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Parametric Study of Embankment Stability And Geotextile Reinforcement On Soft Soil

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ABSTRACT

The Semarang - Demak Toll Road Construction Project Section 1B has a length of 6.736 km, starting from STA. 1+578 to 8+314. There is a zone that has the highest embankment, namely zone N at STA. 4+200 to 4+600. However, based on soil investigation data, it is known that the Semarang - Demak Toll Road Construction Project Section 1B has a very thick compressible layer, which reaches a depth of 50 m. This makes the Semarang - Demak Toll Road Construction Project Section 1B face various challenges of construction on soft soil.

The purpose of this research is to determine the Safety Factor (SF) value and the appropriate configuration of geotextile reinforcement requirements in an embankment with variations in compressible layer thickness, embankment height and embankment slope, especially in the case study of zone N with STA. 4+200 - 4+600. This research will be processed using the Limit Equilibrium Method (LEM) with the GEO5 auxiliary program.

Based on the results in this study, it is known that the variation of compressible layer thickness does not have a significant influence on the calculation of the Safety Factor and geotextile reinforcement configuration. However, the variation of embankment height leads to the conclusion that the higher the embankment, the lower the Safety Factor. The variation of embankment slope also concluded that the steeper the embankment, the lower the Safety Factor. In addition, it is also known that the higher the embankment, the higher the number of geotextile reinforcement requirements and the steeper the embankment, the higher the number of geotextile reinforcement requirements. After making a nomogram of the relationship between these variations and implementing it on the case study, it is known that the embankment in Zone N of the Semarang - Demak Toll Road Construction Project Section 1B has a Safety Factor value of 0.42 and requires 33 layers of geotextile reinforcement with a tensile strength of 200 kN/m, a spacing of 25 cm between layers, and a Reduction Factor value of 1.65.

Keywords : Soft Soil, Embankment Stability, Safety Factor, Nomograph

INTRODUCTION

In the Atlas of Indonesian Soft Soils Distribution (2019), it is known that Indonesia generally has an even distribution of soft soils, starting from Sumatra Island to Papua Island. Central Java Province is included in the provinces with a fairly wide distribution of soft soil and has a high level of compressibility. The cities/districts in Central Java Province that contribute the softest soil include Kendal Regency, Brebes Regency, Tegal Regency, Pekalongan City, and Semarang City. Following up on this, it will be a big challenge when carrying out the construction of a civil building in the area. One of the development projects being built by the government through the Ministry of Public Works is the Semarang - Demak Toll Road Construction Project Section 1B.

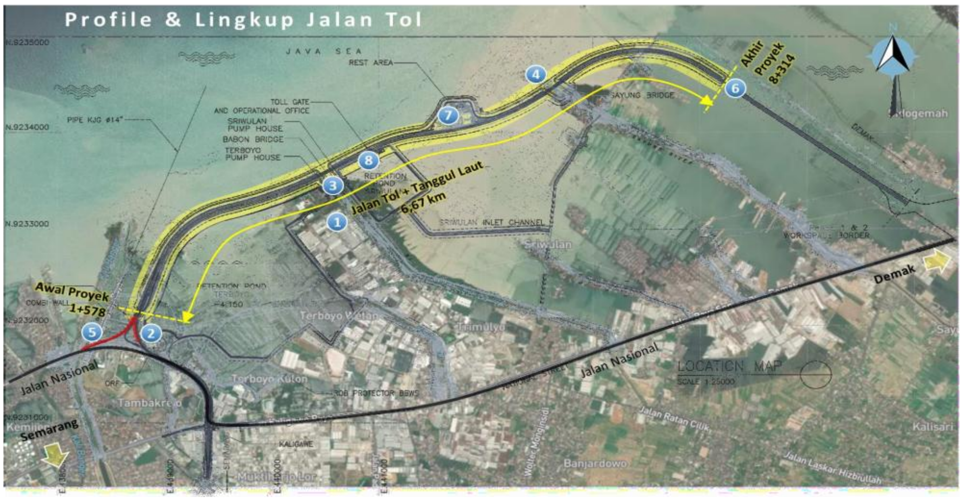

Figure 1. Location Map of Semarang - Demak Toll Road Construction Project Section 1B
Source : BBPJN Central Java – Yogyakarta, 2024

The Semarang - Demak Toll Road Construction Project Section 1B will connect Semarang City with Demak Regency. This project has a length of 6.736 km, starting from STA. 1+578 to STA. 8+314, as shown in Figure 1. The construction work is located 3 km north of the Semarang - Demak National Road. This toll road is expected to be useful for stemming tidal floods as a polder system, which is a method of controlling tidal floods by building sea walls equipped with retention ponds, pumps, sluice gates and regional drainage systems that are an integral part of water management management. In other words, the Semarang - Demak Section 1B Toll Road Development Project is a strategic project to be implemented, not only useful for inter-regional mobilization, but also a vital infrastructure to be able to stem tidal floods.

