Analysis of the Use of a Combination of Soil Embankment and Lightweight Material (Foam Mortar) as an Alternative to Slab on Pile Construction Case Study: Rengat-Pekanbaru Toll Road Construction Project Section Lingkar Pekanbaru-Junction Pekanbaru Sta 193+ 025 - 193+400

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ABSTRACT

The soil condition on the Rengat - Pekanbaru Toll Road Sta 193+ 025 - Sta 193+400 which passes through oil palm plantations, swamp areas, and the Siak River, consists of a compressible layer as thick as 7.0 meters. To handle the problem, a 375 m long slab on pile construction was planned with a construction time of 3 months. However, the design was costly; therefore, alternative planning using ordinary piles and a combination of ordinary and lightweight piles was required. The rate of settlement at the study site did not meet the requirements for t = 1 year (< 2cm/year) or t = 10 years (< 10cm/10 years). Therefore, it is necessary to install PVDs with an installation distance of 1.0 meter and a length of 7.0 m. The stability analysis showed that as the percentage of foam mortar increases, the SF value increases. The bearing capacity of the subgrade was increased by installing geotextiles; the number of geotextile layers required at each site varied depending on the height of the embankment and the combination of soil + foam mortar, the thicker the foam mortar, the less geotextile layers were required. The number of reinforcing piles was also planned according to the thickness of the soil and foam mortar variations; the thicker the foam mortar, the less piles were required. In terms of cost, the slab on pile replacement structures that provide savings are geotextile-reinforced soil backfill and a combination of soil backfill with 25% thick foam mortar. Each of these replacement structures provides savings of Rp 40 billion (without foam mortar) and Rp 12.1 billion (with 25% thick foam mortar). For the implementation time, both methods require the same completion time as slab on pile which is 3.5 months.

Keywords : soft soil, lightweight embankment, foam mortar, *slab on pile*

INTRODUCTION

The Trans Sumatra Toll Road (JTTS) is a strategic infrastructure project that began in 2014 based on Presidential Regulation Number 100 of 2014. One of the sections being built is the Rengat - Pekanbaru Pekanbaru Ring Section - Pekanbaru Junction, the section connects the Pekanbaru - Bangkinang Section and the Pekanbaru - Dumai Section, with a total length of 30.925 km from Siak Regency to Kampar Regency as shown in Figure 1. The location of Sta 191+600 - Sta 193+400 consists of oil palm plantations, swamp areas,

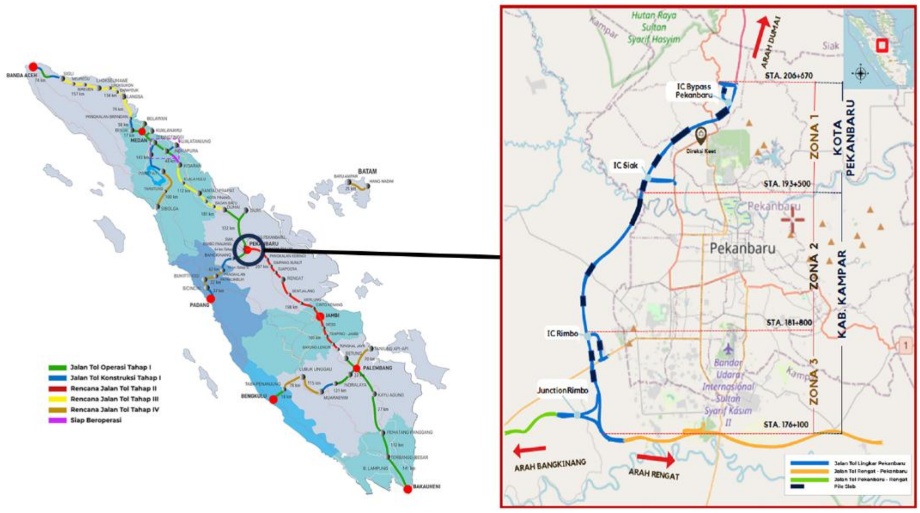

Figure 1. Location of Trans Sumatra Toll Road Project Rengat -Pekanbaru Section Lingkar Pekan Baru - Junction Pekanbaru (PT. Hutama Karya, 2023)

and Siak River which are influenced by groundwater level fluctuations as shown in Figure 2. The soil in this area is classified as very soft with a clay layer thickness of up to 7 m, and low N-SPT < 6 values up to 7 m depth.

Figure 2. Existing condition location sta 193+ 025 - 193+400 (PT. Hutama Karya, 2024)

The existing design at the site uses a 375 m long slab on pile construction with a 250 m long bridge. The slab on pile structure is supported by piles with a diameter of 60 cm and a depth of 24 m, and the bridge abutments consist of 24 piles 20 m deep as shown in Figure 3. This design resulted in very high project costs. Therefore, alternative analyses are needed to deal with soil stability and settlement, including the use of lightweight embankments such as foam mortar. Foam mortar is a lightweight material with a density of 0.6-0.8 t/m³ that can reduce settlement and improve embankment stability. Studies by Fadilah & Hamdhan (2017), show that lightweight materials are more effective than regular embankments in reducing

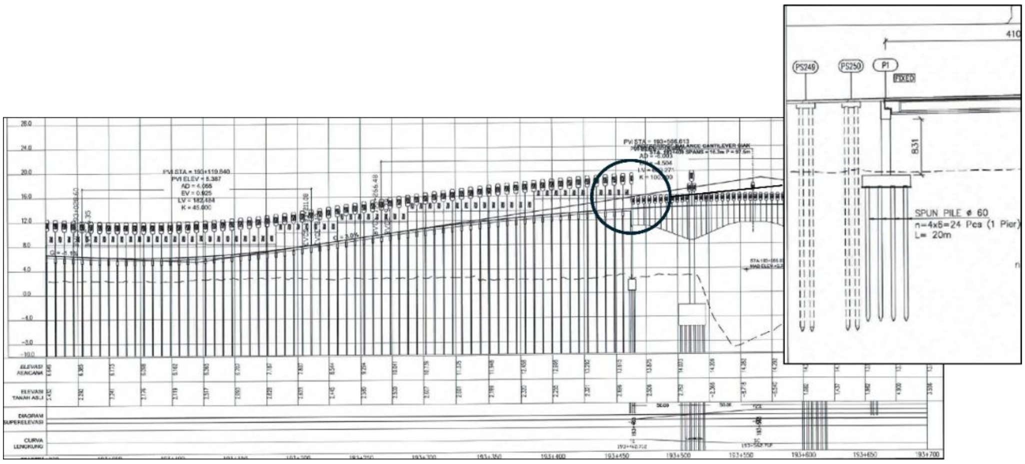

Figure 3. Longitudinal section of slab on pile Sta 193+025 - Sta 193+400 (PT.Hutama Karya(2022))

