Effect of Embankment Construction Pace on Slope Stability Wih Varied Heights on Organic Soft Soil in the Sicincin-Padang Toll Road Sta 10+250-10+400

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ABSTRAK

On the Sicincin-Padang toll road section there are several geotechnical problems, one of which is that at the Sta 10+250-10+400 is dominated by an organic soil. In the implementation of a 4.0 meter high embankment there are cracks appeared on the left side of embankment toe. Based on the evaluation results of monitoring geotechnical instruments in the field, the cracks that occur can be caused by the bearing capacity failure or due to the implementation stages of embankment construction is too fast. The method used in this research is to use finite element method by numerical simulation using Plaxis 2D program to determine the stability of embankment slope stability acording to the stages of implementation in the field and by modeling a staged construction, where the speed of embankment construction depends on the thickness of the embankment layer used, which is 15 cm to 25 cm until the design height is reached and the consolidation time is 1 day to 14 days for each additional 1 meter of embankment height. The porpose of this study is to determine the stages of implementation that are safe and compliant with the design criteria requrements.

From the modeling results the existing embankment construction in the field has a safety factor value of SF=1.156. In this research, variations in the construction stages that have been modeled were obtained that are safe and meet the design criteria at the location under review are; at Sta 10+250 with using 25 cm thickness fill layer and 14 days consolidation time, Sta 10+350 with a 15 cm thickness fill layer and 7 days consolidation time, Sta 10+400 with a 25 cm thickness fill layer and 5 days consolidation time. There are differences in the effective time at each of the locations reviewed, this is due to differences in geometric embankment conditions at each location. From the results of modeling analysis, it also found that by reducing the thickness of the embankment fill layer and increasing the consolidation time, the value of the safety number will increase, the amount of settlement will increase, the amount of lateral movement will decrease and the excess pore water pressure will decrease.

Keywords : Embankment stability, stage construction, settlement, organic soil, Plaxis 2D

INTRODUCTION

The Sicincin-Padang Toll Road with a length of 36.6 km is part of the Trans Sumatra Toll Road Infrastructure which is one of the National Strategic Projects and is a government program in order to accelerate regional development on the island of Sumatra (**Figure 1**). According to Suprayitno and Soemitro (2020), The most important function of infrastructure is divided into two: the first is to serve users in the region and the second is to produce something for the region.

Figure 1. Locaion of Sicincin-Padang Toll Road in Padang, West Sumatera

This research was conducted at Sta 10+250-10+400, where the location was embankment work with improvements made using the surcharge preloading method combined with PVD (Prefabricated Vertical Drain) shown in **Figure 2**. From the soil investigation data, it was found that silty clay at a depth of 1-2 meters with an N-SPT value of 3, organic soil at a depth of 2-4 meters with an N-SPT value of 4, silty sand clay at a depth of 4-8 meters with an N-SPT values of 4 to 5, organic soil at a depth of 8-14 meters with an N-SPT values of 5 to 7, silty clay sand at a depth of 14-30 with an N-SPT values of 36 to 60.

During the embankment work implementation process, when the embankment stage had reached a height of 4 m, a crack occurred at STA 10+275-10+375 as shown in **Figure 3**.

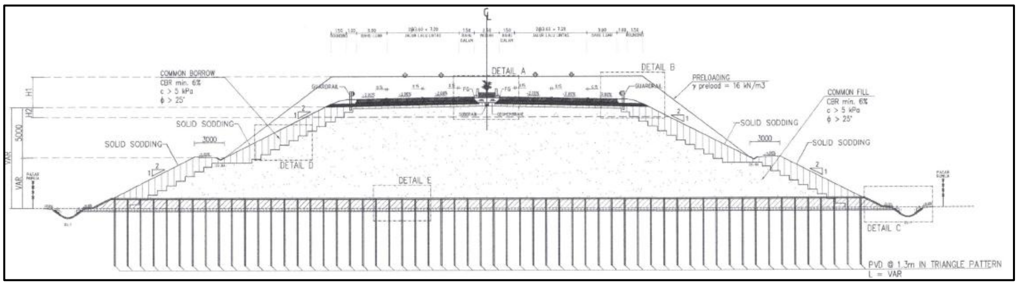


Figure 2. Cross Section STA 10+250-10+400

Figure 3. Cracks in the embankment toe STA 10+275-10+375 Line A (Sicincin-Padang Toll Road Project Team. Padang, 2023)

According to Manudianto, et al (2023), problems that usually arise in the contruction of roads on soft or organic soil include long and large settlements and road embankment slides. The monitoring results of the Settlement Plate STA 10+350 in **Figure 4.** show a large settlement decrease accompanied by a fairly rapid increase in embankment at the beginning of the graph until the occurrence of cracks in the field.