In anticipation of soil problems in the project, it is necessary to conduct a soil investigation as a preventive measure of problems that may occur. The soil investigation on the Semarang - Demak Toll Road Construction Project Section 1B amounted to 115 boring points, 28 CPT investigation points, and 17 CPTu investigation points. Based on the results of the soil examination, it was found that the Semarang - Demak Toll Road Construction Project Section 1B is a project that has a very thick compressible layer, which reaches a depth of 50 m. The soil classification in the compressible layer varies. The soil classification of the soft soil layer varies, including very soft/silty clay and medium stiff clay. In this project, there is one zone that has the highest embankment among other zone locations, namely zone N located at STA. 4+200 - 4+600. This zone is prone to problems because in addition to having a high embankment layer, this zone also has a soft soil layer that is quite deep and will have an impact on the low bearing capacity of the soil and relatively large settlement. Such problems should be detected in advance and corrected. If not, the result can be landslides on the embankment and damage the pavement above the embankment due to the difference in settlement. An illustrative picture of the soft soil conditions that exist in the work of the Semarang - Demak Toll Road Construction Project Section 1B can be seen in Figure 2 below.

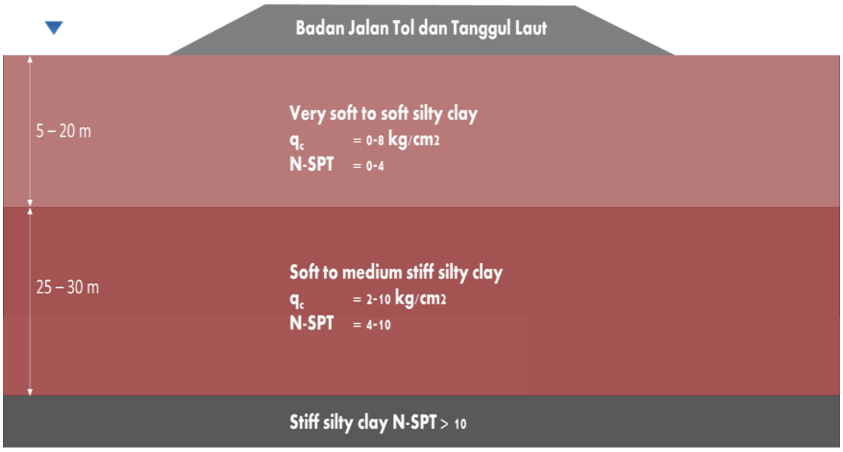

Figure 2. Geotechnical Issues in Semarang - Demak Toll Road Construction Project Section 1B
Source : BBPJN Central Java – Yogyakarta, 2024

Soft soils are soils that if not recognized and investigated carefully can cause intolerable long-term instability and settlement problems; they have low shear strength and high compressibility (Ministry of PUPR, 2002). Embankments on top of soft soils inevitably have slope stability problems that must be considered in a building construction. There are factors that determine the stability of embankments on soft ground surfaces, namely the height and slope of the embankment. Fahrani, F. in his article entitled "Analysis of the Effect of Embankment Height on Slope Stability" in 2016 states that the results of the analysis of the experiments carried out by varying the height of the embankment are known to increase the height of the embankment resulting in a decrease in the slope safety number which indicates a decrease in soil stability. The percentage decrease in the slope Safety Factor every 1 m is decreasing. In the experiment, the percentage decrease up to a height of 5 m decreased to 2.47% against a height of 4 m. Thus, the determination of embankment height is important to investigate the stability of an embankment.

One method of reinforcing embankment soil above soft soil is by applying a layer of geotextile. Geotextiles are sheet materials made from polymeric textile materials, which are water-repellent, which are divided into*non-woven* geotextiles and knitted or*woven* geotextiles, which are commonly used when in contact with soil/rock or other geotechnical materials (Pratama, R. T., et al, 2021). Geotextiles are one of the alternatives that are often used because their application is easy and quick to do in the field. Thus, the reinforcement method with a geotextile layer is considered capable of overcoming soft soil problems, both those in the Semarang - Demak Toll Road Construction Project Section 1b, as well as other projects.

Based on the problems previously described, it is necessary to analyze the stability and amount of geotextile reinforcement on the embankment with variations in embankment height, slope and *compressible layer* thickness. The output of this analysis is a nomogram that will describe the correlation between the value of the Safety Factor (SF) and the amount of geotextile reinforcement with variations in embankment height, slope and variations in *compressible layer* thickness. By finding the Safety Factor value and the amount of geotextile reinforcement that is safe from landslide, further analysis can be conducted on zone N which is the case study location in this research. It is intended to determine whether zone N is safe from landslides with its thickness and soft soil parameters. Thus, the stability analysis and the amount of geotextile reinforcement on the embankment with variations in embankment height, slope and *compressible layer* thickness are very important to do, to determine the safety level of the embankment.