And increase the safety factor. Its use can reduce the cost and time of project implementation. Variation of embankment thickness with foam mortar also provides better stability performance, although it increases construction time and cost. The main problems include planning alternatives to replace slab on pile with plain embankment and combination of plain embankment + foam mortar. This study analyzed stability, settlement, PVD design, additional geotextile reinforcement or pile, as well as cost and time analysis. research aims to design the most efficient alternative to the existing design with various variations.

LITERATURE REVIEW

Soil Parameters and Correlations

1. **Soft Soil**

   A soil layer designated as soft is a layer of clay or silt that has a standard N-SPT penetration of less than 6. There is a correlation between N-SPT and other soil consistency types as described in Table 1.

Table 1. Parameter Correlations for Cohesionless and Cohesive Soils

			COHESIONLESS SOIL		
N-Spt Value	0 - 10	11 - 30	31 - 50	> 50	
Specific gravity, γ , (kN/m3)	12 - 16	14 - 18	16 - 20	18 - 23	
Shear Angle, Ø	25 - 32	28 - 36	30 - 40	> 35	
Consistency	Retrieved	Medium	Solid	Very dense	
			COHESIVE SOIL		
N-Spt Value	< 4	4 - 6	6 - 15	16 - 25	> 25
Specific gravity, γ , (kN/m3)	14 -18	16 - 18	16 - 18	16 - 20	> 20
q_u (kpa)	< 25	20 - 50	30 - 60	40 -200	
Consistency	Very Soft	Software	Medium	Stiff	Hard

Source: Soil Mechanics, Whilliam T, Whitman, Robert V,1969

N-Spt Data and its Correction

Soil investigation results from boring logs obtained N-SPT penetration values from each depth of the soil layer. The N-SPT value must be corrected based on two correction factors, namely due to the groundwater table and due to overburden pressure. Correction of N-SPT values due to the groundwater table is specific to fine sand, silty sand and clayey sand soils that are below the groundwater table and only when the N value is > 15. For clay, silt and coarse sand soil types and when N ≤ 15, no correction is made. The N-SPT value correction formula was used by taking the smallest value from the following formula according to Terzaghi and Peck, 1960 and Bazaraa, 1967.

$$N1 = 15 + \frac{1}{2}(N - 15)$$

$$N1 = 0,6\,N$$

The second correction is the correction of the N-SPT value due to the effect of effective vertical stress (overburden pressure), this correction value is expressed by the notation N1(60) which is taken based on SNI 4153-2008. The formula for calculating the NSPT correction due to overburden pressure, N1(60) is in accordance with the Equation below.

$$N1_{(60)} = N_M x C_N x C_E x C_B x C_R x C_S$$

$$C_N = 2,2/(1,2 + \frac{\sigma vo}{Pa})$$

Soil Compressibility

1. **Primary Compression**

The settlement in consolidation in clay based on the maximum effective stress that has occurred in the past or called preconsolidation pressure, can be divided into normally consolidated clay (NC) and over consolidated clay (OC). A clay soil is normally consolidated if the current effective overburden stress is the maximum stress experienced by the soil. Meanwhile, a clay soil is over consolidated if the current effective overburden stress is less than the stress experienced by the soil in the past. The consolidation settlement of normally consolidated (NC) clay is calculated by Equation (1).

$$Sc = \frac{Cc\,H}{1+e_0} log\left(\frac{\sigma_0{}' + \Delta\sigma}{\sigma_0{}'}\right) \quad \ldots (1)$$

Meanwhile, the consolidation settlement in over consolidated clay (OC) if the valueσ '0+Δσ '≤σ 'c is calculated by Equation (2) and if the valueσ '0+Δσ '>σ 'c then it is calculated by Equation (3).

$$Sc = \frac{Cs\,H}{1+e_0} log\left(\frac{\sigma_0{}' + \Delta\sigma}{\sigma_0{}'}\right) \quad \ldots (2)$$

$$Sc = \frac{Cs\,H}{1+e_0} log\left(\frac{\sigma_c{}'}{\sigma_0{}'}\right) + \frac{Cc\,H}{1+e_0} log\left(\frac{\sigma_0{}' + \Delta\sigma}{\sigma_0{}'}\right) \quad \ldots (3)$$

2. **Secondary Compression**

Secondary settlement plays a more important role than primary consolidation settlement in organic soils and inorganic soils with very high compressibility (Das, 2010). Secondary settlement is calculated using Equation (4) (Mesri and Ajlouni, 2007). Meanwhile, the secondary compression index (Cα') is calculated by Equation (5)

$$Ss = \frac{C_\alpha}{1+e_p} H\,log\left(\frac{t}{t_p}\right) \quad \ldots (4)$$

Where Cα' = secondary compression index = Cα/(1+ep)

According to Dhianty and Mochtar (2018), the secondary compression index (C'α) is a function of the initial pore number (e0) and effective stress (P') or a function of the pore number at the end of consolidation compression (ep) and effective stress (P'), namely:

Cα’ = (0.0077 ep – 0.006) P’ …(5)

3. Consolidation Time

The length of time for consolidation settlement according to Terzaghi in Das (2010) is calculated by Equation (6).

