(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6, Special Issue 3, January 2024

Comparation of Limit Equilibrium Method (LEM) 2D on Safety Factor and Embankment Reinforcement

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ABSTRACT

The analysis of slope stability is crucial during embankment planning to ensure safety and prevent landslides. A stable slope ensures the safety of surrounding infrastructure, minimizing the risk of damage**.** Therefore, with slope stability analysis can manage and maintain infrastructure assets. The primary method used to evaluate slope stability is the Limit Equilibrium Method, frequently employed in a 2D framework using various applications such as Plaxis LE and Geostudio. Using diverse applications for analysis can yield varying safety factors, influencing the required reinforcement. Hence, this study analyzed safety factors and the necessary geotextile reinforcement for embankments on soft soil featuring distinct heights, slopes, and widths in 2D. The analysis was performed using the Plaxis LE application, and the results were subsequently compared with those obtained from the Geostudio application. This research shows that the results of the embankment safety factors with the Plaxis LE application are different from those of the embankment safety factors with Geostudio, resulting in different embankment geotextile reinforcement namely the need for Plaxis LE geotextile reinforcement = 0.7 Geostudio geotextile reinforcement.

Keywords : Infrastructure Asset Management, 2D analysis, geotextile reinforcement, stability of slope, safety factor

INTRODUCTION

During the Joko Widodo administration, the infrastructure sector emerged as a primary focus aimed at enhancing connectivity and fostering economic growth across diverse regions of the country. To ensure sustainable development, implementing infrastructure projects must carefully consider social, economic, and environmental aspects. (Hidayat & Mustafa, 2018), where this is related to Infrastructure Asset Management (IAM). Asset management is a process where owned assets can be monitored, maintained, and held. Additionally, asset management can solve problems experienced by agencies. Managing infrastructure assets strategically and systematically can minimize the risks associated with asset failure (Arsana I.P.J, 2016).

Infrastructure in Indonesia has serious challenges because Indonesia has a diverse landscape consisting of mountains, hills, highlands, lowlands, and seas. Given the diverse topography, infrastructure development, particularly in hilly and valley areas, often involves constructing embankments or excavations that demand careful consideration of safety and stability. An unstable embankment risks potential landslides, which could damage the surrounding infrastructure. Infrastructure only sometimes stands in a location with perfect conditions; it can even be vulnerable to natural disturbances**.** Therefore, conducting slope stability analysis is crucial in designing embankments and excavations to ensure the maintenance of infrastructure assets. Slope stability is determined by considering the slope's safety factor (SF), and SNI 8460:2017 specifies a required safety factor of 1.5 for slope stability analysis.

There are several methods for analyzing the stability of slope, namely the Limit Equilibrium Method or (LEM), Finite Element Method or (FEM), the Finite Difference Method also called as (FDM), and Discrete Element Method or (DEM). Presently, the LEM stands out as the most commonly employed approach. The LEM approach applies the force balance principle, presuming the potential occurrence of landslides. This method determines the ratio between the pushing force (ensuring force equilibrium) and the resistance force (maintaining moment equilibrium). The assumption is that the landslide plane is divided into several slices for analysis. This method allows for slope stability analysis through a 2D approach. The analysis using the LEM in a 2D context can be performed using applications like Plaxis LE and Geostudio, employing methods developed by Fellenius, Bishop, Janbu, and Spencer.

Liong et al. (2012) conducted research on slope stability, specifically focusing on embankment stability in a 2D context. Their analysis employed both the limit equilibrium and finite element methods In this comparative study, data was taken from real cases of slope failure that have been published and that have not been published. The first project involves an embankment in Malaysia constructed on soft clay soil, collapsing at a height of 5.4 m with a slope of 1:2. In the second project, an embankment built on soft soil with a depth of 12 m and a slope of 1:3 experienced a collapse at a height of 4 m. The third project, featuring an embankment with a 1:2 slope, collapsed at a height of 3.2 m and was constructed on clay base soil with a groundwater level approximately 0.5 meters from the original ground level. According to the research findings, safety factor values, determined through the LEM and FEM methods, range from 0.99 to 1.16.. Predictions of collapse patterns from the two methods tend to have the same results where the percentage difference in the analysis results of the two methods is still within acceptable limits (±5%).

In the study conducted by Luriyanto et al. (2014) on the Pringsurat KM road section (22+631 - 22+655) in Temanggung Regency, an analysis of slope stability and mitigation measures was performed in heterogeneous soil types. Geotechnical analysis was carried out using both a manual 2D approach and auxiliary programs. Following Whitlow's (1995) multilayer soil method for manual analysis and utilizing Plaxis V.8.2 software for program analysis, the manual slope stability analysis yielded a safety factor (SF) of 1.01761 (trial 3). In contrast, the Plaxis V8.2 program resulted in an SF value of 0.8305, suggesting landslide susceptibility as the SF was < 1.5. Landslide mitigation involved reinforcement with Geotextile type BW250 Woven, resulting in a safety factor 1.4114. An alternative approach involving Bored Pile reinforcement combined with earth embankment yielded a safety factor 1.4617.