LITERATUR REVIEW

Soft Soil

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 3 below.

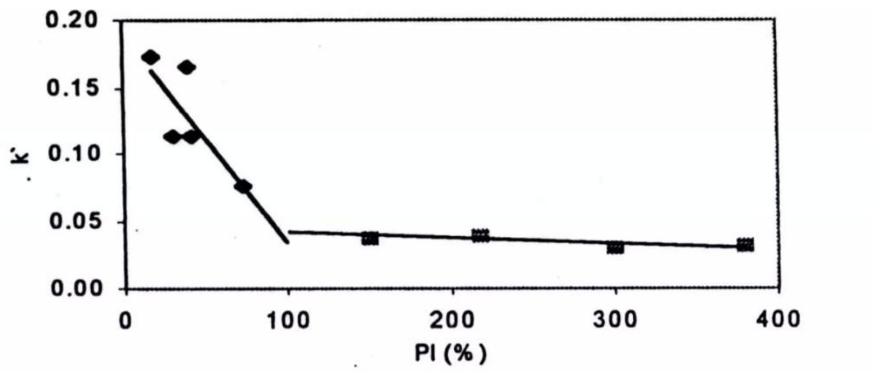

Figure 3. Correlation of Plasticity Index Values
Source : Ardana and Mochtar, 1999

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

- For Plasticity Index (PI) value < 100%

  $Cu\ (kg/cm^2) = 0.0737 + (0.1899 - 0.0016\ PI) \times \sigma'\ (kg/cm^2)$ …(1)

  $Cu\ (kPa) = 7.37 + (0.1899 - 0.0016\ PI) \times \sigma'\ (kPa)$ …(2)
- For the value of Plasticity Index (PI) > 100%

  $Cu\ (kg/cm^2) = 0.0737 + (0.0454 - 0.00004\ PI) \times \sigma'\ (kg/cm^2)$ …(3)

  $Cu\ (kPa) = 7.37 + (0.0454 - 0.00004\ PI) \times \sigma'\ (kPa)$ …(4)

where :
Cu = bearing capacity (kg/cm^2)
PI = soil plasticity index
σ' = stress occurring in the soil layer (kg/cm^2) or (kPa)

2. Internal Shear Angle

The internal shear angle or inner shear angle is the fracture angle that occurs when a material is subjected to a stress or force that exceeds its shear stress (Karlinasari et al, 2020). The internal shear angle is the angle formed from the relationship between normal stress and shear stress in a soil or rock material. If the higher the internal shear angle in a soil, the more resistant the material is to external stresses.

The internal shear angle parameter and the cohesion value of the soil can determine the resistance of the soil due to the stresses acting on the lateral pressure of the soil. This can be seen in Table 3.

Table 3a. Relationship between Internal Shear Angle and Soil Type

Soil Type	Plasticity Level	Inner Shear Angle
Silt	Low	35 – 37
Clayey silt	Medium	31 – 35

Table 3b. Relationship between Internal Shear Angle and Soil Type

Soil Type	Plasticity Level	Inner Shear Angle
Clay	High	< 31

Source : Bjerruan, 1980

Geotextile

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.

$$\text{Tijin} = \text{Tult}\left(\frac{1}{\text{FSID}+\text{FSCR}+1\text{FSCD}+\text{FSBD}}\right) \quad \ldots(5)$$

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
FS = global safety numbers

Table 4. 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

Safety Factor

The factor of safety can be defined as the factor by which the shear strength parameter can be reduced to bring the dam slope or foundation into a state of equilibrium. Safety factors used in conventional geotechnical practice are based on sound experience (Duncan, 2000). If it can be summarized, the following equation is used to find the value of the safety factor, which is as follows.

$$\text{Factor of Safety (FS)} = \frac{(\sum Retaining\ Force)}{(\sum \text{Pushing Force})} \quad ....(6)$$

There are several references that mention the value of the safety factor of an embankment. The following safety factor criteria according to Hoek (1991) are shown in Table 5.

Table 5. Safety Factor Criteria

Safety factor (SF)	Event
SF < 1	Collapse occurs
1 ≤ SF < 1,5	Critical condition (Not significant in design)
SF ≥ 1,5	Stable condition (design above critical value)

Source: Hoek, 1991

Asset Management of Embankments

In ISO 55000 an asset is defined as an item, thing or entity that has potential or actual value to an organization; value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities (ISO, 2018). Based on this definition, it is recognized that one category of assets is assets that consist of earth (soil and rock), or in other words, geotechnical assets, which describe man-made earth materials. Examples of geotechnical assets include retaining walls, embankments, slopes or artificial subgrade that contribute to the performance of the transportation system and are located within the boundary or right of way. Geotechnical assets also contribute to the performance of culverts, stormwater drainage systems and utilities that are often contained within such assets.

