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Implementation of Geosynthetic-Reinforced Soil (GRS) for Railway Project in Indonesia

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Abstract: Railways, or railroad tracks, provide the primary infrastructure designed expressly for passing trains. These tracks facilitate the movement of the train series from one location to another. The construction includes a supporting structure for the tracks, one component of which is a landfill. In practice, unstable soil conditions, characterized by limited bearing capacity, significantly affect landfills. To ensure the safety of the embankment, precise calculations must be conducted to achieve an optimal design that prevents landslides or structural failures. When geosynthetic technology is used in embankment soil, problems like reduced soil-bearing capacity and landslide risk are fixed. The soil becomes more stable and more potent. The study involved an examination utilizing computer simulation to simulate embankment soil through Plaxis Version 8, software for finite element analysis in geotechnics, incorporating geosynthetics for enhanced reinforcement. Alongside the utilization of Plaxis, manual analysis was conducted for traditional verification. Both evaluations were conducted to ascertain the impact of geosynthetics on land subsidence and the value of the safety factor. The simulation findings indicate that employing geosynthetics with a tensile strength of 150 kN/m resulted in a land subsidence of 144×10^{-3} m, whereas a tensile strength of 200 kN/m yielded a land subsidence of 46.59×10^{-3} m. Concurrently, the safety factor value rose, with a tensile strength of 150 kN/m yielding an SF of 1.43 and a tensile strength of 200 kN/m resulting in an SF of 1.52. A tensile strength of 200 kN/m yielded an SF value of 1.51 during manual analysis. The application of geosynthetics in railway embankments has demonstrated efficacy in enhancing stability and minimizing deformation. The results apply to project development.

Keyword: Geosynthetic-Reinforced Soil (GRS), Railway Project in Indonesia.

INTRODUCTION

During the development of transportation infrastructure, adjustments to land elevation are frequently required, such as by using embankments, excavations, or enhancement of road structures on unstable ground. Soil reinforcement technologies, such as Geosynthetic-reinforced soil (GRS) buildings, have been extensively developed. In addition to enhancing soil strength, this system offers benefits such as excellent earthquake resistance, cost-effectiveness, straightforward and rapid construction methods, structural flexibility to accommodate various settlements without pressure, and improved aesthetics. (Abu-Hejleh *et al*., 2013). In Japan, Geosynthetic-reinforced soil (GRS) structures are used not only for soil reinforcement but also in combination with retaining walls (GRS-RW) to increase the benefits (Yonezawa *et al*., 2014).

Railway firms are prompted to explore building methods that reduce railway life cycle costs due to the growing expansion of railway lines. Geosynthetic materials have been demonstrated to effectively enhance the quality of rail structures and lower construction capital expenses (Esen *et al*., 2021). Geosynthetics have been shown to enhance the stress threshold of subgrade, stabilize subgrade, and reduce water levels. Geosynthetics can enhance the safety and efficiency of railway operations under various ground conditions, as Basudhar *et al*. (2010) demonstrated.

In addition, Indonesia utilizes geosynthetics to gain more benefits due to its tropical environment and abundant precipitation. The global concern about the influence of rainfall on wall performance, particularly in embankment design planning, has intensified, especially in the context of prolonged heavy rainfall events over several years (Portlinha *et al*., 2021). Several studies have examined the detrimental impact of rainfall on the stability and deformation of walls (Yoo and Jung, 2006; Portelinha and Zornberg, 2017; Yang *et al*., 2018). These studies have demonstrated that intense rainfall only affects the upper walls, and following severe rainfall, the load on the reinforcement increases by 60%.

Geosynthetics in civil engineering has emerged as a valuable solution to prevent the potentially catastrophic collapse of retaining walls, which poses a significant risk to human life and financial resources. This technological advancement presents numerous advantages that contribute significantly to the advancement of the field. Geosynthetic soil layers serve two primary functions in terms of improving soil stability. Firstly, they act as a means of tensile reinforcement. Secondly, they work as drainage elements, reducing pore water pressure (Tolooiyan *et al*., 2009). Advancements in computerization have led to the creation of numerous numerical approaches that support slope engineering by resolving issues and streamlining the calculation process (Cala *et al*., 2006).

The utilization of geosynthetic materials, which significantly improve track stability, has substantially changed the methods used for constructing and maintaining railway networks. This study will use a design approach based on prior research to calculate GRS-RW calculations. We modified the design approach in Indonesia to incorporate climate concerns specific to the country, particularly the tropical environment characterized by high rainfall intensity. Furthermore, we anticipate directly implementing this research in railway construction projects. The results of these calculations can assist planners in carrying out their responsibilities. To do design calculations for the application of Geosynthetic Reinforced Soil (GRS) on embankment soil for railway tracks.

The research aims to achieve several objectives, including determining the requisite number of geotextile layers for embankment soil, identifying the safety factor of embankment soil reinforced with geosynthetics using Plaxis, and evaluating the results of both external and internal stability analyses of slopes reinforced with geosynthetics through manual calculations. Additionally, the study involves comparing embankment stability analysis findings obtained using the Plaxis program with those derived from manual methods. By setting these objectives, the research establishes clear and specific goals, one of which is to enhance the stability of embankments, slopes, and train retaining walls by implementing Geosynthetic Reinforced Soil (GRS) structures on railway track foundations—an essential component in train operations (Abu-Hejleh et al., 2003; Yonezawa et al., 2014). This approach is expected to improve the understanding of how to design durable and compliant railway infrastructure. Moreover, the application of GRS structures in infrastructure projects across Indonesia holds promise not only for academic research but also for long-term practical use in national development.

METHOD

Overview

This study focused on the development of a new track at the Muaragula Ultimate Depot within the Palembang II Regional Division, namely in the Double Track segment spanning the KM 382 + 950 to KM 386 + 900 area, covering an approximate length of 3.95 KM (Figure 3.1.). The study involved assessing the stability of the embankment's retaining wall with the Plaxis software and manual computations. The planning for slope reinforcement with geosynthetic reinforcement aid.