Similarly, Putra et al. (2012) investigation focused on assessing the stability of slopes along road structures and devising strategies to reinforce retaining walls. The study occurred in Bantas Village, East Selemadeg District, Tabanan Regency. Employing a simplified 2D Bishop Slice Method, the slope stability assessment includes dividing the slope into three sections, categorized by their coordinate locations and soil type present. The analysis findings for slope stability at the road structure's lower and upper sections indicated an average safety factor against landslides below 1. An alternative construction plan was suggested to reduce the risk of landslides. This entails the installation of a cantilever retaining wall with reinforced concrete at the base of the road structure, along with gravity retaining walls incorporating stone masonry at the top. This construction approach is maintained until stability is attained, ensuring a safety factor (Fs) exceeds 1.5. Differences in soil type cause the differences in results from each previous study, assumed landslide planes, and slope slopes used so that the data can only be used in a particular location and not in general. Shoffiana et al. (2022) conducted a study on slope stability using the limit equilibrium method, focusing on general layered soil conditions. The research specifically analyzed the comparison of reinforcement requirements for road body slopes on soft soil using both 2D and 3D methods. The study utilized soft soil layered conditions and explored slope stability across height, width, and slope variations. The findings revealed that the 2D safety factor (SF 2D) was consistently less than 1.5 for all embankment variations, indicating susceptibility to collapse. Interestingly, the safety factor's magnitude showed no distinct correlation with the embankment's height, width, or slope.Moreover, the research highlighted a correlation between the required reinforcement and the embankment's height, width, and slope. This suggests that these specific parameters influence the amount of reinforcement needed. Additionally, a relationship was observed between the amount of reinforcement required and the slope of the embankment, providing valuable insights into optimizing reinforcement strategies based on slope characteristics. This research analyzed slope stability on general layered soil; the application used to analyze slope stability was Geostudio 2D. Apart from that, in this study, the landslide areas that occurred were mostly described as being as wide as variations of embankments, even though the area of landslides that occurred in the field was generally only ½ of the width of the embankments. The results of slope stability analysis using the limit equilibrium method with different applications will produce different safety results and cause the amount of reinforcement required to be different.

Therefore, further research was carried out on the analysis of 2D boundary balance modelling with the length of the landslide area limited to ½ the width of the embankment using the Plaxis LE auxiliary program by paying attention to the need for reinforcement and then comparing it with the analysis results of the Geostudio auxiliary program so that it can be seen which method is more effective to use.

RESEARCH METHOD AND LITERATURE REVIEW

Assessing the stability of slopes in a two-dimensional context

Examining slope stability in a two-dimensional context assumes the infinite extension or continuous length of the landslide area. Several researchers have developed the two-dimensional LEM for the analysis of slope stability. A notable contributor, Fellenius (1936), introduced the slice method, which is considered a straightforward approach. Fellenius' slice method neglects all forces between slices, concentrating solely on moment balance. In this method, the failure plane is depicted as a circular arc. Figure 1 illustrates the planar surface and the forces acting on the slice. According to Fellenius (1936), the safety factor can be calculated using the following equations:

$$F = \frac{\sum_{n=1}^{n=p}(c.\Delta L_n + W_n.cos\alpha_n.\tan\phi)}{\Sigma W_n.sin\alpha_n} \quad \ldots(1)$$

$$F = \frac{\sum_{n=1}^{n=p}(c.\frac{b_n}{cos\alpha_n} + W_n.cos\alpha_n.\tan\phi)}{\Sigma W_n.sin\alpha_n} \quad \ldots(2)$$

The equation for slope stability when influenced by the groundwater table:

$$F = \frac{\sum_{n=1}^{n=p}(c.\Delta L_n + [W_n.cos\alpha_{n-U.\Delta L_n}]\tan\phi)}{\Sigma W_n.sin\alpha_n} \quad \ldots(3)$$

Where:

- c = soil cohesion
- ϕ = angle friction
- b_n = width of n slice
- W_n = weight of n slice
- α_n = slip plane of n slice
- U = pore water pressure

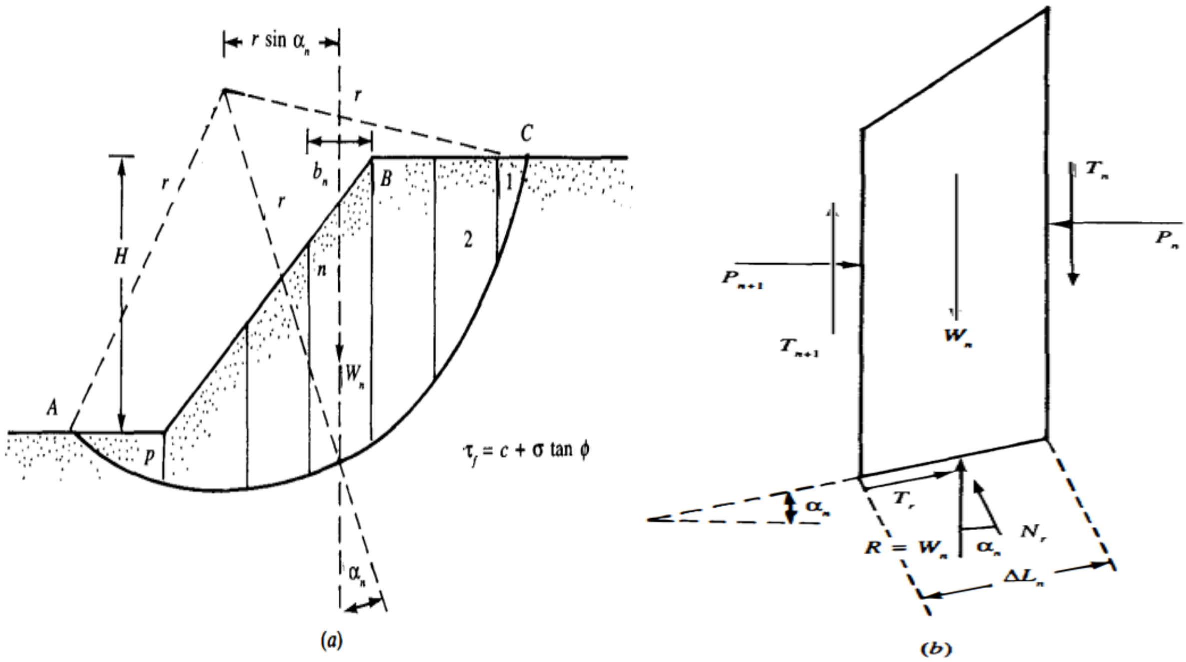

Figure 1. Ordinary method slope stability analysis; (a) Plane surface; (b) the force acting on the n[th] slice (Braja M. Das Volume 2 ; 1993)

Related Application (Plaxis LE)

Plaxis LE is a supporting program that can model and analyze geoengineering projects using the Limit Equilibrium Method (LEM), in 2D and 3D in one application. Plaxis LE carries out analysis using the limit equilibrium method (LEM) or stress-based methods from classical intersection methods such as the Bishop, Janbu, Spencer, Morgenstern-Price, GLE, and Sarma methods.