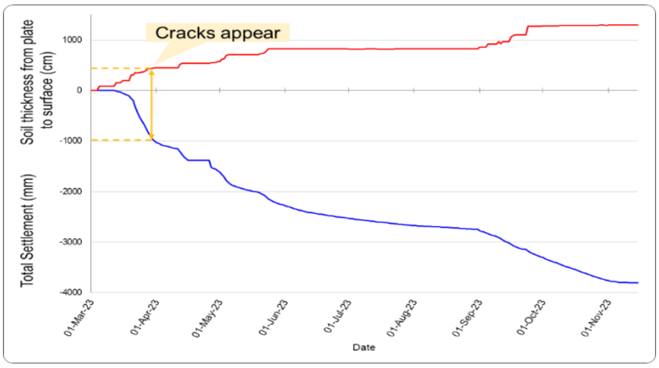


Figure 4. Settlement Plate Sta 10+350 Center Line
(Sicincin-Padang Toll Road Project Team. Padang, 2023)

A study was conducted on embankment construction collapse at an embankment height of 12.3 meters on the border road of Canada-US, New Brunswick, Canada. The failure that occurred in the field was re-modeled in a numerical model using 2D plaxis, the study was conducted to determine the effect of construction speed on the performance of embankment during and after construction. From the modeling results that the design height can be achieved if the embankment constructed with the thickness of the embankment fill layer used to achieve the design height of 0,6 m and the consolidation time of 32 days after the addition of each fill layer. Based on the results of the study, it known that the increase in consolidation time after addition of each embankment layer will increase the stability of the embankment, Badarinath & El Naggar (2021).

Based on this description, it is necessary to analyze the stages of implementation that have been carried out in the field are safe against the possibility of landslides due to the condition of the subgrade which is a soft organic soil with a high water content. As well as research on the effect of the stages of work implementation on variations in embankment height on embankment stability using Plaxis 2D software.

LITERATURE REVIEW

Soil is a material consisting of solid mineral aggregates or grains that are not bound to each other from the weathering of organic matter accompanied by liquids and gases, Braja M. Das (1993). Soil classifications place soils into 3 groups, coarse-grained soils, fine-grained soils and organic soils.

Terzaghi and Peck (1967) classified the consistency of soil layers based on standard penetration values (SPT) of the soil. Very soft soil has an SPT value of < 2, soft soil between 2-4, medium soil between 4-8, stiff between 8-15, very stiff between 8-15 and hard > 30.

Organic Soil

Organic soil is classified based on its organic content. Based on the organic content range, soils with an organic content of more than 25% to 75% are classifed organic soils. Organic soils with organic contents greater than 75 % are known as peat (Huat 2004). In ASTM D4427-92 (1992), peat soils are classified based on fiber content, ash content, absorbency and acidity.

1. Fiber content
   a. Fibric > 67% fibers
   b. Hemic between 33 – 67% fibers
   c. Sapric < 33% fibers
2. Ash content:
   a. Low <5% ash
   b. Medium between 5-15% ash
   c. High > 15% ash
3. Absorbency:
   a. Extremly absorbent – Water capacity(Wc)>1500%
   b. High absorbent – Wc 800-1500%
   c. Moderatly absorbent – Wc 300-800%
   d. Slighty absorebent – Wc <300%

Consolidation Settlement

The addition of load on a soil surface can cause the underlying soil layer to compress. Based on Terzaghi (1925), the calculation of compression on clay soil can be divided into 2 conditions, normally consolidated (NC) and overconsolidated (OC). NC soil or OC soil is determined based on its over condsoildated ratio (OCR) value. NC soil has an OCR = 1, and OC soil has an OCR > 1. Based on these conditions, in calculating settlement (Sc) in the field, the following equation can be used:

NC - soil:

$$Sc = \left[\frac{Hi}{1+e0}\left[Cc\ log\left(\frac{\sigma'0+\Delta\sigma}{\sigma'0}\right)\right]\right] \qquad \ldots(1)$$

OC - Soil:

1. If $\Delta\sigma + \sigma'o > \sigma'c$:

$$Sc = \left[\frac{Hi}{1+e0}\left[Cs\ log\left(\frac{\sigma'c}{\sigma'0}\right) + Cc\ log\left(\frac{\sigma'0+\Delta\sigma}{\sigma'c}\right)\right]\right] \qquad \ldots(2)$$