Embankment assets consist of embankments constructed of rock, soil, or other engineered materials that allow a highway, railroad, or other transportation facility to maintain its required design elevation above lower ground. The recommended embankment height of 10 feet is based on implementation experience for 240,000 geotechnical assets on roads and railways across the UK (NASEM, 2019). Therefore, it is necessary to maintain and maintain an asset, one of which is an embankment, so that it can work optimally and efficiently, for example by calculating the stability of an embankment.

RESEARCH METHOD

The method used in this research is to first look for secondary data needed in this research, such as the amount of geotextile reinforcement used, the tensile strength used in geotextiles, the height of the embankment at the case study location, the thickness of the soft soil layer in the field and so on. After knowing all the data needed, the next thing to do is to input all known data into the Geo5 auxiliary program with variations that become variables in this study. The variations of embankment height are 3 m, 6 m, 9 m, 12 m, and 15 m based on planning without considering certain conditions because in the field there are no restrictions that regulate the height of the embankment. In addition, the variation of compressible layer thickness is carried out in the range of 10 m - 40 m, namely 10 m, 20 m, 30 m, and 40 m. In addition, there is also a variation of embankment slope with a ratio of 1:1.5, 1:2, 1:2.5, and 1:3. After inputting the data, we will know the existing Safety factor so that we can calculate the amount of geotextile reinforcement needed to stabilize the embankment. After all is done, a nomogram of the relationship between all these variables will be made.

DATA COLLECTION

In this research, the soft soil used is in accordance with what is in the case study location, namely the Semarang - Demak Toll Road Construction Project Section 1B. The thickness of compressible soil will be one of the parameters used in the calculation of subgrade analysis which will then be calculated and used as input in the GEO5 auxiliary program. The following is the data used in this study.

Table 6a. Subgrade Data for Compressible Layer Thickness Variations up to 40 meters

Kedalaman	**Tebal Lapisan**	**z**	**e0**	**γsat**	**γsat**	**γ'**	**σ'**	**Cu Ardhana & Mochtar**	**Cu Ardhana & Mochtar**	**Konsist. Tanah**
(m)	**(m)**	**(m)**		**(t/m^3)**	**(kN/m^3)**	**(t/m^3)**	**(t/m^2)**	**(t/m^2)**	**kPa**	
1	1	0,5	2,261	1,491	14,618	0,491	0,245	0,770	7,550	*very soft*
2	1	1,5	2,240	1,494	14,650	0,494	0,741	0,836	8,200	*very soft*
3	1	2,5	2,218	1,497	14,682	0,497	1,243	0,903	8,860	*very soft*
4	1	3,5	2,197	1,500	14,715	0,500	1,752	0,972	9,528	*very soft*
5	1	4,5	2,176	1,504	14,748	0,504	2,267	1,041	10,205	*very soft*
6	1	5,5	2,154	1,507	14,781	0,507	2,790	1,111	10,891	*very soft*
7	1	6,5	2,133	1,511	14,815	0,511	3,320	1,182	11,587	*very soft*
8	1	7,5	2,111	1,514	14,849	0,514	3,857	1,253	12,292	*very soft*
9	1	8,5	2,090	1,518	14,884	0,518	4,401	1,326	13,007	*soft*
10	1	9,5	2,069	1,521	14,920	0,521	4,953	1,400	13,732	*soft*
11	1	10,5	2,047	1,525	14,955	0,525	5,513	1,475	14,467	*soft*
12	1	11,5	2,026	1,529	14,992	0,529	6,081	1,551	15,212	*soft*
13	1	12,5	2,005	1,533	15,029	0,533	6,656	1,628	15,968	*soft*
14	1	13,5	1,983	1,536	15,066	0,536	7,240	1,706	16,735	*soft*
15	1	14,5	1,962	1,540	15,104	0,540	7,833	1,786	17,513	*soft*
16	1	15,5	1,941	1,544	15,142	0,544	8,434	1,866	18,302	*soft*
17	1	16,5	1,919	1,548	15,182	0,548	9,043	1,948	19,102	*soft*
18	1	17,5	1,898	1,552	15,221	0,552	9,662	2,031	19,915	*soft*
19	1	18,5	1,877	1,556	15,261	0,556	10,290	2,115	20,740	*soft*
20	1	19,5	1,855	1,560	15,302	0,560	10,928	2,200	21,577	*soft*
21	1	20,5	1,834	1,565	15,344	0,565	11,574	2,287	22,426	*soft*
22	1	21,5	1,812	1,569	15,386	0,569	12,231	2,375	23,289	*soft*
23	1	22,5	1,791	1,573	15,428	0,573	12,898	2,464	24,164	*soft*
24	1	23,5	1,770	1,578	15,472	0,578	13,575	2,555	25,053	*medium*
25	1	24,5	1,748	1,582	15,516	0,582	14,263	2,647	25,956	*medium*
26	1	25,5	1,727	1,587	15,560	0,587	14,961	2,740	26,873	*medium*
27	1	26,5	1,706	1,591	15,606	0,591	15,671	2,835	27,805	*medium*
28	1	27,5	1,684	1,596	15,652	0,596	16,392	2,932	28,751	*medium*
29	1	28,5	1,663	1,601	15,699	0,601	17,124	3,030	29,713	*medium*
30	1	29,5	1,642	1,606	15,746	0,606	17,868	3,130	30,690	*medium*
31	1	30,5	1,620	1,611	15,795	0,611	18,624	3,231	31,683	*medium*
32	1	31,5	1,599	1,616	15,844	0,616	19,393	3,334	32,693	*medium*

