034	2,513	1,771
	10,010	6,861	3,149	0,85	5,475	4,621	3,033
	14,711	9,981	4,730	1,10	7,978	6,879	4,493
	19,274	13,082	6,192	1,29	10,356	9,064	5,941
	23,598	16,060	7,538	1,45	12,564	11,112	7,310
	27,656	18,880	8,776	1,59	14,596	13,009	8,582

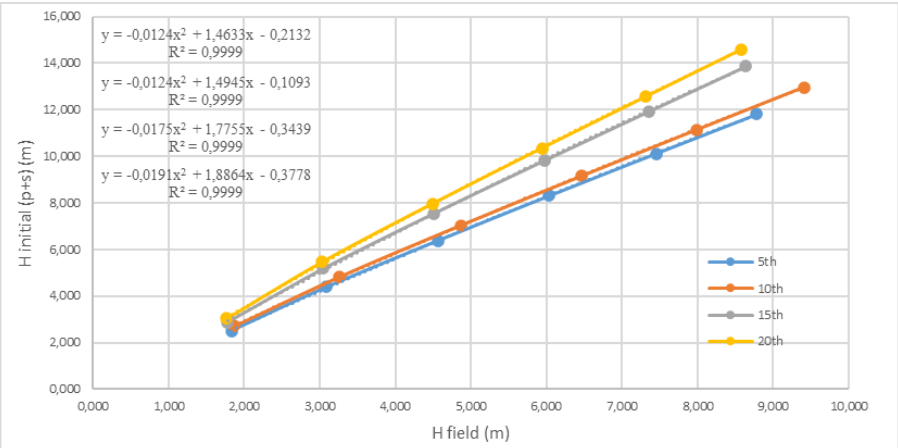

Figure 9. Relationship Curve between H_{field} and $H_{initial(p+s)}$

Table 4. Regression Equation of the Curve between H_{field} and $H_{initial(p+s)}$

Parameter	Regression Equation	R^2
Hfield (5yr)	$H_{i(p+s)} = -0{,}0124\, H_{field}^2 + 1{,}4633\, H_{field} - 0{,}2132$	1
Hfield (10yr)	$H_{i(p+s)} = -0{,}0124\, H_{field}^2 + 1{,}4945\, H_{field} - 0{,}1093$	1
Hfield (15yr)	$H_{i(p+s)} = -0{,}0175\, H_{field}^2 + 1{,}775\, H_{field} - 0{,}3439$	1
Hfield (20yr)	$H_{i(p+s)} = -0{,}0191\, H_{field}^2 + 1{,}8864\, H_{field} - 0{,}3778$	1

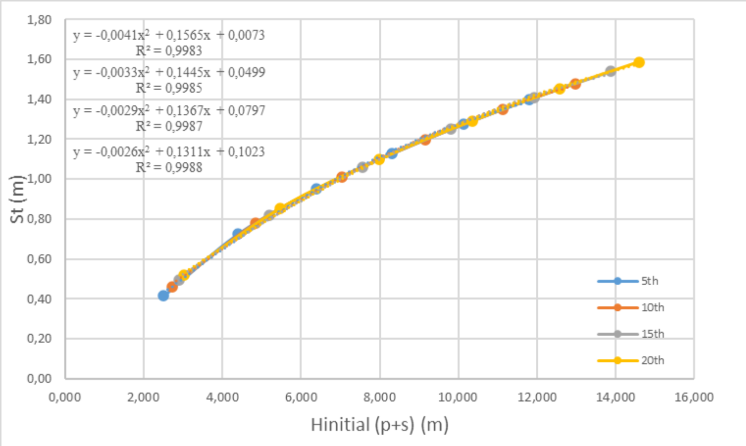

Figure 10. Relationship Curve between $H_{initial(p+s)}$ and Total Settlement (St)

Table 5. Regression Equation of the Curve between $H_{initial(p+s)}$ and Total Settlement (St)

At Year	Regression Equation	R^2
5	$S_t = -0{,}0041 H_{initial(p+s)}^2 + 0{,}1565\, H_{initial(p+s)} - 0{,}0073$	0,9883
10	$S_t = -0{,}0033 H_{initial(p+s)}^2 + 0{,}1445\, H_{initial(p+s)} - 0{,}0499$	0,9985
15	$S_t = -0{,}0029 H_{initial(p+s)}^2 + 0{,}1367\, H_{initial(p+s)} - 0{,}0797$	0,9987
20	$S_t = -0{,}0026\, H_{initial(p+s)}^2 + 0{,}1311\, H_{initial(p+s)} - 0{,}1023$	0,9988

To determine the need for initial embankment height, additional embankment load / preloading to complete primary and secondary compression, as well as the height of the embankment that must be dismantled at the design of the 10-meter plan embankment, the following steps are carried out:

a. The plan embankment height of 10 meters was entered into the equation in Figure 8 to obtain the initial embankment height ($H_{initial}$) due to primary compression. The amount of primary compression and secondary compression in year 5; 10; 15 and 20 due to the initial embankment height was analyzed.
b. To obtain the preload (Δq) to complete the primary and secondary compression (5th; 10th; 15th and 20th years), the primary compression value was added to the secondary compression in the regression equation in Table 2 and the preload (Δq) value was used in equation (10).
c. Meanwhile, to obtain the initial embankment height to complete the primary and secondary compression ($H_{initial(p+s)}$), by entering the value of the field design embankment height (H_{design}) into the regression equation in Table 4.
d. The amount of compression due to the initial embankment height ($H_{intial(p+s)}$) is calculated with the regression equation in Table 5.
e. For the final embankment height due to primary and secondary compression, it is calculated by equation (12) and the height to be eliminated is calculated by equation (14).