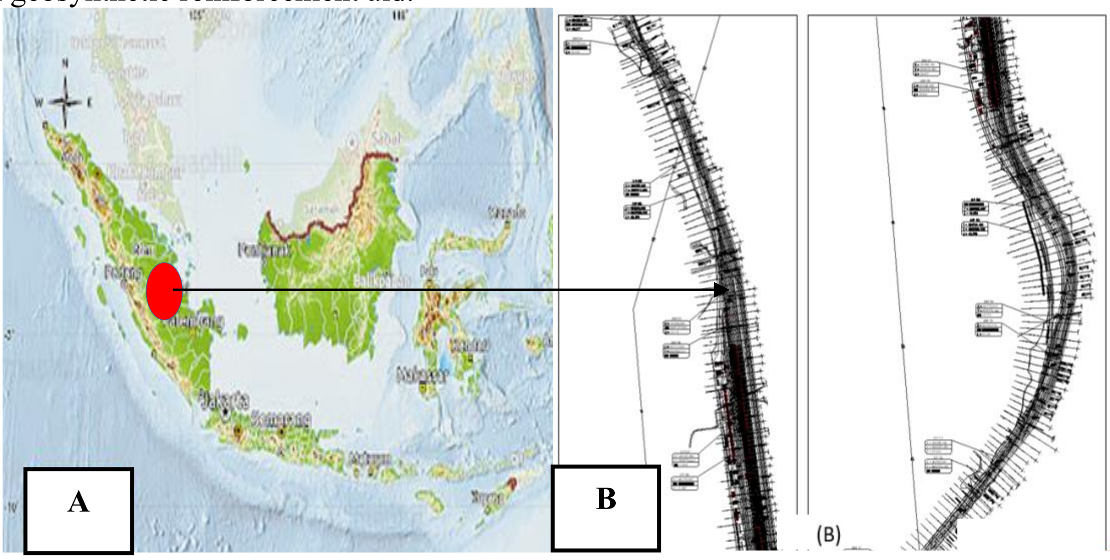

Figure 1. (A) Research Site Map; (B) the location of the double-track route and the specific area designated for investigation (Indonesia Railway Company, 2023)

Phases of Research

This study delineates the research process into multiple stages, including the following:

1. Data collection phase: This phase encompasses acquiring data from PT KAI, including locational and land data. At this point, the necessary parameters for the study will be acquired, including the geometry of the GRS-RW plan, the height of the retaining wall, and the stresses exerted on the GRS.
2. Data Analysis and Management Phase: At this juncture, the acquired data is analyzed by computing the operational load and evaluating the exterior and internal stability of the retaining wall. The wall stability study is conducted utilizing the Plaxis program alongside manual computations.
3. Composing and deriving conclusions: This phase entails composing a study report based on relevant regulations and data processing outcomes. Conclusions are derived from the theoretical framework employed to address the emerging issues.

Method of Data Collection

Data is required to analyze the stability of the retaining wall at the Muaragula final depot site in South Sumatra. This study utilizes secondary data sourced from PT KAI. The supplementary data comprises:

1. Soil data include field test results and laboratory analyses. Field test soil data is derived from the Standard Penetration Test (SPT), and boring test data is presented in graphs and

tables. The laboratory test data yields the following results: wet volume weight (γ), dry volume weight (γ_d), cohesion (c), and internal friction angle (φ).
2. Retaining wall specifications, encompassing base elevation height, reinforcement type employed, base width, intended height of the retaining wall, and higher elevation height.
3. Hydrological information, encompassing groundwater level data.

Data Analysis

The data analysis method is a phase in which research analysis is conducted according to the established stages of work. There are four distinct stages to the job:

1. Initial phase
   The initial phase involves strategic planning of slope reinforcement using geotextiles. Subsequently, the tensile strength of the geosynthetic determines the reinforcing requirements for embankment soil.
2. Second phase
   During this subsequent phase, slope stability analysis uses the finite element method with geosynthetic reinforcement, explicitly employing the Plaxis 2D version 8. Stability analysis is conducted until the requisite safety factor is achieved.
3. Third Stage
   The third stage involves the manual study of retaining wall stability. This analysis is conducted through the subsequent steps:
   a. Determine the self-weight and moment exerted on the retaining wall;
   b. Compute active and passive pressures;
   c. Assess stability against overturning, shifting, and the failure of soil bearing capacity.

RESULT AND DISCUSSION

Determination of the Necessary Quantity of Geotextile

Geotextiles function as reinforcement materials for embankment stability in reinforcement planning. The initial step is determining the geotextile quantity required for the embankment. The calculation requires the permissible geotextile strength (Tallow) as determined by equation 6. Subsequently, the lateral soil value can be ascertained utilizing Equation 2, employing the active soil coefficients (Ka) from Equation 4. The quantity of geotextile layers required for the embankment can be calculated using Equation 5. The calculation involves determining the length of the geotextile at the base of the landslide (Le), the length in front of the landslide plane (Ld), and the length of the geotextile fold (Lo) using equations 7, 8, and 9.

1. Determination of the horizontal forces exerted by soil
   The calculation begins by taking into account the active soil coefficient.
   $$Ka = \tan\left(45 - \frac{\varphi}{2}\right)^2 = 0.406$$
   Subsequently, the outcomes for lateral soil computations are acquired:
   $$\sigma_{hc} = (q \times Ka) + (Ka \times H \times \gamma b) - (2 \times c \times \sqrt{Ka}) = 60.1833 \text{ kN/m}^2$$
   $$\sigma_{vc} = \gamma b \times H = 94.68 \text{ kN/m}^2$$
2. The calculation of the necessary quantity of geotextile is based on a tensile strength of 25 kN/m.
   a. Calculate the permitted tensile strength.
   $$T_a = \frac{T_{ult}}{RF_{ID} \times RF_{CR} \times RF_{CD} \times RF_{BD}} = 8.6088$$
   Calculate the vertical separation between layers of geotextile.
   $$Sv = \frac{T_{all}}{\sigma hc \times SF} = 0.067 \text{ m}$$
   Calculate the quantity of geotextile required for a tensile strength of 25 kN/m.

$n = \frac{H}{Sv}$ = 79 sheets

b. Calculations using various geotextile tensile strengths led to the reported results. Table 1 summarizes the computed outcomes for the quantity and extent of geotextiles necessary for soil embankments.

Table 1. correlates the tensile strength and the quantity of geotextile needed

No	The tensile strength of geotextiles (kN/m)	The quantity of the geotextile needed (Pcs)	The separation between layers (cm)
1	25	79	7
2	50	40	13
3	75	27	20
4	100	20	27
5	125	16	33
6	150	14	40

Figure 1 below illustrates the correlation between the quantity of textile layers necessary for the embankment and the employed tensile strength.