2. If $\Delta\sigma + \sigma'o < \sigma'c$:

$$Sc = \left[\frac{Hi}{1+e0}\left[Cs\ log\left(\frac{\sigma'0+\Delta\sigma}{\sigma'0}\right)\right]\right] \qquad \ldots(3)$$

Which:

H = Soil layer thickness
e_0 = Void ratio
Cc = Compression index
Cs = Swelling index
σo’ = Effective overburden pressure
σ’c = Preconsolidation pressure
Δσ = Increase of stress

The compression that occurs in the organic soil or peat layer lasts quite a long time because organic soil has a high water content and permeability and decomposition is still taking place at the time of compression. Gibson and Lo (1961) tried to establish a rheological model for soils subjected to compression in the one-dimensional direction (**Figure 5**).

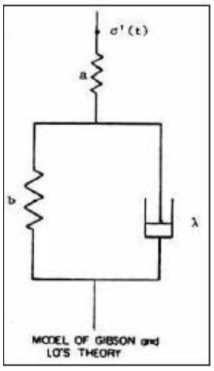


Figure 5. Rheological model for secondary compression (Gibson&Lo,1961)

The strain equation as a function of time proposed by Gibson & Lo(1961) is as follows:

$$\varepsilon\,(t) = \Delta\sigma\,(a + b\,(1 - e^{-\left(\frac{\lambda}{b}\right)t})$$ …(4)

Which:

t = time

λ/b = velocity factor of secondary compression

a = primary compression parameter

b = secondary compression parameter

Finite Element Method(FEM) using Plaxis 2D

Plaxis 2D is a aplication program with concept finite element method(FEM) used for analyzing displacement, deformation and slope stability of contruction in the geotechnical engineering, as well as behavioral simulations from a soil condition. In analyzing using PLAXIS 2D, the steps that must be taken are determining the geometry model, material model, determining model parameters and performing calculations. Soil modeling in PLAXIS 2D is divided into several models such as Mohr Coulomb, Hardening Soil and Soft Soil.

Susila and Apoji 2012 have conducted research on peat behavior in Bereng Bengkel, Central Kalimantan with numerical analysis based on FEM verified by settlement occurred in the field. Based on the research results using model Mohr Coloumb and Hardening by considering the properties of soil being modeled, it can produce fairly suitable deformation behavior shown in **Figure 6**.

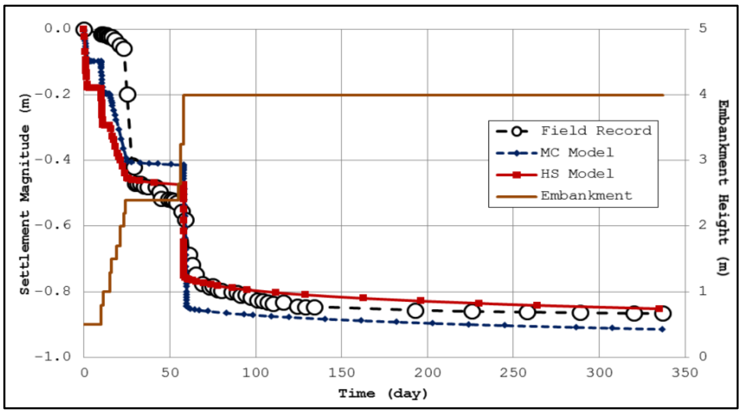


Figure 6. Settlement behavior of foundation soils (Susila & Apoji, 2012)

RESEARCH METHOD

The method used in this research is to use a finite element numerical simulation using the PLAXIS 2D program to determine the stability of the embankment slope according to the stages of implementation in the field and also by simulating the modeling of the phased embankment implementation with variations the thickness of the embankment layer used as thick as 15 cm, 20 cm, and 25 cm and variations in consolidation time of 1 day, 3 days, 5 days, 7 days and 14 days for each additional 1 meter embankment height. Modeling was carried out at 3 location points namely Sta 10+250, Sta 10+350 and Sta 10+400 with the final height of the embankment varying from 4.5-6.5 meters. This study aims to determine the stages of implementation that are safe and in accordance with the requirements of the design criteria. The data used is the secondary data which is the result of field soil data investigation. To complete and confirm the suitability of the secondary data required in conducting research, primary data was also collected. Primary data is the results of testing soil samples taken at the research location.

DATA COLLCETION

Soil Investigation

Based on the secondary data of Standard Penetration Test (SPT test) and laboratorium test at Sta 10+369, the subsoil layer parameters are obtained as shown in the **Table 1**.