The analysis process in Plaxis LE begins by selecting the model concept used, the model concepts that can be selected are: Slope Stability, Consolidation, Groundwater and Dynamics, then selecting the system used in 2D or 3D, if the analysis selected is slope stability then the next step is to select unit and slip direction, where the slip direction contained in the auxiliary program is left to right, right to left and multiple orientation. The next step is to draw the geometry and determine the desired surface by entering (input) the coordinates of the area you want to analyze. After the geometric depiction is carried out, the next step is setting up the model and setting up the analysis method. Analytical methods that can be used include the ordinary/Fellenius, Bishop simplified, Janbu simplified, Spencer, Morgenstren-Prince, GLE (Fredlund) and Sarma methods. The next step is setting the slip direction or setting the plane and angle of sliding that occurs. After that, the properties of the material used are set. The input material properties required in this auxiliary program are the values of wight or gamma units (γ), cohesion (c) and angle of friction in the soil (ϕ) for each layer of soil used. After all the settings have been made, the limit balance analysis can be carried out and the results of the analysis will be known. The output obtained from the analysis using Plaxis LE is the safety factor (SF), resistance moment, pushing moment, landslide center point, and landslide plane radius.

Geotextile Reinforcement

Geotextile, a permeable synthetic material made from polymer textiles like polyester or polypropylene, serves various purposes, including separation, filtration, protection, and reinforcement. Geotextiles are generally classified into two types: woven and non-woven. Woven geotextiles, known for their higher tensile strength than non-woven counterparts, are particularly useful in stabilizing subgrades, especially in soft subgrade conditions.

The calculation of the required geotextile reinforcement relies on the tensile strength of the geotextile, determining its capacity to withstand or bear shear forces during a landslide. This study specifies the ultimate strength of geotextile (Tult) as 250 kN/m. The tensile strength can be determined using the following equation:

$$Tall = Tult \left(\frac{1}{FS_{ID}.FS_{CR}.FS_{CD}.FS_{BD.}}\right) \quad \text{...(4)}$$

Where :

Tall	= The strength of the geotextile is determined based on its specifications
Tult	= ultimate strength of geotextile
FSID	= Safety margin resulting from installation inaccuracies
FSCR	= Safety margin attributable to creep
FSCD	= Safety margin resulting from chemical impact
FSBD	= Safety margin arising from biological impact

When determining the necessary geotextile reinforcement, essential data includes geotextile tensile strength (Tall), safety factor value (SF), resisting moment (MR), the centre point of the failure line, and the failure radius (R). The required reinforcement amount is then derived by calculating the moment to be resisted by the geotextile (ΔMR) using Equations 5 to 7:

$$MD = \frac{\text{MRexisting}}{\text{SF}} \quad \text{...(5)}$$

$$\Delta MR = MR_{plan} - MR_{existing} \quad \text{...(6)}$$

$$\Delta MR = (SF_{plan} \times MD) - MR_{existing} \quad \text{...(7)}$$

Where:

MD	= driving moment
MR	= resisting moment
SF	= existing safety factor value
SF design	= plan safety factor value or minimum = 1.5 (SNI:8460, 2017)
ΔMR	= moment that will be resisted by geotextile

The computation of the required geotextile amount is conducted incrementally, progressing through stages until the cumulative moment of the geotextile (ΣMgeotextile) equals or surpasses ΔMR, as determined by Equations 8 to 10:

$$\text{Mgeotextile} = \text{Tall} \times \text{Ti} \quad \text{...(8)}$$

$$\Sigma\text{Mgeotextile} \geq \Delta MR \quad \text{...(9)}$$

$$\Sigma\,(\text{Tall} \times \text{Ti}) \geq \Delta MR \quad \text{...(10)}$$

Where:

Ti = vertical distance of each geotextile to the landslide center point

DATA AND MATERIAL

Determination of Ground Layer Data

The foundational soil data utilized in this study aligns with the findings of Shoffiana et al. (2022). The soil characteristics correspond to soft soil, encompassing very soft, soft, and medium consistencies. The compressible soil has a total thickness of 30 meters, distributed as follows: 3 meters of very soft consistency, 14 meters of soft consistency, and 13 meters of medium consistency. This soil data was sourced from Ardana and Mochtar (1999), and **Figure 2** provides an illustrative representation of the basic soil profile.