$$t = \frac{T_v \ x \ H_{dr}^2}{C_v} \qquad \dots(6)$$

The value of the time factor (Tv) is influenced by the degree of consolidation (U) and is calculated by Equation (7) for values of U = 0 to 60% and Equation (8) for values of U > 60%.

$$T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2 \qquad \dots(7)$$

$$Tv = 1.781 - 0.933 \log(100 - U\ \%) \qquad \dots(8)$$

PVD Installation and Parameter Changes

1. PVD Planning

PVDs can accelerate the consolidation time because they shorten the pore water flow distance. Without PVDs, the consolidation time of soft clay is illustrated in Figure 4. Pore water flows in the vertical direction according to the vertical consolidation coefficient (Cv) along the thickness of the soft soil layer (Hd). The consolidation time (t) is determined by the square of the soft soil layer thickness (Hd) divided by the vertical consolidation coefficient (Cv). An illustration of the corresponding compression time is shown in Figure 4.

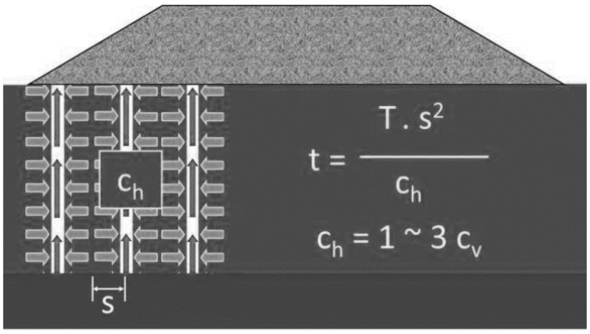

Figure 4 . Illustration of the compression time that occurs when PVDs are installed (kuswanda, 2016)

When PVDs are used, the consolidation time of soft clay can be illustrated in Figure 4. Pore water flows in the horizontal direction according to the horizontal consolidation coefficient (Ch) along half of the PVD installation distance (s). The consolidation time (t) is determined by the square of half the PVD installation distance (s) divided by the horizontal consolidation coefficient (Ch). The determination of consolidation time from Barron's (1948) theory is calculated by Equation (9).

$$t = \left(\frac{D^2}{8Ch}\right) F(n) ln\left(\frac{1}{1-Uh}\right) \qquad \dots (9)$$

2. Parameter Change due to compression

The compression causes the pore space in the soil to decrease so that the void ratio (e) decreases and the soil becomes denser so that the soil volume weight (γ) increases. The new void ratio after settlement is calculated by Equation (9). Meanwhile, the new soil volume weight is calculated by Equation (10).

$$e_1 = e_0 - \frac{1+e_0}{H_0} S_c \quad \ldots (10)$$

$$\gamma_{sat} = \frac{(G_s+e_1)\gamma_w}{1+e_1} \quad \ldots (11)$$

Stability and Reinforcement

Slope stability analysis is conducted to determine the factor of safety (SF) through the comparison between the shear stress acting on the landslide plane and the shear strength of the soil. To improve slope stability, soil reinforcements such as geotextile and pile are used.

1. **Geotextile Reinforcement**

The geotextile planning calculation requires data obtained from the LEM program, including the value of safety factor (SF), moment of resistance (Mr), landslide radius (R), and coordinates of the landslide center point. The installation of the first layer geotextile was done right on top of the subgrade, so that the vertical distance between the geotextile installation and the center point of the landslide becomes the additional holding moment. If the moment of geotextile installed in the first layer still does not meet the requirement of the difference of retaining moment (∆ Mr), it is necessary to install geotextile in the next layer and so on until the cumulative geotextile moment value is greater than ∆ Mr. In geotextile planning, the allowable tensile strength of the geotextile material must be considered in accepting or resisting shear forces when a landslide occurs.

The strength of the geotextile material is calculated using Equation (12).

$$TAllow = TUltimate \times \frac{1}{FSid \times FScr \times FScd \times FSbd} \quad \ldots (12)$$

The cumulative geotextile moment is calculated using Equation (13).

$$M_{Geotextile} = TAllow \times y\ layer_n + TAllow \times y\ layer_{n+1} + \cdots \quad \ldots (13)$$

2. **Reinforcement of Piles**

The relative stiffness factor (T) is calculated using the equation from NAVFAC DM-7 (1986). To calculate the relative stiffness factor (T), Equation (14) is used.

$$T = \left(\frac{EI}{f}\right)^{\frac{1}{5}} \quad \ldots (14)$$

To calculate the force received by 1 niche using Equation (15).

$$P = \frac{Mp}{FM \times T} \quad \ldots (15)$$

Based on the magnitude of P value that 1 niche can withstand, the number of niche (n) required is calculated by Equation (16).

$$n = \frac{\Delta Mr}{P1\ Cerucuk \times R} \quad \ldots (16)$$

Foam Mortar

Foam mortar is a lightweight material used as an alternative to fill for road construction, made from a mixture of vegetable protein-based foam, cement, sand and water. This material is self compacted, so it does not require additional compaction. Foam mortar is used for pavement foundation layers, road sub-foundation layers, or embankment materials, with customized specifications based on minimum compressive strength and dry density according to the Guidelines for the Implementation of Foam Mortar Lightweight Material Embankment (SE No.41/SE/M/2015). The foam mortar specifications can be seen in Table 3.

Table 2 . Foam Mortar Lightweight Material Specification

Application	Maximum dry density (gr/cm3)	Minimum compressive strength (UCS) 14 days old	
		kPa	Kg/cm2
Foundation layer	0,8	2000	20
Lower foundation layer or embankment	0,6	800	8

Source: Ministry of PUPR (2015c)

Fadilah & Hamdhan (2017) conducted a comparative analysis of the use of foam mortar lightweight material with selected embankment material as road embankment on soft soil in terms of stability and settlement. The analysis was carried out by making a model of foam mortar lightweight embankment material and ordinary choice embankment and then analyzed using the finite element method numerical program. Based on the results of the analysis, it was found that the use of foam mortar as embankment material on soft soil resulted in higher factor of safety and smaller settlement than the selected embankment material.