Table 6b. Subgrade Data for Compressible Layer Thickness Variations up to 40 meters

Kedalaman	Tebal Lapisan	z	e0	γsat	γsat	γ'	σ'	Cu Ardhana & Mochtar	Cu Ardhana & Mochtar	Konsist. Tanah
(m)	(m)	(m)		(t/m^3)	(kN/m^3)	(t/m^3)	(t/m^2)	(t/m^2)	kPa	
33	1	32,5	1,578	1,621	15,894	0,621	20,174	3,438	33,719	*medium*
34	1	33,5	1,556	1,626	15,945	0,626	20,969	3,545	34,762	*medium*
35	1	34,5	1,535	1,631	15,997	0,631	21,777	3,653	35,823	*medium*
36	1	35,5	1,513	1,637	16,049	0,637	22,599	3,763	36,902	*medium*
37	1	36,5	1,492	1,642	16,103	0,642	23,434	3,875	37,999	*medium*
38	1	37,5	1,471	1,648	16,157	0,648	24,284	3,989	39,116	*medium*
39	1	38,5	1,449	1,653	16,213	0,653	25,149	4,105	40,251	*medium*
40	1	39,5	1,428	1,659	16,269	0,659	26,030	4,222	41,407	*medium*

Source : Processed by the Author

RESEARCH ANALYSIS

Initial Trial of Safety Factor (SF) Calculation and Geotextile Requirements

After obtaining all the data required for inputting the GEO5 auxiliary program, the next thing to do is the data input process. As an initial experiment, the input process is focused on variations in compressible layer thickness and variations in embankment height. As for the slope, it is adjusted to the slope of the existing embankment in the Semarang - Demak Toll Road Construction Project Section 1B, which is 1:2,5. With the data available in accordance with Table 6, the following Figure 4 is a simulation of the experiment to be carried out in the GEO5 auxiliary program.

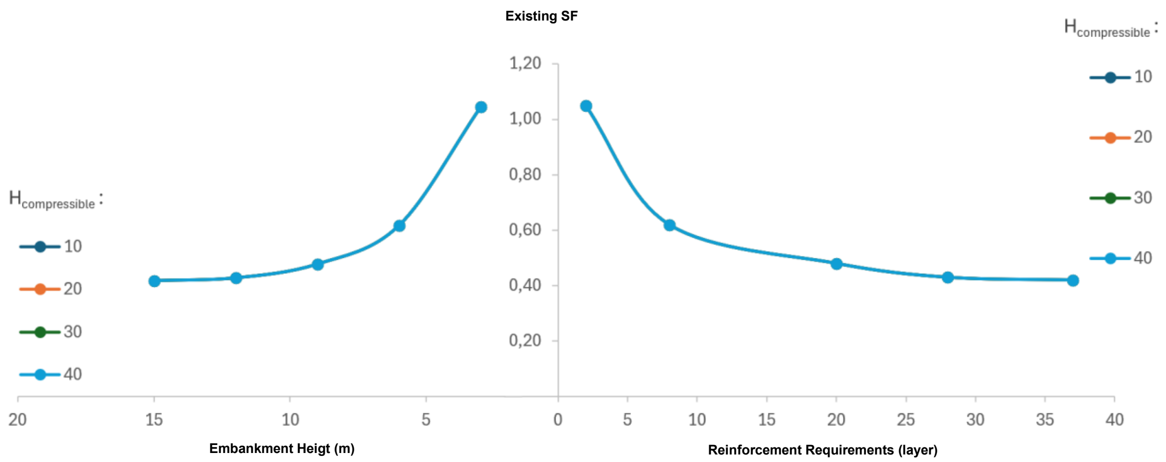

Figure 4. Relationship Graph of Embankment Height, Existing Safety Factor and Geotextile Requirement with Variation of Compressible Layer Thickness

Based on the results, it can be concluded that the variation of compressible layer thickness does not greatly affect the Safety Factor (SF) results and the calculation of geotextile reinforcement requirements. In other words, the Safety Factor (SF) value for each compressible layer thickness variation will remain the same in each height and slope variation of the embankment. This is because the resulting sliding plane of the compressible layer thickness variation is not much different for each embankment height variation, resulting in relatively the same retaining moment and driving moment and resulting in the same Safety Factor (SF) value and geotextile requirement.