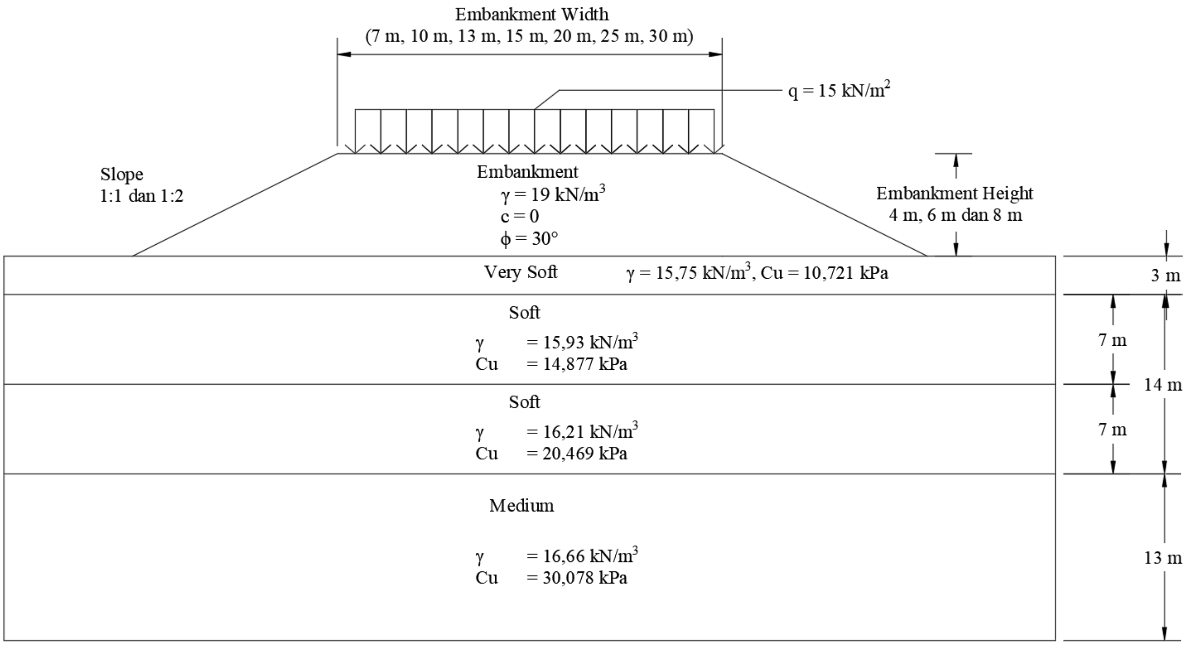

Figure 2. Illustration of embankment and subgrade soil

Determination of Embankment Data

The embankment soil employed in this research consists of granular soil. The parameters for the embankment soil are as follows: the unit weight (γ) is 19 kN/m³, cohesion is 0, the friction angle (ϕ) is 30 degrees, and q is 15 kN/m², representing the applied traffic load.

Determination of Embankment Variations

The variations used in this research are as follows:

The width of the top of the embankment varies based on the type of road as follows:

1. Normal road width (B = 7 – 15 m) → 7 m, 10 m, 13 m
2. Toll road width (B = 15 – 30 m) → 15 m, 20 m, 25 m, 30 m

Variations in embankment height used are 4 m, 6 m, 8 m

The variations in embankment slope used are 1:1 and 1:2

RESEARCH ANALYSIS

2D Safety Factor Calculation Results with Plaxis LE

The analysis of 2D slope stability was conducted using the Plaxis LE auxiliary program, employing the Limit Equilibrium Method (LEM) through the Ordinary Method, also known as the Fellenius Method (1936). The delineation of landslide areas or slopes was accomplished using the entry and exit method, establishing boundaries to identify the locations where landslide occurrences occur.

Each model provides multiple potential landslide areas along with corresponding safety factor values. Additionally, for each identified landslide area, crucial information such as the landslide centre point (X and Y), radius (R), and moment of resistance (Mres) can be determined. These parameters are instrumental in calculating the required reinforcement for the slope. **Figure 3** displays the results of the slope stability analysis for an embankment with dimensions H = 4 m, B = 7 m, and a 1:1 slope ratio. The smallest or most critical safety factor obtained from the analysis is 0.624. The same comprehensive analysis is replicated for all variations in the embankment's height, width, and slope.

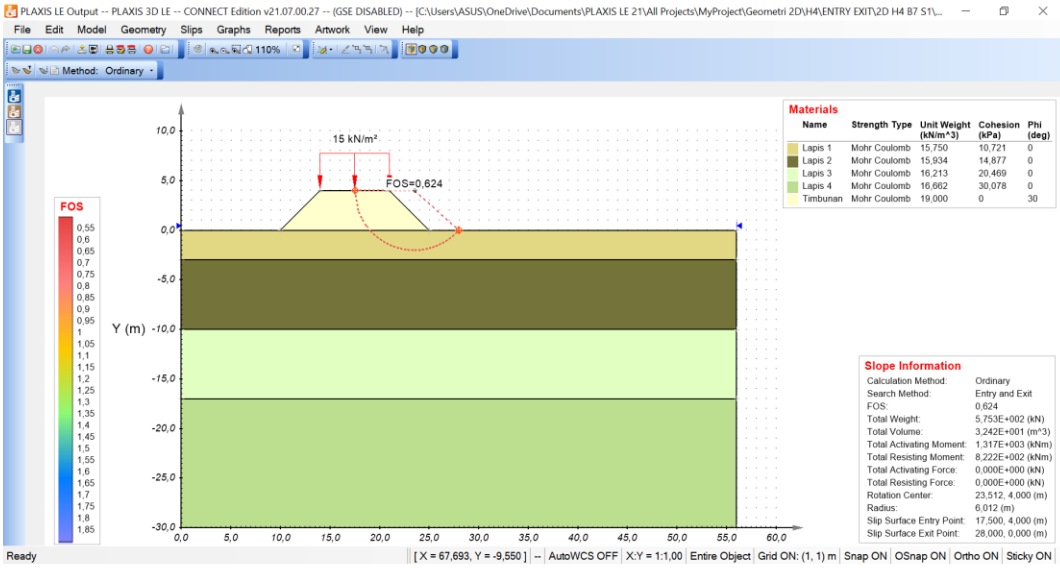

Figure 1. Plaxis LE 2D output for Embankment H = 4 m, B = 7 m, and Slope 1:1

In planning slope reinforcement, the safety factor chosen is not necessarily the smallest or most critical; instead, the safety factor associated with the largest number of reinforcement requirements is considered. Consequently, the reinforcement quantity is initially computed for each potential landslide area, and subsequently, the safety factor linked to the greatest reinforcement amount is selected. Following the calculation of reinforcement needs for 11 possible landslide areas, the areas requiring the most substantial strengthening become evident. **Table 1** summarises the 11 potential amounts of geotextile reinforcement required for variations of the embankment with dimensions H = 4 m, B = 7 m, and a 1:1 slope ratio using the 2D method.