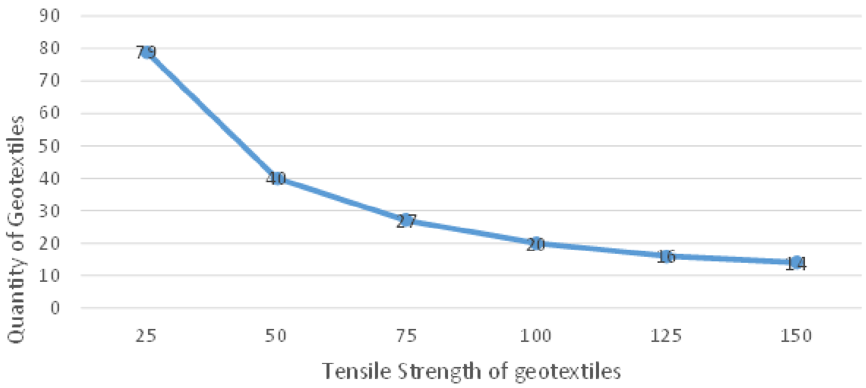

Figure 2. the correlation calculation findings between the tensile strength and the number of geotextile layers needed

The calculation findings indicate that the tensile strength of the geotextile employed significantly affects the distance necessary between them. For installation convenience in the field, a geotextile with a strength of 150 kN/m is utilized for subsequent calculations, with a needed spacing of 40 cm between geotextiles. The lateral soil pressure is computed using the H value in conjunction with the z value, representing the distance between layers. The results of the lateral soil pressure calculations are presented in Table 2 below.

Table 2. Summary of lateral soil pressure at depth z with geosynthetic reinforcement of 150 kN/m² (z increments of 0.4 cm)

z	σ'_{hl} (kN/m^2)	σ'_{hq} (kN/m^2)	σ'_{hs1} (kN/m^2)	σ'_h	σ'_v
0.4	0.0071	44.6655	2.9222	47,5948	7.2
0.8	0.0142	44.6655	5.8444	50.5241	14.4
1.2	0.0212	44.6655	8.7665	53.4533	21.6
1.6	0.0283	44.6655	11.6887	56.3826	28.8
2	0.0354	44.6655	14.6109	59.3119	36
2.4	0.0425	44.6655	17.5331	62.2411	43.2
2.8	0.0496	44.6655	20.4553	65.1704	50.4
3.2	0.0567	44.6655	23.3775	68.0997	57.6
3.6	0.0637	44.6655	26.2996	71.0289	64.8
4	0.0708	44.6655	29.2218	73.9582	72
4.4	0.0779	44.6655	32.1440	76.8875	79.2
4.8	0.0850	44.6655	35.0662	79.8167	86.4
5.2	0.0921	44.6655	37.9884	82.7460	93.6

3. Determination of geotextile length specifications
   Research from Japan determines the required length of geotextile. The study suggests using either 35% of the length (L) or 1.5, whichever is larger.
   a. Length of Effectiveness
      $L_R = (H - z)\tan\left(45 - \frac{\varphi}{2}\right) = 7.53$ m
   b. Length of Overlap
      $L_E = \frac{\sigma_{hci} \times Svi \times SF}{4\,(c + \gamma \times z \times \tan\delta)} = 0.814$ m → min = 1 m
   The length of the geotextile is determined: L = L_R + Lo = 8,5 m ≈ 9 m > 1,5 m
   Length used = 14 m
   The subsequent layer is illustrated in the table 3 below.

Table 3. Comprehensive overview of geosynthetics applications.

Z (m)	Sv (m)	L_r (m)	Le (m)	Le min (m)	L (m)	Lmin (m)	Lused (m)
0.4	0.4	7.53	0.81	1.00	8.53	9	14
0.8	0.4	6.91	0.73	1.00	7.91	8	14
1.2	0.4	6.28	0.68	1.00	7.28	8	14
1.6	0.4	5.65	0.63	1.00	6.65	7	14
2	0.4	5.02	0.59	1.00	6.02	7	14
2.4	0.4	4.40	0.56	1.00	5.40	6	14
2.8	0.4	3.77	0.54	1.00	4.77	5	14
3.2	0.4	3.14	0.52	1.00	4.14	5	14
3.6	0.4	2.51	0.50	1.00	3.51	4	14
4	0.4	1.88	0.49	1.00	2.88	3	14
4.4	0.4	1.26	0.47	1.00	2.26	3	14
4.8	0.4	0.63	0.46	1.00	1.63	2	14
5.2	0.4	0.00	0.45	1.00	1.00	1	14

The Analysis of computations utilizing the plaxis Software

Plaxis is utilized for the analysis and planning of embankments reinforced with geotextiles. This examination examines the slope to ensure its stability against internal and external influences. Utilizing the soil data presented in Table 1, slope reinforcement modelling is conducted employing geotextiles with a tensile strength of 150 kN/m and a length of 14 m, incorporating train loads and rail support structure loads with the Plaxis 8 program. Figure 2 depicts the preliminary embankment soil model in Plaxis.

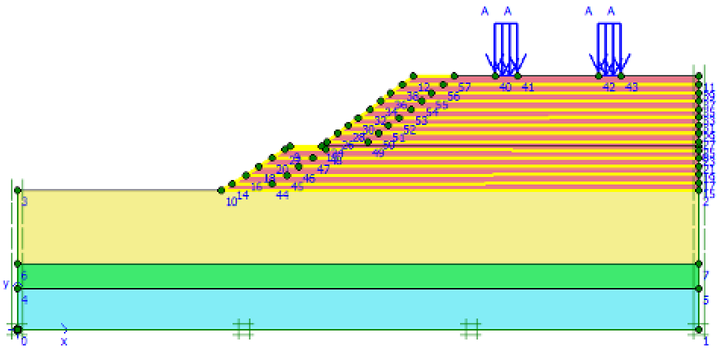

Figure 3. Model of the initial slope

The subsequent stage involves the slope's meshing configuration. Figure 4.3 depicts the meshing arrangement outcomes on a slope fortified with geotextiles. In contrast, Figure 4.4 demonstrates the deformation occurring in the meshing region due to train and track structure loads.