Table 1. Soil Parameter at Sta 10+369 and Fill

Layer	Depth (m)	Type of Soil	N-SPT	γsat kN/m^3	C kN/m^2	Ø (^{o})	e0	Cc	Cs	Consistency
1	0-2	Silty clay	3	15,39	24,14	17,21	2,23	0,622	0,094	Soft
2	2-4	Organic soil	4	10,88	15,66	16,37	7,14	-	-	Soft
3	4-8	Silty clay	5-6	13,08	16,42	21,45	1,96	0,792	0,11	Medium
4	8-14	Organic soil	5-7	10,61	15,66	16,37	5,92	-	-	Medium
5	14-20	Silty sand	39-38	15,78	53,04	34,29	1,16	-	-	Hard
6	20-30	Silty sand	46-60	16,50	36,22	44,59	0,89	-	-	Hard
		Fill		18,50	10	35	-	-	-	-

The sample of organic soil layers ared tested in the laboratory to determine their classification and parameters based on ASTM D4427-92.The test results can be seen in **Table 2**.

Table 2. ASTM D4427-92 Soil Classification Result

No	Parameter	Result	Classification
1	Organic Content	73,28%	Organic soil (25-75%)
2	Ash Content	26,72%	High Ash (>15%)
3	Fiber Content	74,92%	Fibric (>67%)
4	Water Content	468,14%	Moderately absorbent (300-800%)

Back Analysis

Back analysis is carried out on the actual conditions of work implementation in the field with using Plaxis 2D. Location modeled in the back analysis at Sta 10+350. The model was created from the cross section of the soil profile in **Fig. 2**. The embankment construction satges were modeled according to the embankment conditions in the field shown in the **Figure 7**. In this research, the soil models used in Plaxis 2D modelling are the Mohr coloumb (MC), soft soil (SS) and hardening soil (HS). Soil parameters input in Plaxis 2D based on **Table 1** with additional parameters in **Table 3**.

Table 3. Parameter Input in Plaxis 2D

Layer	Depth (m)	Type of Soil	Model Material			Poisson ratio (v)	E	Lambda (λ)	Kappa (κ)	kx	ky
			I	II	III						
1	0-2	Silty clay	MC	SS	SS	0,4	3000	-	-	0,000864	0,000864
2	2-4	Organic soil	MC	SS	SS	0,4	300	0,223	0,039	0,0864	0,0864
3	4-8	Silty clay	MC	SS	SS	0,4	5865	-	-	0,000864	0,000864
4	8-14	Organic soil	MC	SS	SS	0,4	300	0,146	0,035	0,0864	0,0864
5	14-20	Silty sand	MC	MC	HS	0,2	50000	-	-	0,00864	0,00864
6	20-30	Silty sand	MC	MC	HS	0,2	69000	-	-	0,00864	0,00864
		Fill	MC	MC	HS	0,2	10000	-	-	0,0864	0,0864

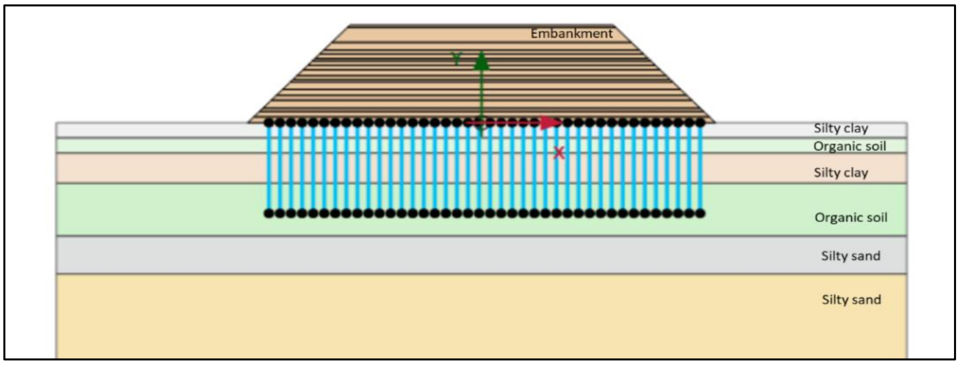


Figure 7. Embankment modelled in PLAXIS 2D

Stability of embankment was carried out using Plaxis 2D, with the results shown in the Table 4.

Table 4. Plaxis modeling results

No	Description	Model I	Model II	Model III	Settlement Plate
1	Safety Factor	1,156	1,166	1,185	-
2	Deformation (m)	4,028	5,264	5,259	3,81
3	Lateral Displacement (m)	1,609	1,513	1,586	-

Based on the output results of Plaxis 2D modeling with several material model variations, the safety number values are obtained successively 1.156, 1.166 and 1.185 where this shows that the stability of the embankment does not meet the requirements of the toll road safety factors, SF < 1.35 (SNI 8460: 2017). The Mohr Coulomb modeling variation produces a deformation that is quite close to the condition of the deformation in the field can be seen in the **Figure 8**. So based on these conditions, modeling with the Mohr Coloumb material model was selected for the next analysis.