Table 1. The Summary 11 Possible Amount of Geotextile Reinforcement Requirements for Most Variations of H = 4 m, B = 7 m, and Slope 1:1 2D Method

No.	SF	Center X (m)	Center Y (m)	Radius (m)	Resistance Moment (kNm)	Geotextile Reinforcement (Layer)
1	0,832	22,317	4,000	4,817	705,7	3
2	0,658	22,691	4,000	5,191	618,5	3
3	0,632	23,092	4,000	5,592	710,0	4
4	0,624	23,512	4,000	6,012	822,2	5
5	0,629	23,946	4,000	6,446	956,1	5
6	0,641	24,390	4,000	6,890	1105,0	6
7	0,689	24,985	4,481	7,500	1332,0	6
8	0,747	25,771	5,702	8,444	1592,0	4
9	0,810	26,233	5,808	8,918	1887,0	4
10	0,874	26,890	6,703	9,772	2188,0	4
11	0,926	27,000	5,281	9,586	2559,0	5

According to Table 1, for embankment variations with H = 4 m, B = 7 m, and a 1:1 slope ratio, the safety factor associated with the greatest reinforcement requirement is 0.689. The corresponding outcomes from the Plaxis LE auxiliary program are illustrated in **Figure 4**.

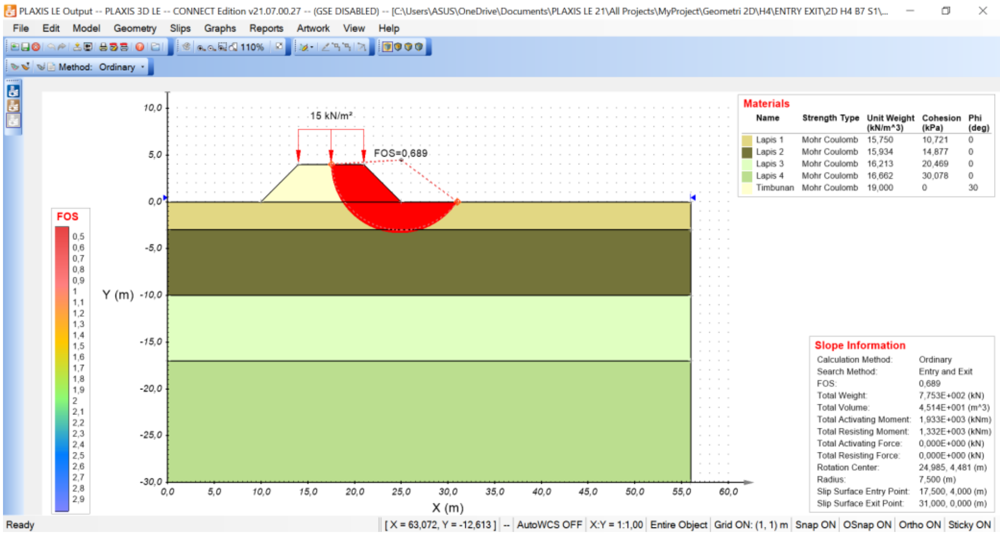

Figure 2. Landslide plane for embankments with variations of H = 4 m, B = 7 m, and Slope 1:1, which has the most reinforcement

Based on **Table 1**, the maximum reinforcement required does not depend on the SF or moment resistance values. Therefore, the same analysis will be carried out for all variations in the embankment's height, width, and slope. A recapitulation of 2D slope stability safety figures can be seen in **Table 2**.

Table 2. Summary of 2D Slope SF Values

Embankment Width (m)	Slope	SF 2D		
		H = 4 m	H = 6 m	H = 8 m
7	1:1	0,689	0,661	0,558
	1:2	0,960	0,671	0,542
10	1:1	0,838	0,586	0,502
	1:2	0,903	0,644	0,513
13	1:1	0,795	0,562	0,470
	1:2	0,845	0,610	0,494
15	1:1	0,779	0,563	0,456
	1:2	0,828	0,606	0,486
20	1:1	0,765	0,551	0,438
	1:2	0,806	0,589	0,521
25	1:1	0,770	0,550	0,436
	1:2	0,804	0,584	0,539
30	1:1	0,787	0,559	0,441
	1:2	0,812	0,585	0,559

Table 2 indicates that, for all variations in embankment dimensions, the 2D safety factor is consistently less than 1.5 (SF 2D < 1.5), indicating that the embankments have collapsed. Notably, the 2D safety factor varies for embankments with the same height but widths. Interestingly, the magnitude of the 2D safety factor does not exhibit a specific correlation with the embankment width. This discrepancy is attributed to the fact that the 2D safety factor is associated with the highest reinforcement requirements rather than the minimum safety factor

2D Moment Resistance Calculation Results with Plaxis LE

The output of the slope stability analysis using the Plaxis LE application, apart from the safety factor value, is the value of the moment of resistance. This moment resistance value will calculate the need for strengthening embankments with Geotextiles can be seen in **Table 3**.

Table 3. The Summary of 2D Slope Moment Resistance Values

Embankment Width (m)	Slope	Momen Resistance (kNm)		
		H = 4 m	H = 6 m	H = 8 m
7	1:1	1332	3326	4503
	1:2	4030	5368	8027
10	1:1	3077	3508	5068
	1:2	4647	6566	8878
13	1:1	3629	4058	5653
	1:2	5324	6826	9782
15	1:1	4016	4936	6093
	1:2	5801	7907	10410
20	1:1	5093	6064	7230
	1:2	7085	9381	13333
25	1:1	6322	7370	8588
	1:2	8504	10970	15890
30	1:1	7648	8777	10100
	1:2	10030	12740	18560