RESEARCH METHOD

This research was conducted by collecting secondary data, such as DED, topography, RTA, and field documentation. Primary data was collected in the form of disturbed and undisturbed soil test specimens for laboratory testing. Furthermore, soil parameters were determined to determine the characteristics of the subgrade, analysis of the existing slab on pile design, and planning of embankment as a substitute for slab on pile with variations in embankment height with the same width and slope. The replacement materials used in this planning are ordinary backfill soil and foam mortar. In this case, the thickness of foam mortar planned is 25%, 50%, and 75% of the final height of the road.

The calculation of soil compression is carried out to determine the rate of settlement that occurs is qualified or not. If it does not meet the requirements, PVD installation is planned to accelerate the compression. The types of reinforcement that may be used are geotextile and pile. The selection of the optimal alternative method is based on cost and implementation time.

DATA AND ANALYSIS

Soil Data

Based on the results of Boring testing at point BHT-3 to a depth of 15 meters, it was found that passive clay with a blackish brown color containing 43.06% moisture content at a depth of 0 - 3 meters with an N-SPT value of 2 including a very soft consistency. Passive clay soil at a depth of 3 - 5.5 meters with a water content of 48.54% and an NSPT value of 4 including soft consistency. Passive clay at a depth of 5.5 - 7 meters has an N-SPT value of 5 including soft consistency. Sand soil at a depth of 7 - 10 meters with an N-SPT value of 25 including medium - solid consistency soil. Based on the soil data, it is known that the soil in the study area has several very soft layers with N-SPT values < 4 at a depth of 5.5 m and soft - medium clay at a depth of 7 meters. The physical and mechanical parameters used for the analysis are given in Table 4 and Table 5.

Table 3. N-SPT data of point BHT-32

Depth (m)	Description	N-SPT	N1(60)	Consistency
0 - 3	Clay	2	2.7	Soft
3 - 5.5	Clay	4	4.6	Soft
5.5 - 7	Clay	5	6.4	Medium
7 - 10	Sand	25	17.6	Solid

Source: PT.Hutama Karya (2022)

Table 4. Parameter Data Used for Stability and Settlement Analysis

Depth (m)	Description	ɣt (gr/cm3)	Wc (%)	Gs	e	Cv (cm2/dt)	Cc	Cs	Φ(◦)	C (kg/cm2)
0 - 3	Clay	1.40	54.67	2.52	1.48	0.00100	0.86	0.14	21.83	0.12
3 - 5.5	Clay	1.60	38.54	2.68	1.47	0.00070	0.86	0.14	21.83	0.26
5.5 - 7	Clay	1.65	31.98	2.67	1.23	0.00200	0.58	0.04	21.94	0.71
7 - 10	Sand	1.60	17.61	2.66	1.22	-	-	-	32.37	-

Source: PT.Hutama Karya (2022)

Planning Data of Plain Soil Embankment and Combination Soil Embankment +Foam Mortar

Existing embankment planning with heights varying from 4.0 to 10.0 meters and a top subgrade width of 37.9 m. The variations of embankment to be reviewed are 4.0 m, 6.0 m, 8.0 m, 10.0 m. The variations of soil and foam mortar embankment combinations to be reviewed can be seen in Figure 5, Figure 6, Figure 7.

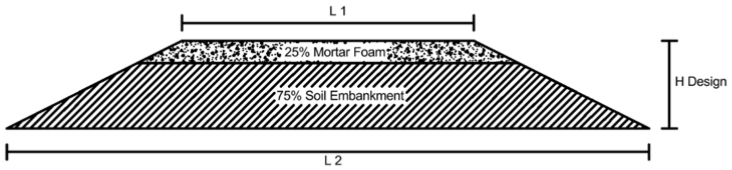

Figure 5 . MB-01 design illustration

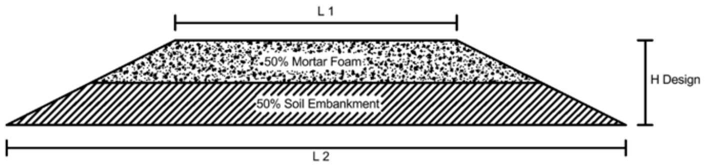

Figure 6 . MB-02 design illustration

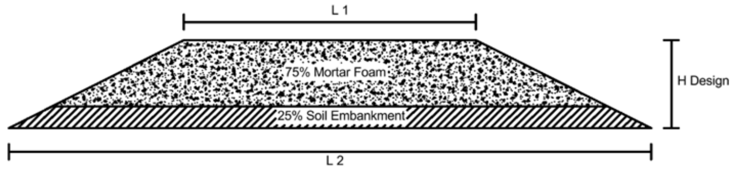

Figure 7 . MB-03 design illustration

RESEARCH ANALYSIS

Primary Compression

Based on the results of calculations using Equation (1), Equation (2), and (3) for variations in embankment heights of 4m, 6m, 8m, and 10m and their combinations, the amount of compression caused by each combination is given in Table 6. Meanwhile, the relationship curve of the final H and Sc is given in Figure 8.

Table 5. Recapitulation of Compression Magnitude Occurring for Each Variation of Embankment Combination

Variations	H initial	Hinitial Soil	H Foam Mortar	q end	Sc	H final
	m	m	m	t/m2	m	m
Soil Embankment	5.21	5.21	-	8.16	1.21	4.00
	7.55	7.55	-	12.07	1.55	6.00
	9.79	9.79	-	15.79	1.79	8.00
	11.97	11.97	-	19.29	1.97	10.00
(MB.01) SE 75% + FM 25%	5.10	4.10	1.00	7.16	1.10	4.00
	7.43	5.93	1.50	10.57	1.43	6.00
	9.67	7.67	2.00	13.79	1.67	8.00
	11.84	9.34	2.50	16.79	1.84	10.00
(MB.02) SE 50% + FM 50%	4.97	2.97	2.00	6.16	0.97	4.00
	7.30	4.30	3.00	9.07	1.30	6.00
	9.53	5.53	4.00	11.79	1.53	8.00
	11.70	6.70	5.00	14.29	1.70	10.00
(MB.02) SE 25% + FM 75%	4.83	1.83	3.00	5.16	0.83	4.00
	7.14	2.64	4.50	7.57	1.14	6.00
	9.36	3.36	6.00	9.79	1.36	8.00
	11.53	4.03	7.50	11.79	1.53	10.00