ANALYSIS AND DISCUSSION

The analysis was conducted on a 10-meter high embankment plan, where the initial height of the embankment due to primary compression was 11.31 meters. From the analysis, it was found that the amount of primary compression was 1.35 meters with a compression time to reach 90% consolidation degree of 7.35 years. The consolidation time of primary compression can be accelerated with the use of Prefabricated Vertical Drain (PVD). As for the secondary compression, it is calculated up to the 20th year after the primary compression is completed. The results of the calculation of primary compression and secondary compression in years 5; 10; 15 and 20 can be seen in Table 6. The rate of secondary compression each year until year 20 can be seen in Figure 11.

Table 6. Primary and Secondary Compression Due to Initial Height of Planed Embankment

Hfield (m)	Hinitial (m)	Sc (m)	Ss at year (m)			
			5	10	15	20
10,00	11,31	1,35	0,13	0,21	0,27	0,32

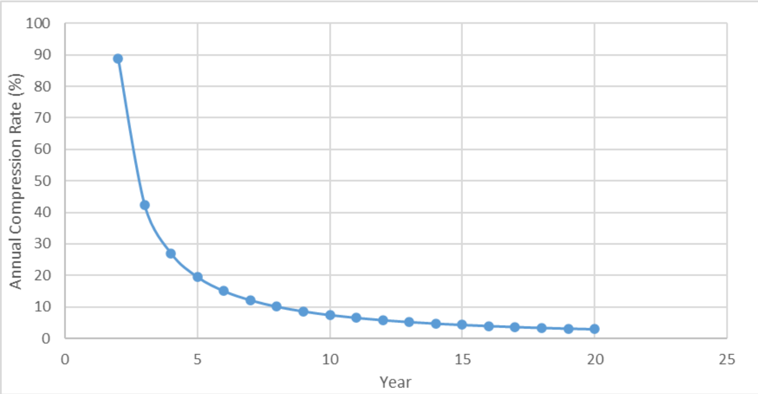

Figure 11. Annual Secondary Compression Rate

Primary *settlement* is considered complete, then monitoring of the *rate of settlement* based on Bina Marga requirements of 2 cm/year or 10 cm in 10 years is carried out on secondary *settlement* . Checks were carried out at year 2 to 3 and at year 2 to 10, which is the period after construction was completed. In addition, checks were carried out at year 5 to 6 and at year 5 to 15, where the maintenance period by the contractor was completed and became the maintenance period by the concessionaire. The rate of settlement analysis at the study site can be seen in Table 7.

Table 7. Rate of Settlement

At year 2 to 3	Requirement	At year 2 to 12	Requirement	At year 5 to 6	Requirement	At year 5 to 15	Requirement
(cm)	< 2 cm/ yr	(cm)	< 10cm in 10yrs	(cm)	< 2 cm/ yr	(cm)	< 10cm in 10yrs
2,48	Not OK	10,44	Not OK	2,06	Not OK	7,36	OK

With the *rate of settlement* values not meeting the requirements, it is considered that secondary compression can be eliminated or resolved by adding preloading. The analysis to eliminate secondary compression by preloading was carried out for the amount of compression in the 5th; 10th; 15th and 20th years. By following the analysis method presented earlier, the initial embankment height, preloading load, total compression and height to be removed were obtained, as shown in Table 8.

Table 8. Recapitulation of the Calculation Results of the Initial Height of Embankent ($H_{initial(p+s)}$), Preload Load (Δq), Total Compression (St), and Eliminated Height of Embankment ($H_{eliminated}$)

Parameters	Unit	At year			
		5	10	15	20
Initial Embankment Load (q_{final})	t/m2	24,32	26,81	28,74	30,34
Initial Height of Embankment ($H_{initial(p+s)}$)	m	13,18	13,60	15,66	16,58
Preloading (Δq)	t/m2	3,54	4,49	7,98	9,59
Total Settlement (St)	m	1,36	1,40	1,51	1,56
Height of Design (H_{field})	m	10,00	10,00	10,00	10,00
Final Height of Embankment ($H_{final(p+s)}$)	m	11,48	11,85	13,81	14,67
Eliminated Thickness of Embankment ($H_{eliminated}$)	m	1,48	1,85	3,81	4,67

From Table 8, the relationship between preloading load and total settlement and height unloaded by preloading was graphed, as shown in Figure 12 and Figure 13.