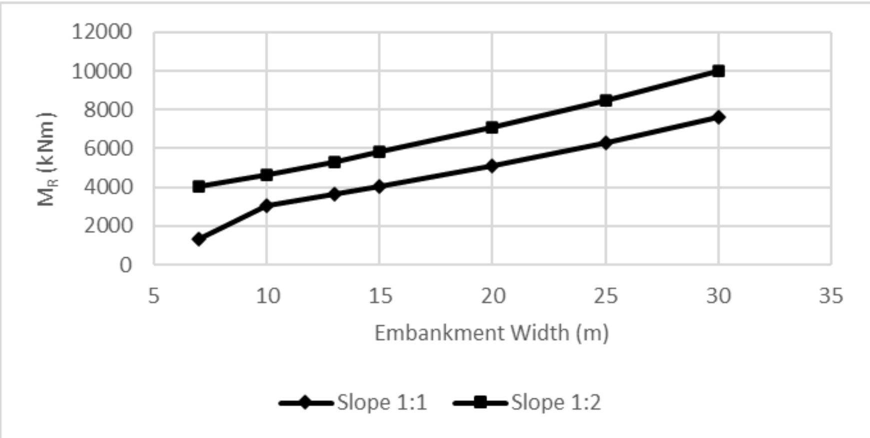

Figure 3. The relationship between embankment width and Mr value for embankment H=4 m

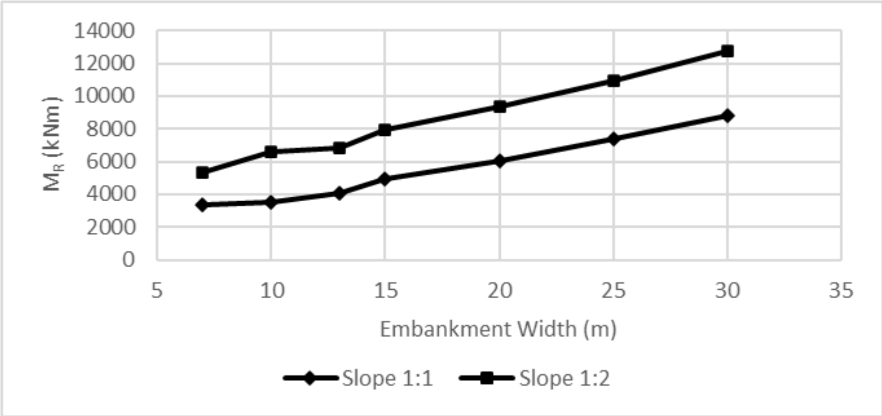

Figure 4. The relationship between embankment width and Mr value for embankment H=6 m

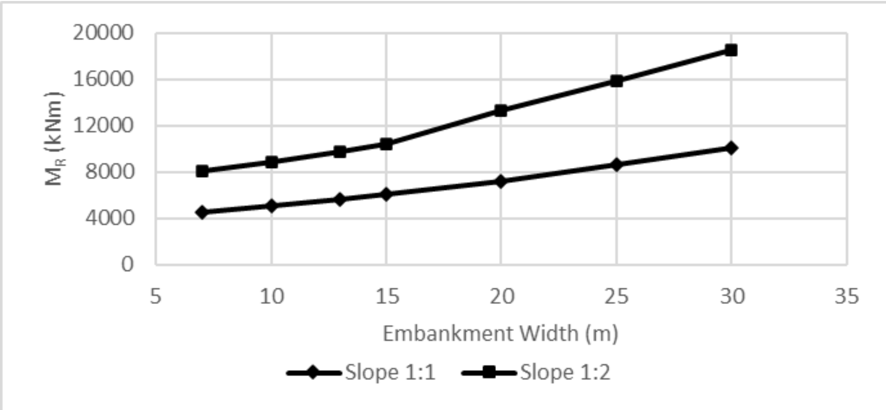

Figure 5. The relationship between embankment width and Mr value for embankment H=8 m

Based on **Table 3** and **Figures 5 to 7**, it can be seen that there is a relationship between embankment width and moment resistance value. If viewed at the same height, the wider the embankment, the more excellent the moment resistance. There is another relationship between the width of the embankment and the moment resistance value, namely that with the same width and height, an embankment with a gentler slope will produce a more excellent moment resistance value.

Perform the computation to determine the necessary quantity of geotextile reinforcement

Compute the required amount of geotextile reinforcement using Equations 4 to 10. The summarized reinforcement requirements are presented in **Table 4**.

Table 4a. Summary of Geotextile Reinforcement Needed

Embankment Width (m)	Slope	Geotextile Reinforcement (layer)		
		H = 4 m	H = 6 m	H = 8 m
7	1:1	6	12	17
	1:2	7	23	36
10	1:1	7	20	29
	1:2	8	24	44
13	1:1	8	23	33
	1:2	10	27	57

Table 4b. Summary of Geotextile Reinforcement Needed

Embankment Width (m)	Slope	Geotextile Reinforcement (layer)		
		H = 4 m	H = 6 m	H = 8 m
15	1:1	9	23	36
	1:2	11	28	60
20	1:1	12	28	45
	1:2	13	29	66
25	1:1	12	28	58
	1:2	13	29	76
30	1:1	13	31	65
	1:2	14	32	87

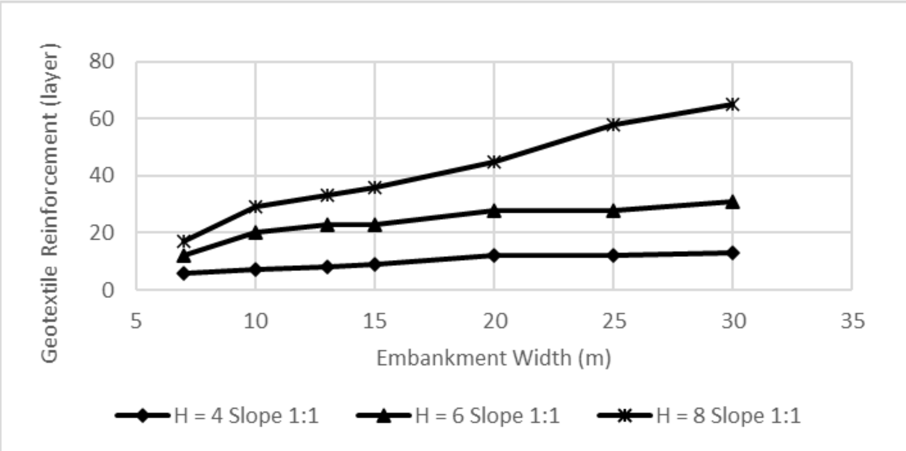

Figure 6. Chart illustrating the correlation between the width of the embankment and the quantity of geotextile required for a slope with a 1:1 ratio.