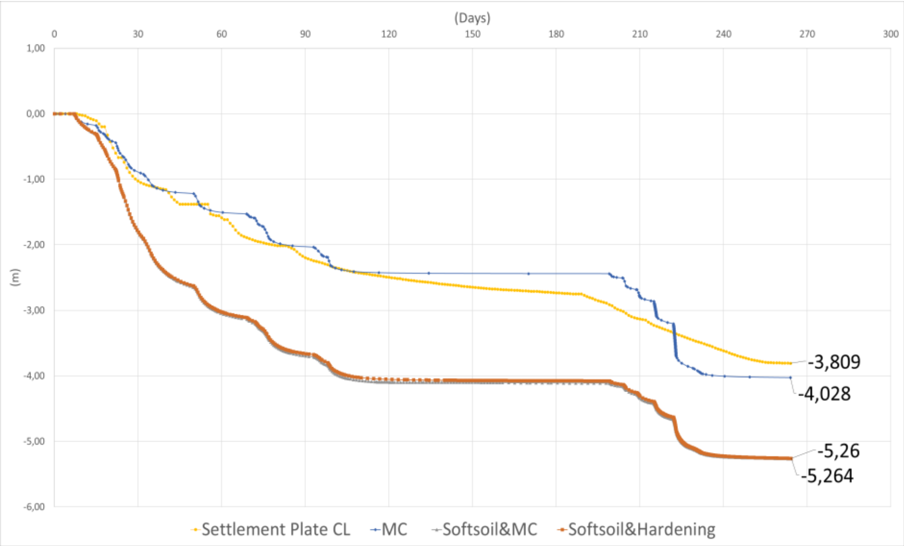


Figure 8. comparison of soil settlement in the field with plaxis modeling results

RESEARCH ANALYSIS

Calculation of Settlement, Hinitial and Hfinal

Planning the embankment height is done by calculating the subgrade settlement due to the embankment load. The method used is by assuming several implementation heights so as to obtain the height of the embankment at the time of physical implementation in a graphical way, namely based on the relationship graph between Settlement vs Hfinal and Hinitial vs Hfinal from the calculation of each embankment load assumption. The calculation of settlement was carried out at 3 locations with varying embankment heights, the calculation of settlement for inorganic soil using Terzaghi's theory in equations 1 to 3 and for organic soil using the Gibson and Lo model in equation 4 with the results as in **Table 5**.

Table 5. Recapitulation of H Initial, H final and Sc Results

Location	Hfinal (m)	Settlement (m)	Hinitial (m)
Sta 10+250	4,5	2,3	6,80
Sta 10+350	6	2,72	8,72
Sta 10+400	6,5	2,86	9,36

Analysis Based on Variations Construction Stages using Plaxis 2D

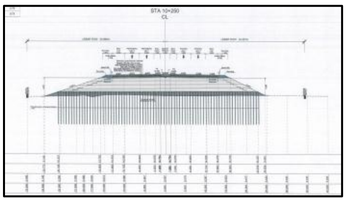
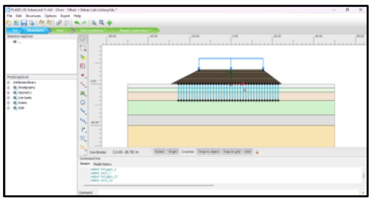
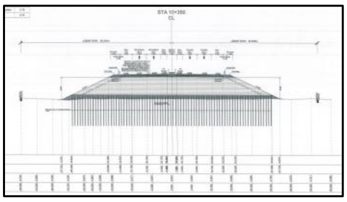
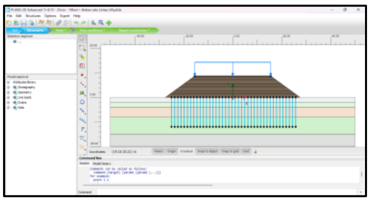
After obtaining the high plan embankment from the results of the previous calculation, modeling with Plaxis 2D was then carried out at the three locations under review. Modeling was performed by varying the thickness of the embankment layer used to achieve the planned embankment height and providing variations in consolidation time. The thickness of the embankment layer used, which is 15 cm to 25 cm until the design height is reached and the consolidation time is 1 day to 14 days for each additional 1 meter of embankment height. The purpose of varying the stages of embankment work implementation is to determine the effect of the stages of embankment work implementation built on organic soft soil from the aspects of embankment stability, settlement, lateral movement and excess pore water pressure. The best combination was selected for the fulfillment of the safety number and the achievement of 90% consolidation degree as required by SNI 8460: 2017. The variations of the modeled stages of embankment work implementation are shown in the **Table 6**.