Calculation of Safety Factor (SF) for All Variations Before Using Geotextile Reinforcement

In this section, the Safety Factor (SF) calculation will be carried out using the GEO5 auxiliary program by applying variations in the height and slope of the embankment and the thickness of the compressible layer in accordance with the research stages previously described. The resulting Safety Factor (SF) value is the Safety Factor (SF) value that has not been reinforced by any method, so it can be referred to as the existing Safety Factor (SF).

After all the results of the Safety Factor (SF) value are known, both from the slope of the embankment (slope) 1: 1.5, 1: 2, 1: 2.5, to 1; 3, a recapitulation of the results can be compiled comparing the variations in compressible layer thickness, height and slope of the embankment and the results of the Safety Factor (SF) itself. The existing Safety Factor (SF) values are dominated by values that tend to be unstable or have values less than 1.5. However, the next discussion will look for the amount of geotextile reinforcement needed to make the embankment stable or in other words have a Safety Factor value equal to or more than 1.5.

As a result, the following is a recapitulation of the Safety Factor (SF) values that have been found based on variations in compressible layer thickness, height and slope of the embankment shown in Figure 5 below.

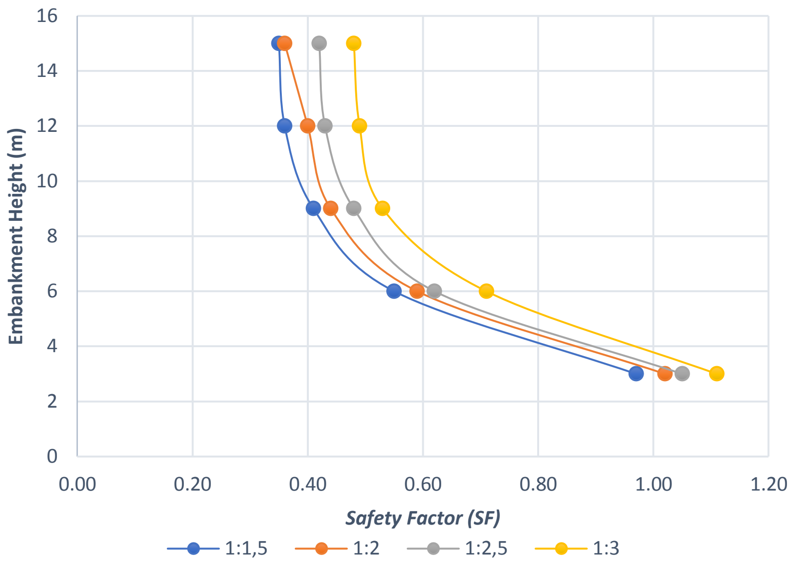

Figure 5. Recapitulation of Existing Safety Factor (SF) Calculation for All Variations Before Using Geotextile Reinforcement

The figure above shows a correlation graph between the embankment height shown on the y-axis and the existing Safety Factor (SF) value shown on the x-axis. There are 4 different conditions according to the experiments conducted, namely experiment 1 using embankment slope 1:1.5, experiment 2 using embankment slope 1;2, experiment 3 using embankment slope 1:2.5, and experiment 4 using embankment slope 1:3. From the graph, it can be seen that both curves with embankment slopes ranging from 1:1.5 to 1:3 have the same characteristics, that is, regardless of the embankment slope, the greater the embankment height value, the lower the Safety Factor (SF) value. The graph also shows that the resulting Safety Factor (SF) value is less than 1.5. Because of this, it is very important to calculate the amount of geotextile reinforcement needed so that an embankment can be categorized as a stable embankment.

Calculation of Geotextile Requirements for All Variations

In this section, the discussion will focus on the calculation of geotextile requirements in accordance with the results of the Safety Factor values obtained in the previous section. In terms of geotextile reinforcement, tensile strength is one of the determinants to determine the number of suitable geotextile requirements in an embankment or slope. In this research, the geotextile specifications used are geotextiles with a tensile strength of 100 kN/m 2 layers or the same as geotextiles with a tensile strength of 200 kN/m 1 layer, the spacing distance between layers is 25 cm, and the reduction factor used is 1.65.

The number of geotextile reinforcement requirements referred to in this study is how many geotextile layers are needed for an embankment with the results of the Safety Factor (SF) value that has been obtained previously to be more stable. Therefore, this geotextile reinforcement is calculated so that the Safety Factor (SF) value can increase to 1.5. The following is a recapitulation of the amount of geotextile reinforcement per layer required in each variation that has been carried out can be seen in Figure 6 below.