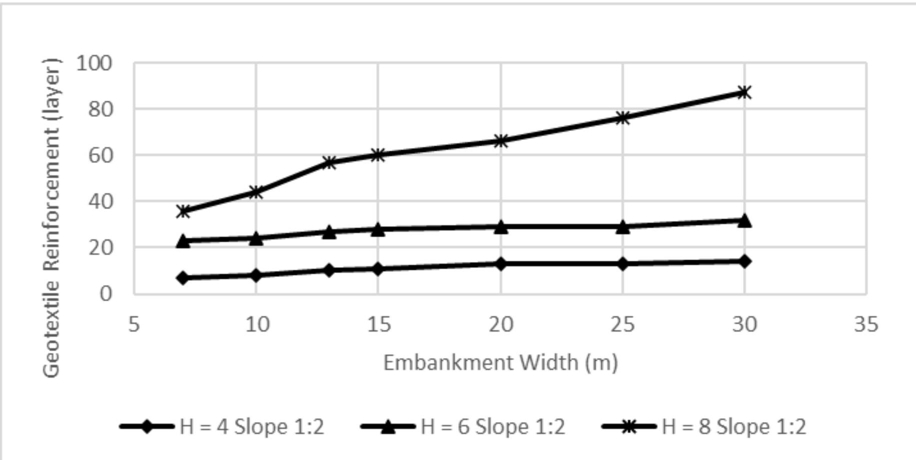

Figure 7. Chart illustrating the correlation between the width of the embankment and the quantity of geotextile required for a slope with a 1:2 ratio.

Based on the data presented in **Table 4** and the patterns observed in Figures 8 to 9, a correlation exists between the quantity of reinforcement needed and the embankment's height, width, and slope. Specifically, an increase in the embankment width corresponds to a higher demand for geotextile reinforcement for embankments with the same height and slope. This aligns with the findings of a prior study on the comparison of reinforcement needs for road slopes on soft soil using both 2D and 3D methods, which emphasized that the requirement for geotextile reinforcement escalates with an increase in the width of the embankment with consistent height and slope (Shoffiana et al., 2022).

Additionally, other research focusing on the analysis of geotextile reinforcement needs for varying embankment heights in soft soil suggests a linear correlation between embankment height and the required amount of geotextile, indicating that as the embankment height rises, there is an increased need for geotextile reinforcement (Septiandri et al., 2021). These findings echo the results obtained in the present study.

Moreover, another observed relationship involves embankments with the same height and width but with a gentler slope (slope 1:2), necessitating a notably higher quantity of geotextile reinforcement. This phenomenon is attributed to embankments with gentler slopes exhibiting greater moment resistance values, requiring more reinforcement. Furthermore, Figures 8 to 9 illustrate that with the same width and slope of the embankment, an increase in the embankment height corresponds to a heightened demand for geotextile reinforcement.

Comparison of the Amount of 2D Slope Stability Strengthening Requirements

The analysis of the amount of 2D slope stability reinforcement needed in this research will be compared with the results of previous research from Shofiana, et al (2022) , which used the Geostudio support program in its analysis. A plot of the reinforcement required between Plaxis LE and Geostudio can be seen in **Figures 10 to 12.**

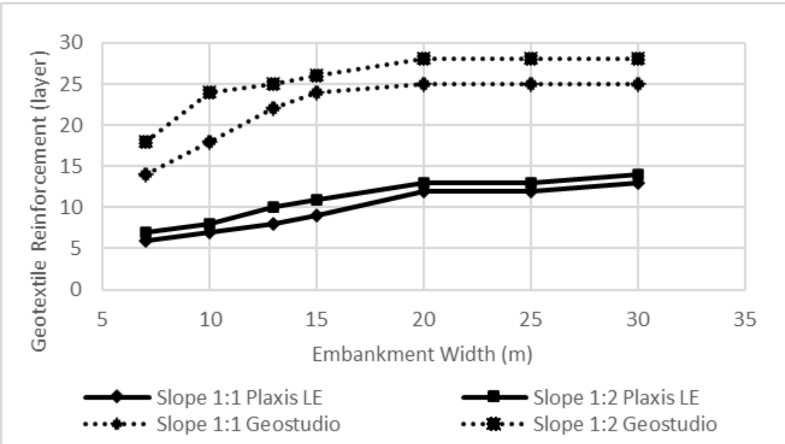

Figure 8. Comparison graph of the use of the Plaxis LE application with Geotudio on the results of strengthening requirements for embankments with H = 4 m

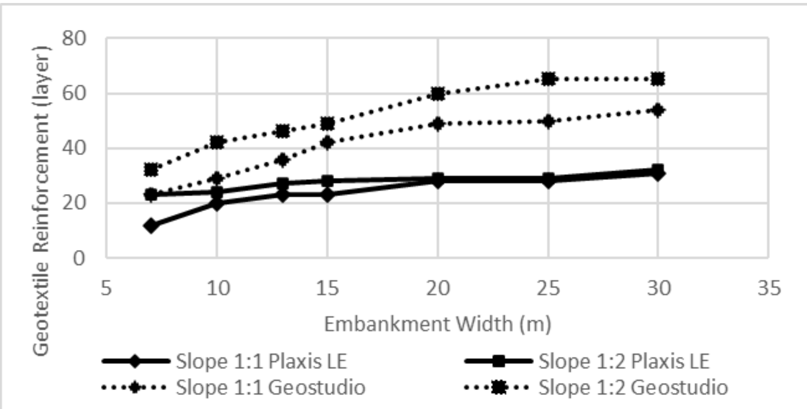

Figure 9. Comparison graph of the use of the Plaxis LE application with Geotudio on the results of strengthening requirements for embankments with H = 6 m