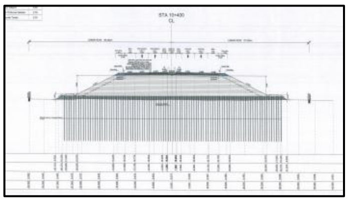
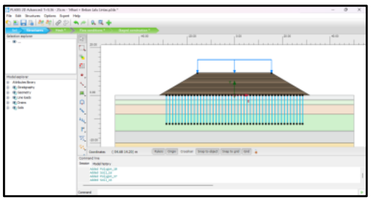
Table 6. Modeling with Variations in Height, Layer Thickness and Consolidation Time

Location	Hfinal (m)	Settlement (m)	Hinitial (m)	Layer thickness (cm)	Consolidation time period (Days)
Sta 10+250	4,5	2,3	6,80	15, 20, 25	1,3,5,7 and 14
Sta 10+350	6	2,72	8,72	15, 20, 25	1,3,5,7 and 14
Sta 10+400	6,5	2,86	9,36	15, 20, 25	1,3,5,7 and 14

Modeling in Plaxis is carried out based on existing geometrics on the asbuilt drawing at Sta 10+250, Sta 10+350 and 10+400 can show on **Table 7**.

Table 8. Modeling of embankment geometry conditions

Location	Cross Section	Plaxis 2D Model	Description
Sta 10+250			Hinitial = 6,8 m Hfinal = 4,5 m Slope = 1:3&1:2 PVD depth=8m
Sta 10+350			Hinitial= 8,72 m Hfinal = 6 m Slope = 1:2 PVD depth =12m

Sta 10+400			Hinitial= 9,36 m Hfinal = 6,5 m Slope = 1:3 PVD depth =12m

RESULT

Plaxis 2D calculation results are presented in the graph in the **Figure 9-11**. From the graph, the parameters considered, namely the value of safety factor, settlement, lateral displacement and excess pore water pressure are plotted on the y-axis against the consolidation period in days on the x-axis.

<u>Factor of safety</u>

Based on the results of Plaxis 2D modeling, there is an increase in the number of safety values for the addition of the consolidation duration under review by an average of 2.18%. The increase in the number of safety values for each reduction in the thickness of the embankment layer averaged 0.97%. **The figure 9** shows that the increase in consolidation time from 1 day to 14 days and the decrease in the thickness of the embankment layer are accompanied by an increase in the safety number value resulting in an increase in embankment stability.

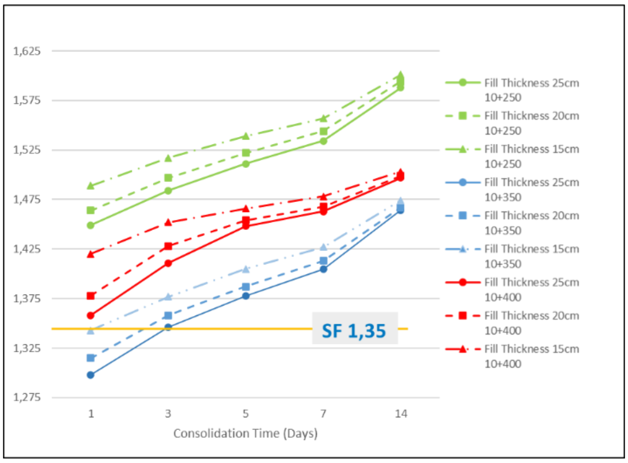


Figure 9. Factor of safety plotted against consolidation time

<u>Settlement</u>

Figure 10. shows that at the same review location point with increasing consolidation time and decreasing the thickness of embankment fill layer, the settlement that occurs will increase. This will cause the soil to increase in strength as evidenced by the increase in the amount of settlement accompanied by an increase in the value of the safety number. The amount of settlement that occurred increased with the addition of the consolidation duration under review by an average of 1.29%. The increase in the amount of settlement at each reduction in embankment layer thickness averaged 0.58%.