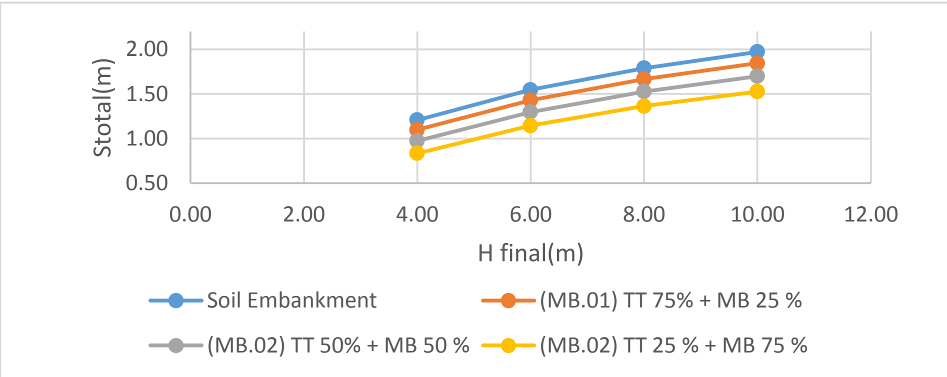

Figure 8. Graph of relationship between H final and settlement

Based on Figure 8, it can be seen that for all variations of embankment combinations, the greater the final H value, the greater the compression. For the same final H value, the thicker the foam mortar layer is in relation to the total embankment height, the smaller the compression value.

Primary Compression Time

By using Equation (6), the consolidation time that occurs is obtained. From the consolidation time data, the degree of consolidation U can be obtained . The graph of the relationship between the degree of consolidation (U) and the compression time (t) can be seen in Figure 9. The recapitulation of the results of the rate of settlement calculation is given in Table 7.

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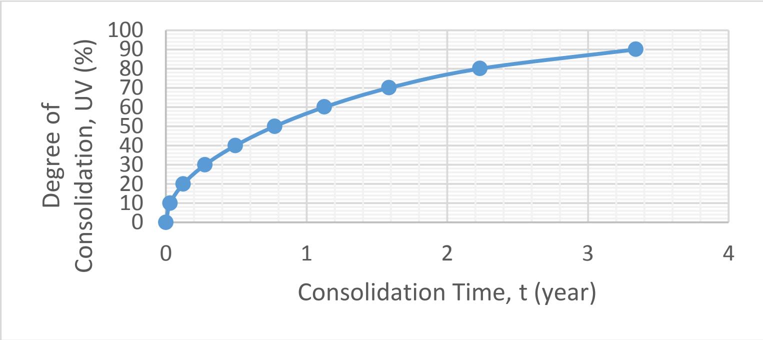

Figure 9. Relationship between degree of consolidation and time

Table 6. Recapitulation of Rate of Settlement Results before PVD

	Settlement Years to-								
	H Final	**2 to 3**	**Bina Marga requirements**	**2 to 12**	**Bina Marga requirements**	**5 to 6**	**Bina Marga requirements**	**5 to 15**	**Bina Marga requirements**
	m		**< 2 cm /years**		**< 10 cm /10 years**		**< 2 cm /years**		**< 10 cm /10 years**
Soil Embankment	4.00	13.02	Not Ok	27.90	Not Ok	1.99	Ok	4.26	Ok
	6.00	16.68	Not Ok	35.75	Not Ok	2.54	Not Ok	5.45	Ok
	8.00	19.28	Not Ok	41.33	Not Ok	2.94	Not Ok	6.31	Ok
	10.00	21.26	Not Ok	45.58	Not Ok	3.24	Not Ok	6.95	Ok
(MB.01) TT 75% + MB 25 %	4.00	11.84	Not Ok	25.37	Not Ok	1.81	Ok	3.87	Ok
	6.00	15.42	Not Ok	33.05	Not Ok	2.35	Not Ok	5.04	Ok
	8.00	17.96	Not Ok	38.50	Not Ok	2.74	Not Ok	5.88	Ok
	10.00	19.89	Not Ok	42.63	Not Ok	3.03	Not Ok	6.51	Ok
(MB.02) TT 50% + MB 50 %	4.00	10.51	Not Ok	22.53	Not Ok	1.60	Ok	3.44	Ok
	6.00	13.99	Not Ok	29.99	Not Ok	2.13	Not Ok	4.58	Ok
	8.00	16.46	Not Ok	35.28	Not Ok	2.51	Not Ok	5.38	Ok
	10.00	18.31	Not Ok	39.25	Not Ok	2.79	Not Ok	5.99	Ok
(MB.02) TT 25 % + MB 75 %	4.00	8.99	Not Ok	19.27	Not Ok	1.37	Ok	2.94	Ok
	6.00	12.34	Not Ok	26.45	Not Ok	1.88	Ok	4.04	Ok
	8.00	14.70	Not Ok	31.52	Not Ok	2.24	Not Ok	4.81	Ok
	10.00	16.46	Not Ok	35.29	Not Ok	2.51	Not Ok	5.38	Ok

Based on Table 7, it can be seen that the requirements for year 2 to year 3, year 2 to year 12, year 5 to year 6 are not met for all embankment combinations. Therefore, PVD planning is required to accelerate the consolidation time.

PVD Planning

Using Equation (9), the consolidation time that occurs due to PVD installation for each spacing variation is obtained. From the consolidation time data, the degree of consolidation (U) can be obtained. The graph of the relationship between degree of consolidation (U) and compression time (t) for each variation of PVD spacing can be seen in Figure 10.