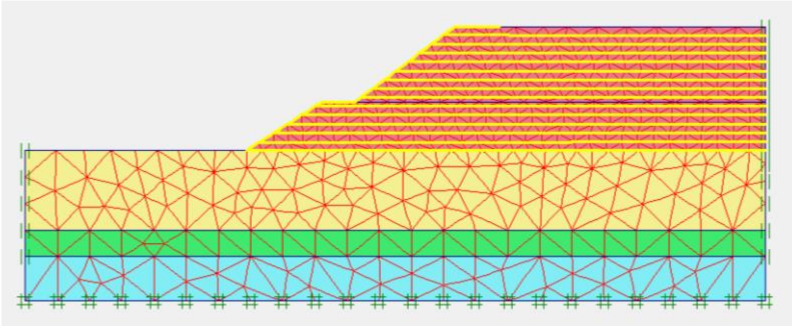

Figure 4. meshing on the initial slope.

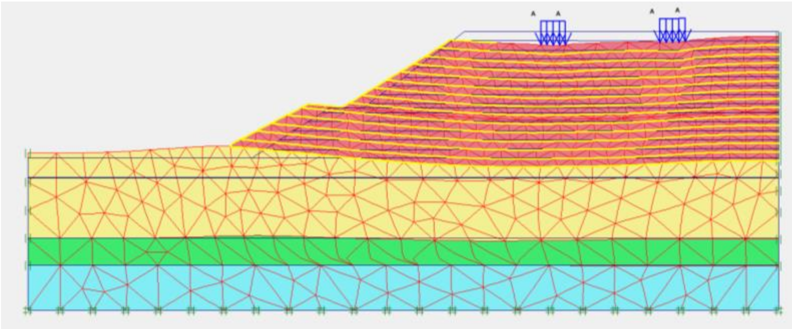

Figure 5. deformed mesh on an actual slope under train load using geosinthetic 150 kN/m

The cumulative displacements on the initial slope utilizing geosynthetic 150 kN/m are 144.86 x 10^{-3} m. The vehicle load refers to the train load, determined as a consistent weight on the bearings. The cumulative displacement value on the slope illustrated in Plaxis is presented in Figure 4.

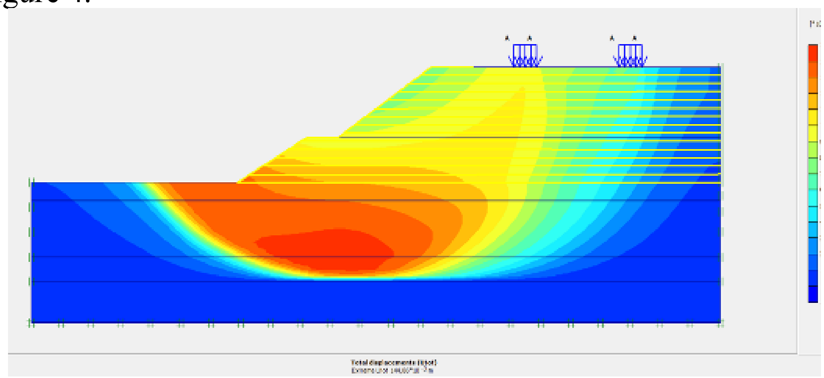

Figure 6. Total displacement that happens on the slope owing to the train load using geosinthetic 150 kN/m

Simultaneously, the trajectory of motion on the incline is illustrated in Figure 4.6 below.

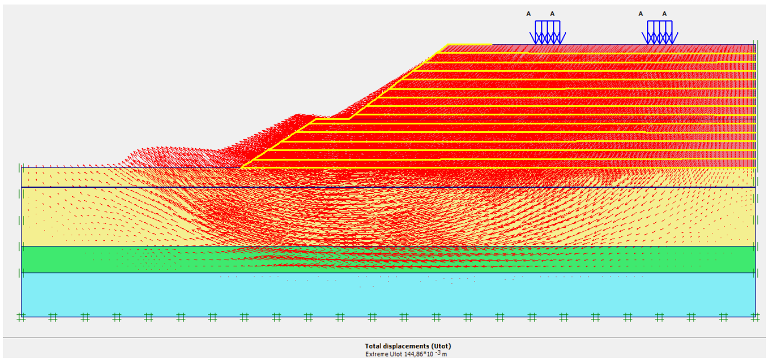

Figure 7. illustrates the direction of ground movement in relation to train load using geosinthetic 150 kN/m

The research indicates that the slope's safety factor is 1.4315. The secure numerical value acquired is illustrated in Figure 7.

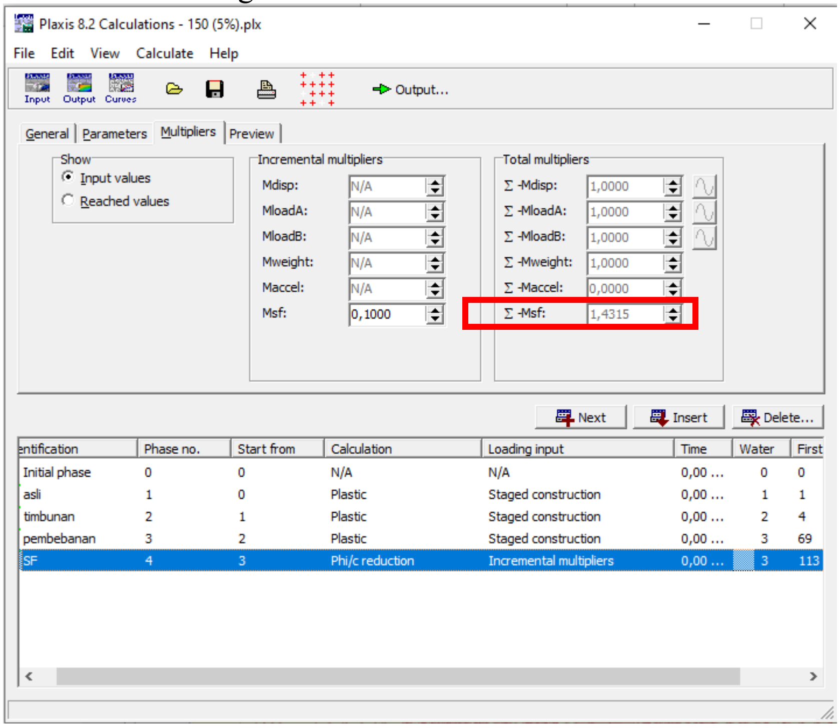

Figure 8. SF Value using geosinthetic 150 kN/m

The study by Plaxis indicates an SF value of 1.4315, below the required threshold of SF > 1.5. A recalculation is performed utilizing a tensile strength of 200 kN/m for the geotextile. In this calculation, the number of reinforcement layers is no longer factored in, as a strength of 150 kN/m corresponds to a distance of 40 cm between the geosynthetic layers. Consequently, applying geosynthetics at the site, where soil compaction occurs at intervals of 20 cm, facilitates the application of geosynthetics built at intervals of 40 cm.