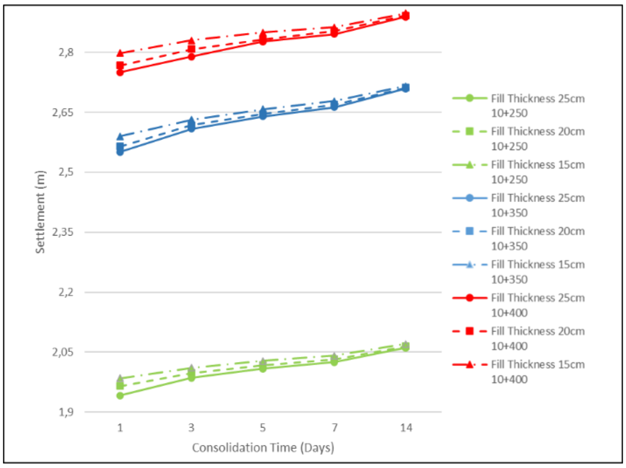


Figure 10. Settlement plotted against consolidation time

Lateral Displacement

From the graph shown in the **Figure 11.** that the lateral displacement decreases with increasing consolidation time and with decreasing the thickness of embankment fill layer. The lateral displacement that occurred decreased with the addition of the consolidation duration under review by an average of 3.39%. The decrease in lateral movement at each reduction in embankment layer thickness averaged 1.51%.

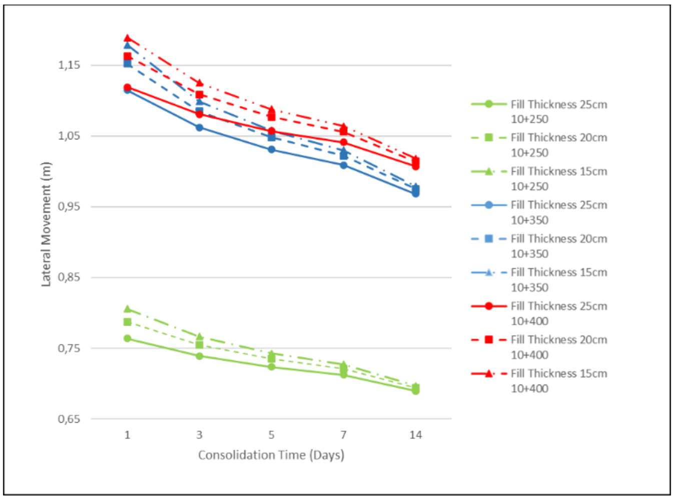


Figure 11. Lateral movement plotted against consolidation time

Excess Pore Water Preasure

The **Figure 12.** shows that the excess pore water pressure decreases as the consolidation time increases and the thickness of the embankment layer decreases. An excessive increase in pore water pressure will have an impact on reducing embankment stability and in certain cases can cause landslides. The excess pore water pressure that occurs decreases with the addition of the consolidation duration under review by an average of 16.23%. The decrease in pore water pressure at each reduction in embankment thickness averaged 6.25%.

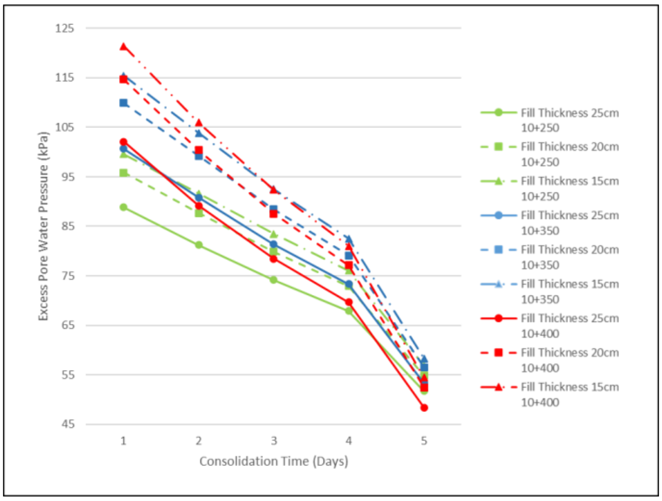


Figure 12. Lateral movement plotted against consolidation time

<u>Determining the Most Effective Stages of Implementation</u>

Based on the results of the 2D plaxis analysis, then a recapitulation table is made to determine the best stage of work implementation and meet the requirements of SNI 8460: 2017 (**Tabel 7**).