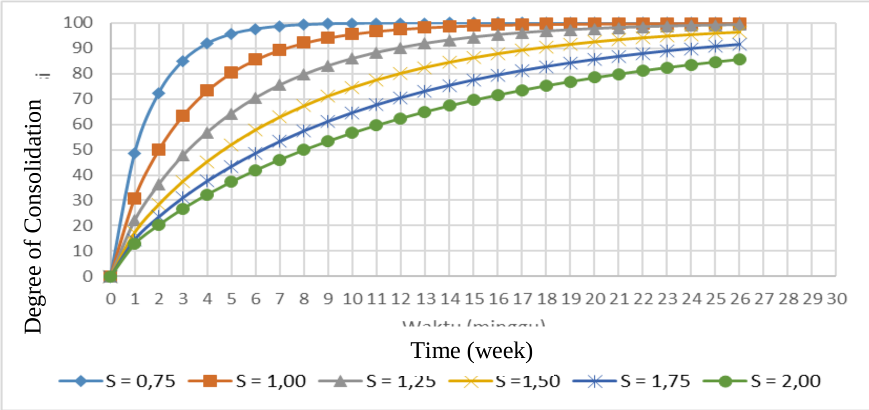

Figure10 . Graph of the relationship between degree of consolidation and consolidation time

Based on Figure 10, it can be seen that the time required to achieve 99% consolidation is determined to occur within 12 weeks. In Figure 13, a vertical line is drawn upwards until it meets one of the PVD graphs located above the horizontal line of the degree of consolidation, the installation distance obtained is 1m.

Secondary Compression

By using Equation (4) and Equation (5), the secondary compression values for 2 years, 3 years, 5 years, 6 years, 12 years, and 15 years were obtained. The results of secondary compression with variations in the final embankment height along with their combinations for all review times are given in Table 8.

Table 7 . Recapitulation of Secondary Compression

	q final	**Sc**	**H initial**	**Ss (m)**						**H Mortar Foam**	**H final**
	t/m2	**m**	**m**	**t2 = 2 years**	**t2 = 3 years**	**t2 = 5 years**	**t2 = 6 years**	**t2 = 12 years**	**t2 = 15 years**	**m**	**m**
Soil Embankment	8.16	1.21	5.21	0.03	0.04	0.05	0.06	0.09	0.10	-	4.00
	12.07	1.55	7.55	0.03	0.04	0.06	0.07	0.10	0.11	-	6.00
	15.79	1.79	9.79	0.03	0.04	0.06	0.07	0.11	0.12	-	8.00
	19.29	1.97	11.97	0.03	0.05	0.07	0.08	0.11	0.13	-	10.00
(MB.01) TT 75% + MB 25 %	7.16	1.10	5.10	0.03	0.03	0.05	0.06	0.08	0.09	1.00	4.00
	10.57	1.43	7.43	0.03	0.04	0.06	0.06	0.09	0.10	1.50	6.00
	13.79	1.67	9.67	0.03	0.04	0.06	0.07	0.10	0.11	2.00	8.00
	16.79	1.84	11.84	0.03	0.05	0.06	0.07	0.11	0.12	2.50	10.00
(MB.02) TT 50% + MB 50 %	6.16	0.97	4.97	0.02	0.03	0.05	0.05	0.08	0.09	2.00	4.00
	9.07	1.30	7.30	0.03	0.04	0.05	0.06	0.09	0.10	3.00	6.00
	11.79	1.53	9.53	0.03	0.04	0.06	0.06	0.10	0.11	4.00	8.00
	14.29	1.70	11.70	0.03	0.04	0.06	0.07	0.10	0.11	5.00	10.00
(MB.02) TT 25 % + MB 75 %	5.16	0.83	4.83	0.02	0.03	0.04	0.05	0.07	0.08	3.00	4.00
	7.57	1.14	7.14	0.03	0.04	0.05	0.06	0.08	0.09	4.50	6.00
	9.79	1.36	9.36	0.03	0.04	0.05	0.06	0.09	0.10	6.00	8.00
	11.79	1.53	11.53	0.03	0.04	0.06	0.06	0.10	0.11	7.50	10.00

From the results of the calculation of the *rate of settlement*, it shows that it meets the requirements of both of all years reviewed, so there is no need for Preloading / surcharge planning.

Stability Analysis

Using the LEM-based program, the safety value for each variation of embankment combination was obtained. The results of the safety factor can be seen in Figure 11.

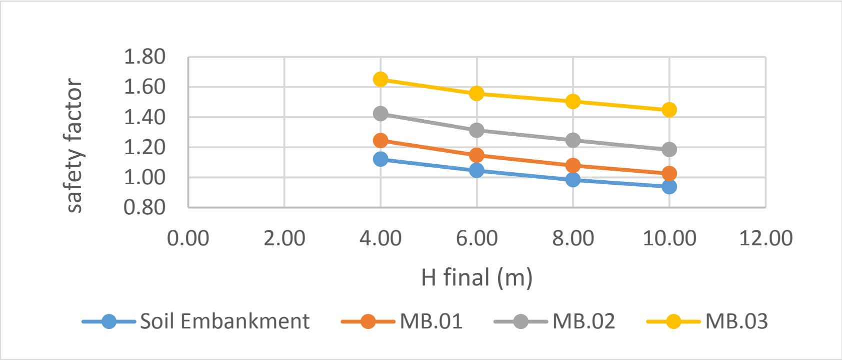

Figure 11. Graph of the relationship between final h and number

Based on Figure 5.23, it can be seen that for all variations of embankment combinations, the greater the final H value, the smaller the safety number value, for the same final H value, the greater the percentage of foam mortar to the soil embankment, the greater the safety number value. The percentage increase in the safety number value at each location under review can be seen in Table 9.