Enhancing the tensile strength value is anticipated to diminish the forces exerted on the slope, enhance the forces that counteract landslides, and elevate the safety factor on the slope. The reinforcement planning design for the slope employs a geotextile with a strength of 200 kN/m; the deformed mesh results on the slope are seen in Figure 4.8 below.

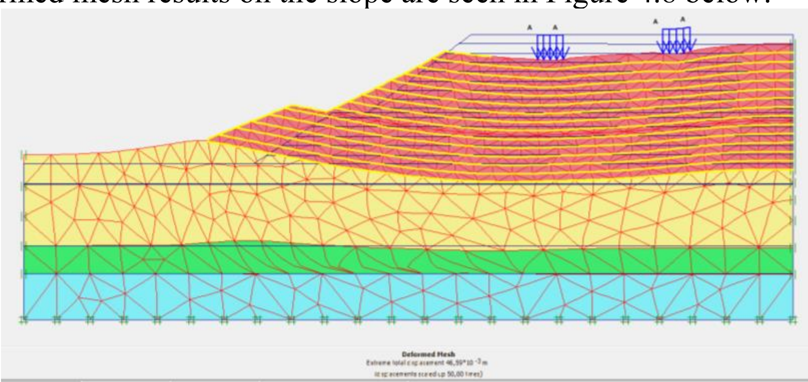

Figure 9. deformed mesh on an actual slope under train load using geosinthetic 200 kN/m

As shown in Figure 9, the total movement on the first slope when geosynthetic 200 kN/m is used is 46.59×10^{-3} m.

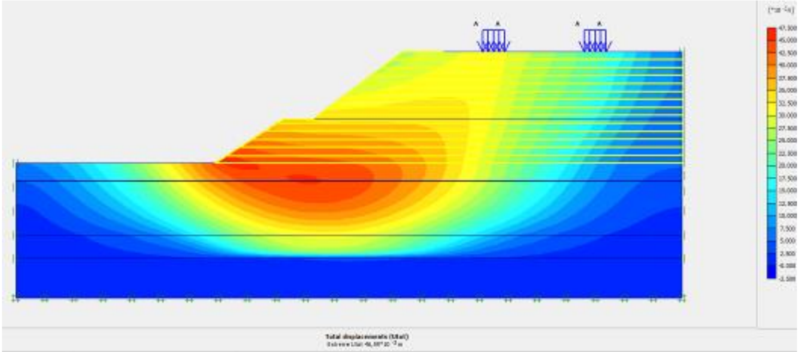

Figure 10. Total displacement that happens on the slope owing to the train load using geosinthetic 200 kN/m.

The movement of soil on slopes, influenced by the applied load, is illustrated in Figure 10 below.

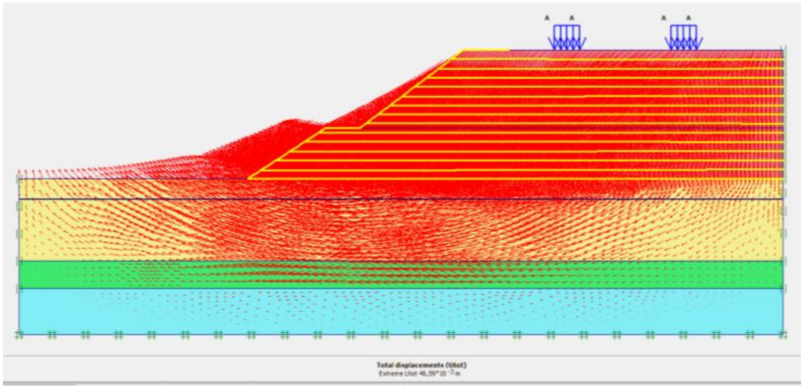

Figure 11. illustrates the direction of ground movement in relation to train load using geosinthetic 200 kN/m

The embankment's safety factor achieved a secure value of 1.5296 with the enhancement of geotextile tensile strength to 200 kN/m. This value satisfies the minimum criterion for a safe stability rating of 1.5, indicating that the slope is secure against landslides. The secure value derived from Plaxis is seen in Figure 11 below.

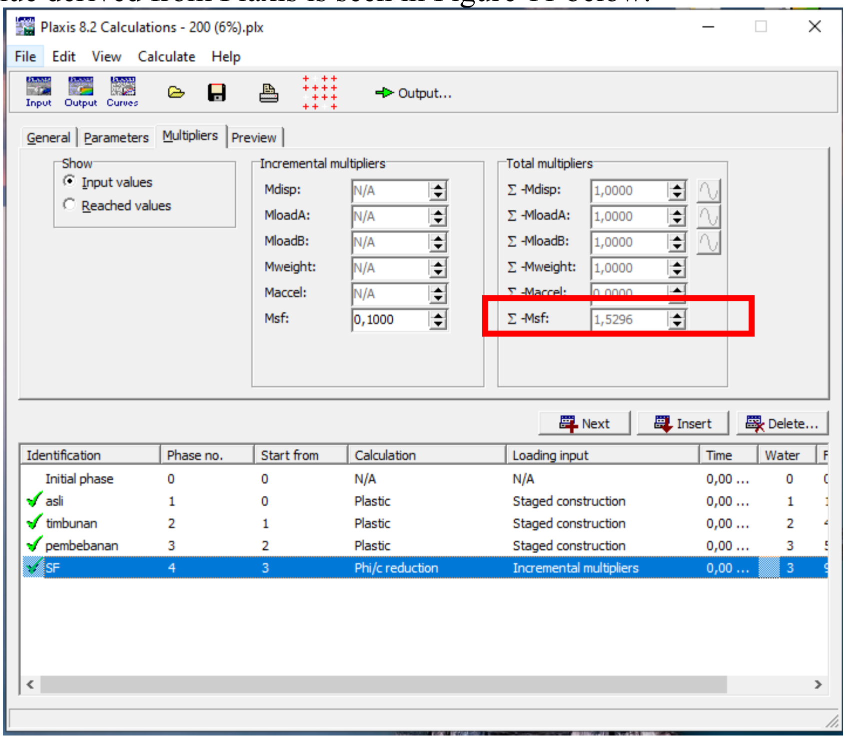

Figure 12. SF Value using geosinthetic 200 kN/m

The research shows that the SF value is higher than 1.5, so the calculations will continue using geosynthetics with a strength of 200 kN/m spread out over 14 layers, with 40 cm gaps between each layer.