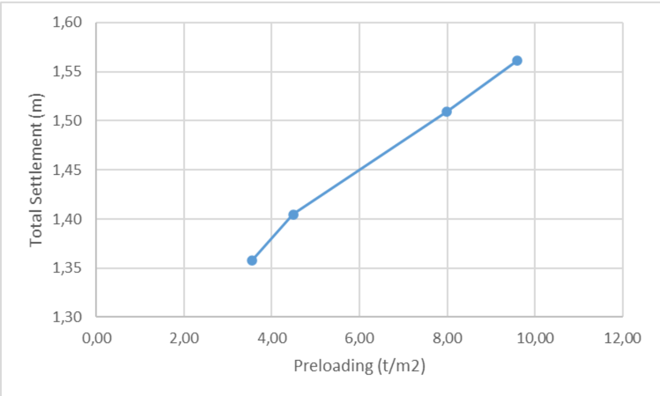

Figure 12. Relation Curves between Preloading and Total Settlement

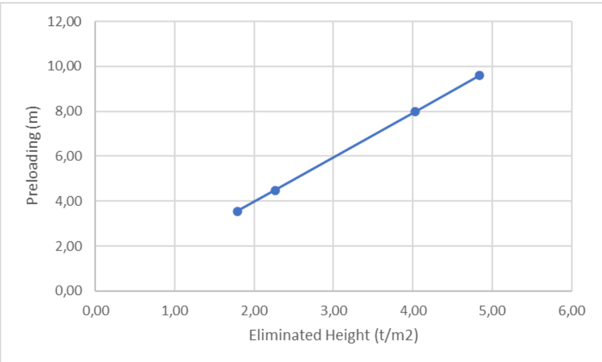

Figure 13. Relation Curves between Eliminated Height of Embankment and Preloading

From Figure 12 and Figure 13, it is found that the need to complete the secondary compression in years 5 and 10 is not so far away, while from year 10 to 15 has a considerable gap. In addition, considering that the annual rate of settlement decreases after the 10th year, the secondary compression in the 10th year is considered to be eliminated.

CONCLUSION

Based on the research, it can be concluded that the consolidation analysis for the approach area with an embankment height of 10 meters showed that primary consolidation results in a settlement of 1.35 meters, with the time required to reach 90% consolidation is

7.35 years. Consolidation time can be accelerated by using Prefabricated Vertical Drain (PVD). Secondary consolidation under the same load leads to settlements of 12.65 cm, 20.93 cm, 27.11 cm, and 32.03 cm after the 5th, 10th, 15th, and 20th years, respectively, which represent 9.37%, 15.50%, 20.07%, and 23.72% of the primary settlement. To eliminate both primary and secondary consolidation, the required initial embankment heights at the 5th, 10th, 15th, and 20th years are 13.18 m, 13.60 m, 15.66 m, and 16.58 m, resulting in settlements of 1.36 m, 1.40 m, 1.51 m, and 1.56 m, respectively. The additional preloading embankment (Δq) for granular backfill to achieve this are 3.54 t/m², 4.49 t/m², 7.98 t/m², and 9.59 t/m², corresponding to 1.79 m, 2.26 m, 4.03 m, and 4.84 m. The height of the embankment that must be dismantled is 1.48 m, 1.85 m, 3.81 m, and 4.67 m, respectively. For consideration, the secondary compression at year 10 can be omitted because the annual secondary compression rate decreases after year 10.

REFERENCES

[1] Alihudien, A. & Mochtar, I. B. (2009). Usulan Perumusan Pemampatan Konsolidasi Sekunder untuk Tanah Lempung. *Tesis*. Institut Teknologi Sepuluh Nopember. Surabaya.

[2] Das, B. M (1985), Alih bahasa :Noor Endah dan Indrasurya B. Mochtar, (1988). *Mekanika Tanah : Prinsip – prinsip Rekayasa Geoteknik Jilid 1.* Erlangga. Surabaya.

[3] Dhianty, E. & Mochtar, (2018). "Method of Removing Secondary Compression on Clay Using Preloading". *MATEC Web of Conference 195, 03006, ICRMCE 2018.*

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

[5] Kosasih & Mochtar, (2007). *Pengaruh Kadar Air, Angka Pori, dan Batas Cair Tanah Lempung terhadap Harga Pemampatan Konsolidasi Cc dan Indeks Pengembagannya Cs.* Surabaya.

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

[7] Mochtar, I. B. (2023). *Modul Ajar Metode Perbaikan Tanah.* Surabaya.

[8] Olson, Roy E. (1989). *Secondary Consolidation, Advances Soil Mechanics Secondary Effects*. Department of Construction Engineering, Chaoyang University of Technology.

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

[10] PT Jasamarga Probolinggo Banyuwangi, (2023). *Laporan Hasil Penyelidikan Tanah Proyek Pembangunan Jalan Tol Probolinggo – Banyuwangi Seksi 3.*

[11] Wahyu, A. L. dan Mochtar, I. B., (2019). Efektifitas Vacuum Preloading dalam Menghilangkan Pemampatan Sekunder pada Proyek Pembangunan Kawasan Kota Summarecon Bandung. *Tesis*. Institut Teknologi Sepuluh Nopember. Surabaya.

[12] Wahyudi, H dan Lastiasih, Y. (2021). *Teknik Reklamasi*. Surabaya.