Table 8. SF Value Recapitulation Results

Variation of Backfill Combination	STA 193+025 - STA 193+400	
	SF	% increase in SF
Soil Embankment	1.022	0.00%
(MB.01) SE 75% + FM 25%	1.123	9.94%
(MB.02) SE 50% + FM 50%	1.291	26.37%
(MB.02) SE 25% + FM 75%	1.448	41.68%

Based on Table 8, it can be seen that the greater the percentage of foam mortar, the higher the safety number. The percentage increase in the safety number for Sta 192+300-193+025 is 9.94% - 41.68%. Judging from the results of the stability analysis, the value of the safety factor number is below 1, it can be concluded that the embankment has collapsed and has not met the requirements in the planning design, namely the minimum safety number of 1.25. Therefore, it is necessary to plan the reinforcement of the embankment using geotextiles or piles.

Geotextile Reinforcement or Piles

In this study, a geotextile with an ultimate tensile strength of 200 kN and a minipile with a size of 25 x 25 were used. Reinforcement was carried out when the safety number value was < 1.25. To obtain the required amount of geotextile reinforcement, Equation (12) and Equation (13) were used. Meanwhile, to calculate the amount of reinforcement required, Equation (14), Equation (15), and Equation (16) are used. The number of geotextiles and cores for each variation of embankment and subgrade replacement can be seen in Figure 12 and Figure 13.

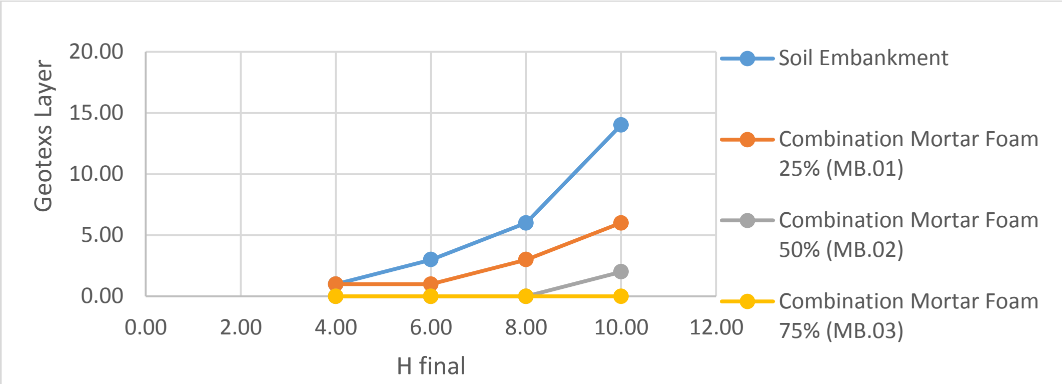

Figure 12. Graph of the relationship between final h and number of geotextile layers

Based on Figure 12, it can be seen that at the location of Sta 193+025 - Sta 193+400 for all variations of embankment combinations the greater the final H value, the more geotextile layers are required, for the same final H value the greater the percentage of foam mortar to soil embankment the less geotextile layers are required.

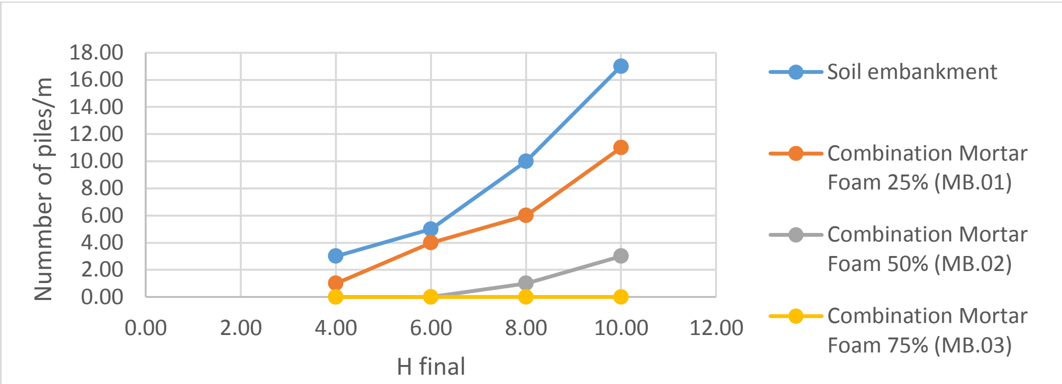

Figure 13 . Graph of the relationship between the final h and the number of points

Based on Figure 13, it can be seen that at the location of Sta 193+025 - Sta 193+400 for all variations of embankment combinations, the greater the final H value, the greater the number of pile points required, for the same final H value, the greater the percentage of foam mortar to soil embankment, the fewer pile points required.

Cost Analysis of Work Implementation

The cost of implementing the work is calculated based on the volume of each job and the predetermined unit price. The unit price of work is obtained from the analysis of the unit price of work on the contract for the construction of the Trans Sumatra Toll Road Project Rengat Pekanbaru Ring Road Section in accordance with the General Specifications for Barriers and Toll Roads in 2020. As for the results of the analysis of the calculation of the cost of soil embankment work in combination with foam mortar can be seen in Figure 14.

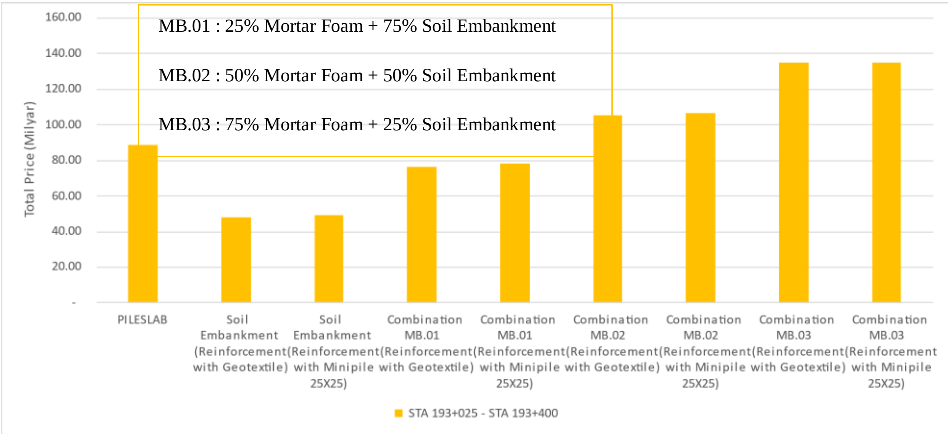

Figure 14 . Graph of the relationship between treatment alternatives and implementation costs

Based on Figure 14, it can be seen that the thicker the foam mortar, the more the cost increases because the price of foam mortar is more expensive than the price of ordinary soil. The most cost-effective combination is the geotextile-reinforced soil backfill and the combination of soil backfill with foam mortar at 25% of the final H thickness. Each of these replacement structures provides savings of Rp 40,762,857,362.39 (without foam mortar) and Rp 12,173,929,687.39 (with 25% thick foam mortar).