The analysis of Slope Stability Using Method of Slice

The soil at the work location is heterogeneous and has multiple layers. Consequently, while assessing slope stability, the slice approach evaluates the equilibrium of each segment. Figure 12 below depicts this slicing technique.

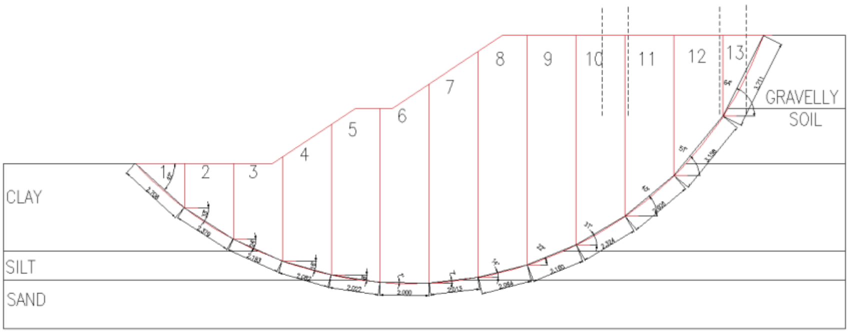

Figure 13. SF Value using geosinthetic 200 kN/m

The choice of materials for embankment construction is critical, particularly for embankment structures. This can enhance the safety factor (FS) and diminish the likelihood of instability, establishing a secure foundation for the embankment against structural failure. Limit equilibrium analysis is used to figure out how stable a slope is. It does this by comparing the strength of the soil mass to the forces, especially gravity, that can move the mass. When the magnitude of the retention force equals the pushing force, the embankment achieves a condition of equilibrium with FS = 1.0. A meticulous examination of various slope geometries and underlying conditions and stability analysis are conducted. Calculations have been conducted to evaluate the numerous driving forces that compromise slope stability, including gravitational pressures, hydrological factors, and seismic activities. Additionally, the calculations consider the overall stability of the slope, as previously noted (Li et al., 2015).

The calculations conducted using the Excel application yielded the following values (detailed calculations are available in the appendix):

$\sum(c.L) = 528.8$

$\sum(W\ cos\alpha\ \times\ tan\emptyset\ ) = 560{,}8$

$\sum W\ sin\alpha = 510.5$

$$FS = \frac{\sum(c.L + W\ cos\alpha\ \times\ tan\emptyset\ )}{\sum W\ sin\alpha} = \frac{528.8 + 560.8}{510.5} = 2.134 > 1.5\ (OK)$$

Analysis of Soil Reinforcement Stability Using Geotextile

This stability study calculation considers the embankment's secure values against lateral movement and the soil's potential to resist collapse and overturning.

Analysis of External Stability

Determination of active soil pressure (Pa)

$P_{a1} = K_a \times q \times H$ = 232.261 kN/m

$M_1 = 603.878$ kN.m

$P_{a2} = P \times x^2 \times H^2 / R^5$ = 0.98 kN/m

$M_2 = 3.39$ kN.m

$P_{a3} = K_a \times \gamma \times H^2/2 = 18.99$ kN/m
$M_3 = 98.77$ kN.m
So, $\sum P_a = 252.23$ kN/m; $\sum P_a \times \cos\delta = 241.64$ kN/m and $\sum P_a \times \sin\delta = 72.34$ kN/m
$\sum M = 706.63$ kN.m

Additionally, the formula for verifying the safety value in comparison with Plaxis considers the following factors:

a. Safety factor against shear failure

$$SF_{sliding} = \frac{c_a \times L + \sum w \times \tan\emptyset}{P_a \times \cos\delta} > 1.5$$

$$\frac{757}{242} > 1.5$$

$3.13 > 1.5$ (OK)

b. Safety factor for preventing overturning failure

$$SF_{overtuning} = \frac{\sum w \times x}{P_a \times \cos\delta \times ad}$$

$$\frac{1068}{706} > 1.5$$

$1.51 > 1.5$ (OK)

c. Safety factors about the failure of the bearing capability of the foundational soil

$$SF_{foundation\ soil} = \frac{q_{ult}}{q}$$

$$\frac{1593}{801.9} > 1.5$$

$1.986 > 1.5$ (OK)

The computation results indicate that Table 4 and Figure 13 elucidate the correlation between geotextile length and safety value.

Table 4. Correlation between the length of the geotextile utilized and the safety value

L (used)	SF		
	Shear failure	Overturning Failure	The bearing capability of the foundational soil
9	2.063	**1.000**	**1.369**
10	2.277	**1.103**	**1.493**
11	2.491	**1.205**	1.616
12	2.704	**1.307**	1.739
13	2.918	**1.410**	1.863
14	3.132	1.512	1.986

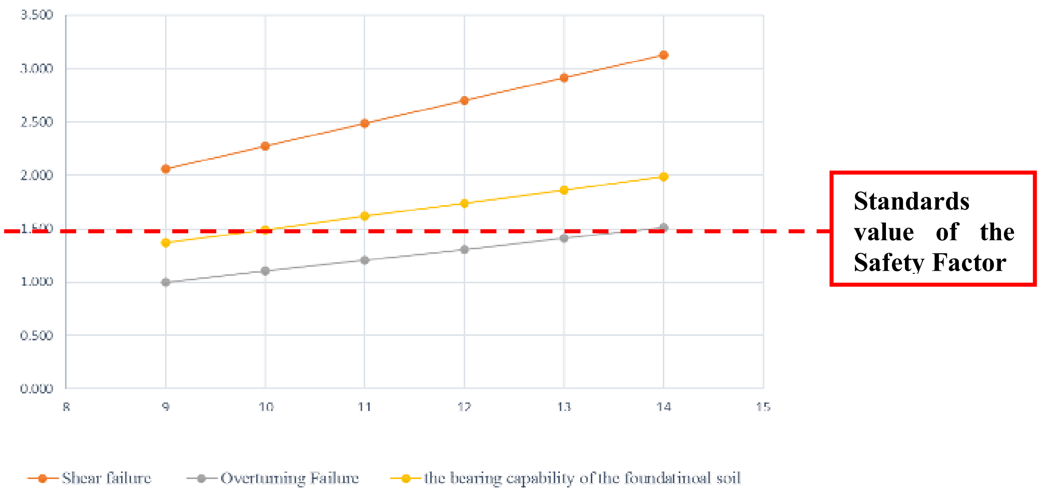

Figure 14. Correlation between geotextile length and safety value

Analysis of Internal Stability

During internal stability assessments, calculations are performed on internal forces about the failure of reinforcement and the extraction of reinforcement. The conducted analysis is as follows:

a. Safety factor for the failure of reinforcement

An internal stability study performed by manual verification involves finding the safety factor value for reinforcement failure. The secure numerical value, assessed according to the height of the embankment per layer, is presented in Table 5 below.

Table 5. Control for the failure reinforcement

Layer	**Sv**	**T_{all} (kN/m)**	**$T_{intermediary}$** σ_h x S_v **(kN/m)**	**FK_{os}**	**Control** $FK_{os} \geq 1.5$
1	0.4	68.87052	19.0379224	3.617544	ok
2	0.4	68.87052	20.20962819	3.407808	ok
3	0.4	68.87052	21.38133397	3.221058	ok
4	0.4	68.87052	22.55303976	3.053714	ok
5	0.4	68.87052	23.72474554	2.902898	ok
6	0.4	68.87052	24.89645133	2.766279	ok
7	0.4	68.87052	26.06815711	2.641941	ok
8	0.4	68.87052	27.2398629	2.528299	ok
9	0.4	68.87052	28.41156869	2.424031	ok
10	0.4	68.87052	29.58327447	2.328022	ok
11	0.4	68.87052	30.75498026	2.239329	ok
12	0.4	68.87052	31.92668604	2.157146	ok
13	0.4	68.87052	33.09839183	2.080782	ok

b. Safety factor against the extraction of reinforcement

The computation for reinforcement extraction uses varying geotextile lengths based on the determined length requirements. Table 6 presents the results of the control against reinforcement extraction.

Table 6. Control for against the extraction of reinforcement using varying geotextile

Layer	**z**	**L**	**Tan (45^0-Ø/2)**	**H-z**	**σ'$_v$**	**tan δ**	**$T_{retainer}$**	**$T_{intermediary}$**	**FK_{po}**	**Control** $FK_{po} \geq 1.5$
1	0.4	9	0.6371	4.8	7.2	0.2994	25.62	19.03792	**1.35**	**Cek**
2	0.8	8	0.6371	4.4	14.4	0.2994	44.81	20.20963	2.22	Ok
3	1.2	8	0.6371	4	21.6	0.2994	70.51	21.38133	3.30	Ok
4	1.6	7	0.6371	3.6	28.8	0.2994	81.16	22.55304	3.60	Ok
5	2	7	0.6371	3.2	36	0.2994	106.94	23.72475	4.51	Ok
6	2.4	6	0.6371	2.8	43.2	0.2994	109.06	24.89645	4.38	Ok
7	2.8	5	0.6371	2.4	50.4	0.2994	104.75	26.06816	4.01	Ok
8	3.2	5	0.6371	2	57.6	0.2994	128.50	27.23986	4.72	Ok
9	3.6	4	0.6371	1.6	64.8	0.2994	115.65	28.41157	4.07	Ok
10	4	3	0.6371	1.2	72	0.2994	96.37	29.58327	3.26	Ok
11	4.4	3	0.6371	0.8	79.2	0.2994	118.09	30.75498	3.84	Ok
12	4.8	2	0.6371	0.4	86.4	0.2994	90.28	31.92669	2.83	Ok
13	5.2	1	0.6371	0	93.6	0.2994	56.04	33.09839	1.69	Ok

Given the simplicity of field installation and the outcomes of internal analytical computations, a geotextile length of 14 cm is employed for each layer. The results of the calculations are presented in Table 7.

Table 7. Control for against the extraction of reinforcement

Layer	z	L	Tan (45^0-Ø/2)	H-z	σ'$_v$	tan δ	$T_{retainer}$	$T_{intermediary}$	FK_{po}	Control $FK_{po} \geq 1.5$
1	0.4	14	0.6371	4.8	7.2	0.2994	47.17	19.03792	2.48	Ok
2	0.8	14	0.6371	4.4	14.4	0.2994	96.54	20.20963	4.78	Ok
3	1.2	14	0.6371	4	21.6	0.2994	148.11	21.38133	6.93	Ok
4	1.6	14	0.6371	3.6	28.8	0.2994	201.87	22.55304	8.95	Ok
5	2	14	0.6371	3.2	36	0.2994	257.83	23.72475	10.87	Ok

Layer	z	L	Tan (45^0-Ø/2)	H-z	σ'$_v$	tan δ	$T_{retainer}$	$T_{intermediary}$	FK_{po}	Control $FK_{po} \geq 1.5$
6	2.4	14	0.6371	2.8	43.2	0.2994	315.99	24.89645	12.69	Ok
7	2.8	14	0.6371	2.4	50.4	0.2994	376.35	26.06816	14.4	Ok
8	3.2	14	0.6371	2	57.6	0.2994	438.90	27.23986	16.11	Ok
9	3.6	14	0.6371	1.6	64.8	0.2994	503.65	28.41157	17.73	Ok
10	4	14	0.6371	1.2	72	0.2994	570.59	29.58327	19.29	Ok
11	4.4	14	0.6371	0.8	79.2	0.2994	639.74	30.75498	20.80	Ok
12	4.8	14	0.6371	0.4	86.4	0.2994	711.08	31.92669	22.27	Ok
13	5.2	14	0.6371	0	93.6	0.2994	784.62	33.09839	23.71	Ok

Discussion

The stability analysis of the embankment on the railway line for the Muaragula depot aims to determine the proposed slope's safety factor (SF). Geotextiles enhanced the slope in this study. The investigation employed Plaxis Version 8 software and manual calculations derived from Rankine theory. The load data consists of a compilation of train and railway structural loads. The necessary safety factor (SF) value surpasses 1.5. The safety factor (SF) is obtained from SNI 8460:2017.