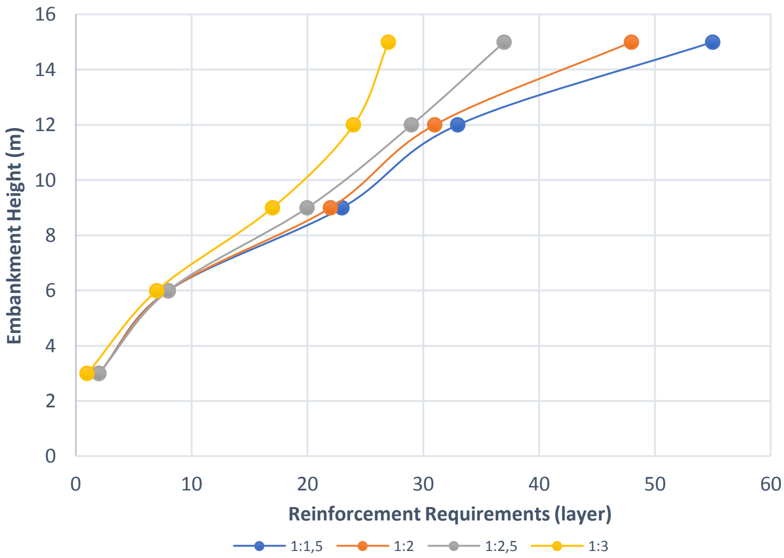

Figure 6. Recapitulation of Geotextile Requirement Calculation for All Variations

Based on the results of the analysis of the calculation of the number of geotextiles in all variations, a correlation graph can be formed. The graph above is a correlation graph between the embankment height shown on the y-axis and the amount of geotextile reinforcement required and shown on the x-axis. In this graph there are 4 different conditions according to the experiments carried out, where each illustrates a different slope from 1: 1.5 to 1: 3. After analyzing and calculating the geotextile requirements, it is known that both curves with a slope of 1:1.5 to 1:3 have the same characteristics, that is, regardless of the slope, if the height of the embankment increases, the geotextile requirements will also increase.

Nomogram of Safety Factor (SF) and Geotextile Requirements

The entire series of analyses has been carried out, starting from determining the subgrade parameters, inputting into the GEO5 auxiliary program to obtain the results of the Safety Factor (SF) value, to the stage of calculating the number of geotextile reinforcement requirements from the results of the Safety Favtor (SF) value that has been obtained previously. The analysis that has been carried out uses 3 (three) types of variations, namely:

1. Variation of compressible layer thickness, starting from 10 m, 20 m, 30 m, to 40m,
2. Variation of embankment slope, starting from 1:1.5, 1:2, 1:2.5, and 1:3, as well as
3. Variation of embankment height, starting from 3 m, 6 m, 9 m, 12 m, and 15 m.

By performing these variations, a relationship nomogram is obtained that correlates between these variations. The Safety Factor (SF) value and the amount of geotextile reinforcement are also important elements in the nomogram that has been produced earlier. With this nomogram, it is expected to be a reference for the next work project to analyze the stability of the embankment and the geotextile reinforcement required for the conditions previously discussed. The following is a graph of the relationship nomogram that correlates between variations and can be seen in Figure 7 below.

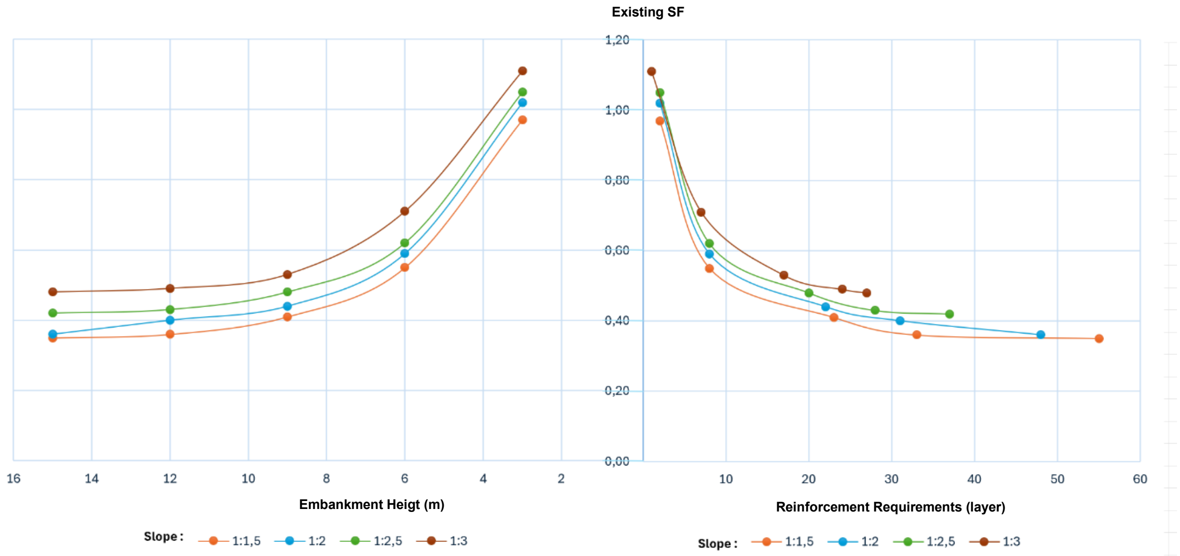

Figure 7. Nomogram of Relationship between Embankment Height and Safety Factor (SF) value and Number of Geotextile Reinforcement Requirements