Time Analysis of Work Implementation

The implementation time is obtained based on the volume of work in accordance with the plan drawings then associated with productivity for each job. The productivity of the work used refers to the description of the analysis of the unit price of work on the JTTS Project Rengat Pekanbaru Lingar Pekanbaru Section Based on the volume and productivity of the work, the duration of work required to complete the work can be calculated. The results of the calculation of the duration of work are shown in Figure 15.
mortar.

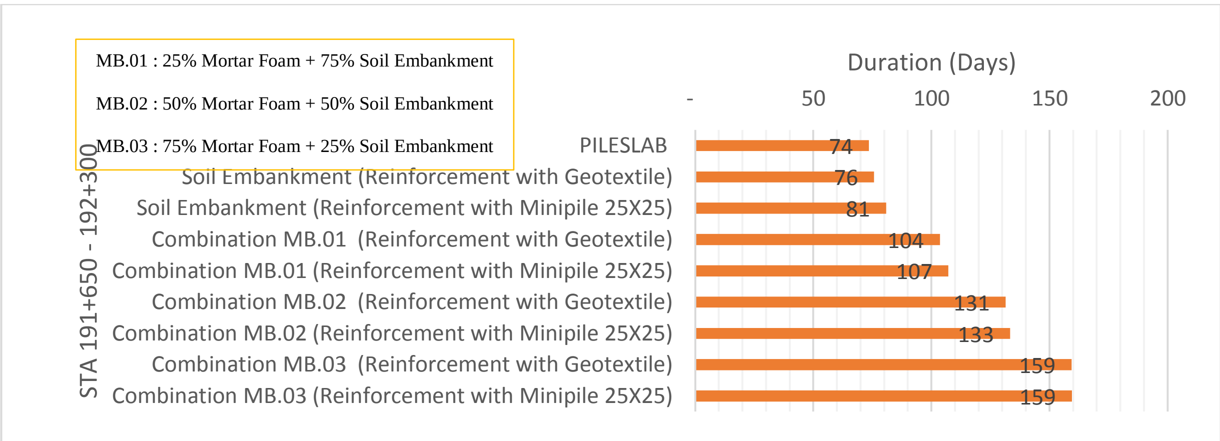

Figure15 . Graph of the relationship between treatment alternatives and implementation time

From Figure 15 it can be seen that for the handling of ordinary soil backfill with slab on pile construction, the implementation time is almost the same; while for the combination of ordinary backfill + 25%, 50%, and 75% foam mortar requires a longer time because the productivity of foam mortar implementation is smaller than the implementation of soil backfill alone. The most effective combination in terms of implementation time is the replacement of the *slab on pile* structure with soil embankment alone or a combination of soil embankment + 25% foam mortar using geotextile reinforcement with an estimated completion time of 3 - 3.5 months.

CONCLUSIONS

1. Rate of Settlement Sta 193+025 - Sta 193+400 for all variations of embankment height and combination of soil + foam mortar embankment in year 2 to year 3 (>2 cm / year), year 2 to year 12 (>10 cm / 10 years), year 5 to year 6 requirements have not met (>2 cm / year), while year 5 to year 15 have met
2. PVDs were planned with an installation spacing of 1 m in a 7 m long triangular installation pattern to meet the requirements.
3. Reinforcement of geotextile and pile with variation of embankment height 4, 6, 8, 10 as follows:

Soil Embankment		Reinforcement with Geotexstil			Reinforcement with minipile		
Embankment final H (m)	H mortar foam (m)	T ultimate (kN/m)	Layer	Length	Size (cmxcm)	Pile/m	Length
4.00	-	200.00	1.00	55.90	25 x 25	3.00	28.00
6.00	-	200.00	3.00	190.20	25 x 25	5.00	47.00
8.00	-	200.00	6.00	423.90	25 x 25	10.00	140.00
10.00	-	200.00	14.00	1,073.10	25 x 25	17.00	267.00
4.00	1.00	200.00	1.00	51.90	25 x 25	1.00	10.00
6.00	1.50	200.00	1.00	57.90	25 x 25	4.00	38.00
8.00	2.00	200.00	3.00	190.20	25 x 25	6.00	84.00
10.00	2.50	200.00	6.00	411.90	25 x 25	11.00	173.00
4.00	2.00	200.00	-	-	25 x 25	-	-
6.00	3.00	200.00	-	-	25 x 25	-	-
8.00	4.00	200.00	-	-	25 x 25	-	-
10.00	5.00	200.00	2.00	119.30	25 x 25	3.00	48.00
4.00	3.00	200.00	-	-	25 x 25	-	-
6.00	4.50	200.00	-	-	25 x 25	-	-
8.00	6.00	200.00	-	-	25 x 25	-	-
10.00	7.50	200.00	-	-	25 x 25	-	-

4. The most cost-effective combination is the geotextile-reinforced soil embankment and the combination of soil embankment with 25% thick foam mortar. Each of these replacement structures provides savings of Rp 40,762,857,362.39 (without foam mortar) and Rp 12,173,929,687.39 (with 25% thick foam mortar).
5. The most effective combination in terms of implementation time is the replacement of the slab on pile structure with soil embankment alone or a combination of soil embankment + 25% foam mortar using geotextile reinforcement with an estimated completion time of 3 - 3.5 months.

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