The effects of the tensile strength of geosynthetic materials on the required number of layers

The stability of embankments is critical for the dependability of infrastructure construction. The application of geotextiles in embankments is anticipated to enhance embankment stability. Tensile strength is a key factor determining how well geotextiles resist the stress caused by the load on the embankment soil.

This study investigated the geotextile specifications for embankment soil utilizing different tensile strengths. The tensile strength values used to determine the requisite number of layers varied from 25 kN/m to 150 kN/m in increments of 25 kN/m. This investigation's variation in tensile strength needs was confined solely to determining the necessary number of geotextile layers for embankment soil.

The research findings indicate that the material's tensile strength significantly affects the required geotextile. With reduced tensile strength, the number of geotextile layers required for embankment soil will rise as the distance between consecutive layers increases. On the other hand, using a higher tensile strength will reduce the number of geotextile layers needed for embankment soil, making the spaces between layers more enormous. A geotextile layer with a tensile strength of 25 kN/m necessitates 79 layers or a spacing of 79 cm between layers, whereas a tensile strength of 150 kN/m requires 14 layers or a spacing of 40 cm.

Safety Factor Value Derived from Plaxis Testing

The PLAXIS simulation findings show that the embankment represents geotextile as an additional layer. The parameters inputted in PLAXIS for geotextile include the modulus of elasticity derived from the material's tensile strength. The stability analysis of an embankment soil yields a safety factor (SF) of 1.4315 when it measures 5.26 m in height, possesses a geotextile tensile strength of 150 kN/m, and is subjected to the load of a train and the railroad structure above. The safety value remains below 1.5, as stipulated in SNI 8460:2017; therefore, an alternative is necessary to enhance the safety value to comply with the standards.

When 20 cm gaps compact the soil, the analysis shows that the tensile strength goes up to 200 kN/m, and 14 layers are used, which equals a 40 cm depth. Geotextiles can be put on the second layer of compaction and subsequent layers. The simulation results conducted with Plaxis yielded a safety factor (SF) value of 1.5296. The safety metric complies with the criteria since the safe value of the analytical data must exceed 1.5. Following the enhancement of the tensile strength value, it is evident that there is a corresponding increase in the safety factor for slope stability. The summary of the SF analysis findings is presented in Table 8 below.

Table 8. Summary of SF values derived from Plaxis testing results.

The slope elevation (m)	Tensile Strength (kN/m)	Safety Factors Value
5,25	150 kN/m	1.4315
	200 kN/m	1.5296

Stability of the embankment according to manual calculation outcomes

The investigation utilizes manual calculations and begins with a limit equilibrium analysis to evaluate slope stability. This slope stability assessment employs the slicing approach, which involves analyzing numerous factors that could jeopardize slope stability. The analysis considered slope stability before load application and excluded geotextile reinforcement. The study indicates an SF value of 2.134, which exceeds the requirement of 1.5.

An exterior stability analysis addressed shifting risks, soil-bearing capacity issues and overturning. The study was conducted similarly to the PLAXIS program, with an embankment soil height of 5.26 m, a tensile strength of 200 kN/m, and a material length of 14 m. The study shows that the circumferential stability of the embankment soil is not affected by the number of layers used but is greatly affected by the geotextile's length. According to the test findings for external stability, a geotextile length of 14 cm is necessary to attain the specified SF value. The safety factor against shear failure is 3.13, the safety factor for preventing overturning failure is 1.51, and the safety factor for the failure of the bearing capacity of the fundamental soil is 1.986.

Simultaneously, the internal analysis employs the parameters identical to those in PLAXIS and the aforementioned external calculation. The internal analysis encompasses the examination of reinforcement removal and the assessment of rupture. The calculation results show that the spacing between geotextile layers (Sv) and the length of the geotextile significantly influence this internal analysis. The minimum safety factor for the failure of the reinforcement value in the 13th layer, located at a depth of 5.26, is 2.08. Conversely, the minimum safety factor against the extraction of reinforcement in the first layer, or at a depth of 0.4 m, is 2.48.

The external and internal computations results show that we have reached a secure figure of more than 1.5. Table 9 below encapsulates the outcomes of the safe number computation derived from manual computations.

Table 9. Secure numerical values derived from manual calculations

Analysis	**Safety Factors Value**
Slice Method	2.134
Eksternal:	
Safety factor against shear failure	3.13
Safety factor for preventing overturning failure	1.51
Safety factors about the failure of the bearing capability of the foundational soil	1.986
Internal	
Safety factor for the failure of reinforcement	2.08
Safety factor against the extraction of reinforcement	2.48

Comparative Analysis of Results with PLAXIS and Manual Methods

PLAXIS is a software utilized to determine the safety factor (SF) for the stability of embankment soil. The SF value derived from the calculation results is 1.5296 compared to PLAXIS. Conversely, the minimum Safety Factor (SF) derived from the manual computation is 1.51, which is intended to avert overturning failure.

The calculation results indicate that the SF value derived via manual computations closely aligns with that acquired by the PLAXIS program. The discrepancy in the computation findings is 1.28%.

CONCLUSION

Based on the significant findings of the analysis and computations conducted in the preceding chapter, the following conclusions can be inferred:

1. The study showed that tensile strength affects the number of layers used. More specifically, a higher tensile strength value creates more space between layers, so fewer geosynthetics are installed.
2. Following Plaxis's simulations, using geotextiles with a tensile strength of 150 kN/m on soft soil and gravelly soil embankments results in a safety factor of 1.43, which is not high enough to meet the standard of 1.5. As a result, Plaxis elevates the tensile strength to 200 kN/m, leading to an analysis that shows an increase in the SF value beyond 1.5.
3. Alongside elevating the SF value, enhancing the tensile strength to 200 kN/m has effectively diminished the initial deformation from 144.86 x 10^{-3} m to 46.59 x 10^{-3} m, thereby augmenting the stability of the soil structure.
4. Utilising a tensile strength of 200 kN/m with S_v = 0.4 m, Plaxis yields a safety factor of 1.529, while manual calculations yield a safety value of 1.51. The results indicate that PLAXIS and manual calculations are closely aligned, suggesting that the manual calculation results are sufficiently accurate for straightforward computations.

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