Safety Factor (SF) and Geotextile Requirements at the Case Study Site

After obtaining a nomogram of the relationship between the height of the embankment with the Safety Factor (SF) value and the number of geotextile reinforcement requirements, it can be applied to a project that is in accordance with the existing problems. The Semarang - Demak Toll Road Construction Project Section 1B is a work package with embankment work as the main work. Thus, the project can also implement the nomogram that has been described in the previous Subchapter.

The case study location used in this research is Zone N at STA 4+200 - 4+600, Semarang - Demak Toll Road Construction Project Section 1B. The information can be implemented in this relationship nomogram. Data that has been known include the thickness of the compressible layer in Zone N is around 40 m, the slope of the embankment used in Zone N is 1: 2.5, and the height of the existing embankment in Zone N is 13.6 m. The following is an example of the nomogram implementation on existing data in the project.

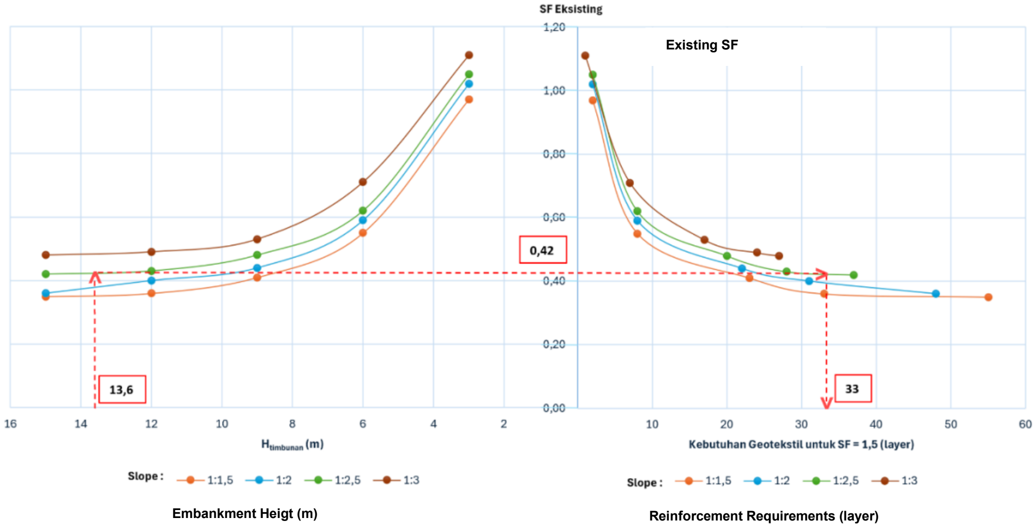

Figure 8. Relationship between Embankment Height and Slope with Existing Safety Factor (SF) and Number of Geotextile Reinforcement Layers Applied at the Case Study Site

The implementation of the nomogram on the Semarang - Demak Toll Road Construction Project Section 1B can be seen and done well. From the results of the nomogram implementation, it is known that the Safety Factor (SF) value is 0.42 and of course the embankment work requires reinforcement to support the load on it. The reinforcement used in this project is geotextile. The amount of geotextile reinforcement has also been obtained, which is 33 layers. However, it should be noted that the geotextile reinforcement calculation used in this study is a geotextile with a tensile strength of 100 kN/m 2 layers or 200 kN/m 1 layer, a spacing distance between geotextiles of 25 cm, and the reduction factor used is 1.65.

CONCLUSIONS

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

1. The variation of compressible layer thickness is known to have no significant effect on the stability calculation of an embankment. However, in the variation of embankment height, it is known that the higher the embankment, the lower the Safety Factor value and vice versa. The variation of embankment slope gives the result that the steeper the embankment, the lower the Safety Factor value and vice versa.
2. To achieve the required Factor of Safety value, the right geotextile reinforcement configuration is required according to the variation. The variation of compressible layer thickness has no influence on the calculation of geotextile reinforcement requirements. In addition, with the variation of embankment height, it is known that the higher the embankment, the higher the geotextile reinforcement requirement and vice versa. The variation of embankment slope also concluded that the steeper the embankment, the higher the geotextile reinforcement requirement and vice versa.
3. After making a relationship nomogram and implementing it with existing field data on the Semarang - Demak Toll Road Construction Project Section 1B STA. 4+200 - 4+600, it is known that the Safety Factor value in the zone is 0.42 and the number of geotextile reinforcement required is 33 layers with a tensile strength configuration of 200 kN/m, the spacing distance between geotextile layers (Sv) is 25 cm, and the Reduction Factor is 1.65.

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