Table 7. Recapitulation of the results of safety factors value and settlement

Sta	Thickness fill layer (cm)	Consolidation Time (Days)	Construction Time Total (Days)	SF	Settlement (m)	Total Settlemen (m)	% Consolidation	SF > 1,35	90% Consolidation	Effective Time Constriction
		1	34	1,45	1,94	2,38	81,5%	√	X	
		3	48	1,48	1,99	2,36	84,2%	√	X	
	25	5	62	1,51	2,01	2,34	85,7%	√	X	
		7	76	1,53	2,03	2,33	86,8%	√	X	
		14	125	1,59	2,06	2,30	90%	√	√	**OK**
		1	41	1,46	1,97	2,37	82,8%	√	X	
		3	55	1,50	2,00	2,35	85,0%	√	X	
10+250	20	5	69	1,52	2,02	2,34	86,3%	√	X	
		7	83	1,54	2,03	2,33	87,3%	√	X	
		14	132	1,59	2,07	2,30	90%	√	√	
		1	53	1,49	1,99	2,36	84,1%	√	X	
		3	67	1,52	2,01	2,34	85,9%	√	X	
	15	5	81	1,54	2,03	2,33	87,0%	√	X	
		7	95	1,56	2,04	2,32	87,8%	√	X	
		14	144	1,60	2,07	2,30	90,0%	√	√	
		1	44	1,30	2,55	3,07	83,15%	X	X	
		3	62	1,35	2,61	3,03	86,25%	X	X	
	25	5	80	1,38	2,64	3,00	87,91%	√	X	
		7	98	1,41	2,66	2,99	89,12%	√	X	
		14	161	1,46	2,71	2,96	91,46%	√	√	
		1	53	1,32	2,57	3,05	84,10%	X	X	
		3	71	1,36	2,62	3,02	86,75%	√	X	
10+350	20	5	89	1,39	2,65	3,00	88,26%	√	X	
		7	107	1,41	2,67	2,99	89,38%	√	X	
		14	170	1,47	2,71	2,96	91,62%	√	√	
		1	71	1,34	2,59	3,04	85,34%	X	X	
		3	89	1,38	2,63	3,01	87,53%	√	X	
	15	5	107	1,41	2,66	2,99	88,87%	√	X	
		7	125	1,43	2,68	2,98	90%	√	√	**OK**
		14	188	1,47	2,72	2,96	91,82%	√	√	
		1	47	1,36	2,75	3,22	85,40%	√	X	
		3	67	1,41	2,79	3,18	87,76%	√	X	
	25	5	87	1,45	2,83	3,16	90%	√	√	**OK**
		7	107	1,46	2,85	3,14	90,64%	√	√	
		14	177	1,50	2,89	3,12	92,66%	√	√	
		1	56	1,38	2,77	3,20	86,44%	√	X	
		3	76	1,43	2,81	3,17	88,58%	√	X	
10+400	20	5	96	1,45	2,83	3,15	90%	√	√	
		7	116	1,47	2,85	3,14	90,83%	√	√	
		14	186	1,50	2,89	3,12	92,78%	√	√	
		1	75	1,42	2,80	3,18	88,02%	√	X	
		3	95	1,45	2,83	3,16	90%	√	√	
	15	5	115	1,47	2,85	3,14	90,65%	√	√	
		7	135	1,48	2,86	3,13	91,35%	√	√	
		14	205	1,50	2,90	3,12	93,03%	√	√	

Based on **Table 7**, the implementation duration at Sta 10+250 using 25 cm thickness embankment and 14 days consolidation time and total time construction is 125 days, Sta 10+350 with 15 cm thickness fill layer embankment and 7 days consolidation time and total time construction is 125 days, Sta 10+400 with 25 cm thickness fill layer embankment and 5 days consolidation time and total time construction is 87 days. There are differences in the effective time at each of the locations reviewed, this is due to differences in geometric conditions of different soil embankments at each location.

CONCLUSION

According to the result data analysis and modeling analysis that has been carried out, the following conclusions were reached:

1. Based on results of laboratory testing, the soil from the Sicincin-Padang toll road project, West Sumatra studied is included in the category of organic soil with organic content of 73.28% and ash content of 26.72% including high ash with fibric type organic soil based on fiber content, and water content of 468.149% including moderately absorbent based on its water absorption capacity.
2. Back Analysis with finite element method using Plaxis 2D on the initial condition (according to the field stage) which is closest to the field condition is the Mohr Coloumb Material Model. Existing embankment construction in the field has a safety factor value of SF=1.156.
3. From the results of modeling analysis, it was found that by reducing the thickness of the embankment fill layer and increasing the consolidation time, the value of the safety number will increase, the amount of settlement will increase, the amount of lateral movement will decrease and the excess pore water pressure will decrease.
4. The stages of implementation of embankment work built on soft organic soil were obtained at Sta 10+250 with using 25 cm thickness fill layer and 14 days consolidation time, Sta 10+350 with a 15 cm thickness fill layer and 7 days consolidation time, Sta 10+400 with a 25 cm thickness fill layer and 5 days consolidation time.

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