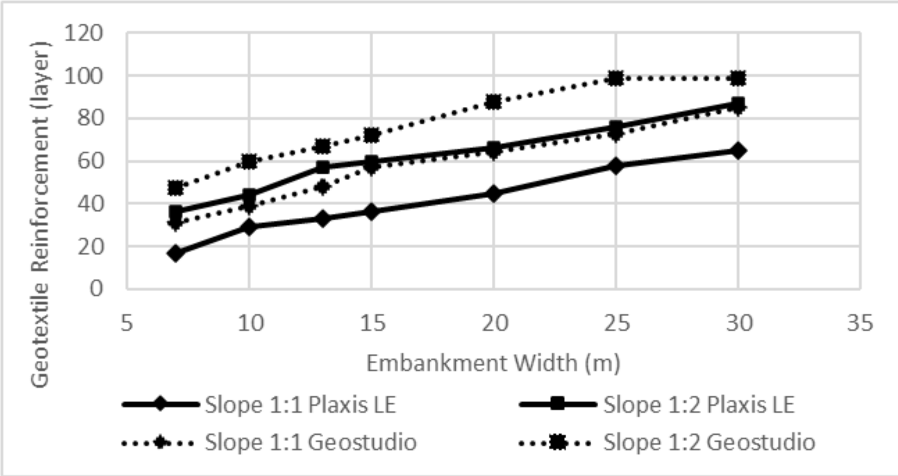

Figure 10. Comparison graph of the use of the Plaxis LE application with Geotudio on the results of strengthening requirements for embankments with H = 8 m

Figures 10 to 12 depict the reinforcement requirements for enhancing the stability of 2D embankments using Plaxis LE, while Geostudio yields distinct results. Geostudio exhibits a higher count of reinforcement requirements compared to Plaxis LE across all variations. This disparity in the required reinforcement may be attributed to variations in the positions of landslide planes on identical embankment configurations between Plaxis LE and Geostudio**.** **Figure 13** illustrates the contrast in the landslide field positions between Plaxis LE and Geostudio**.**

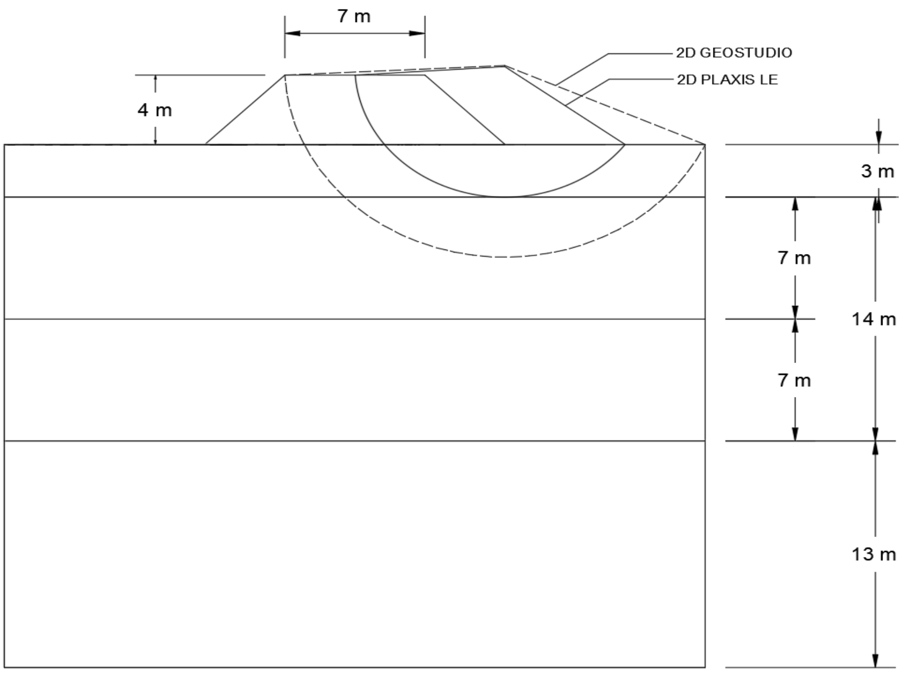

Figure 11. Landslide plane for embankment with H = 4 m, B = 7 m, slope 1:1 with the help of Plaxis LE and Geostudio programs

Observing **Figure 13** reveals that the landslide plane in the embankment exhibits similar variations between different Plaxis LE and Geostudio analyses. However, the Geostudio landslide plane possesses a larger radius than the Plaxis LE landslide plane. This discrepancy contributes to differences in the safety factor and moment resistance values, influencing the required amount of embankment reinforcement. Subsequently, we will quantify the extent of the difference in the reinforcement amount by calculating the ratio between the two reinforcement quantities, as illustrated in **Table 4**.

Table 4. Recapitulation of Geotextile Ratio Reinforcement Needed Plaxis LE and Geostudio

Embankment Width (m)	Slope	Geotextile Reinforcement Plaxis LE/ Geotextile Reinfocement Geostudio		
		H = 4 m	H = 6 m	H = 8 m
7	1:1	0,548	0,522	0,548
	1:2	0,766	0,719	0,766
10	1:1	0,744	0,690	0,744
	1:2	0,733	0,571	0,733
13	1:1	0,688	0,639	0,688
	1:2	0,851	0,587	0,851
15	1:1	0,632	0,548	0,632
	1:2	0,833	0,571	0,833
20	1:1	0,703	0,571	0,703
	1:2	0,750	0,483	0,750
25	1:1	0,795	0,560	0,795
	1:2	0,768	0,446	0,768
30	1:1	0,765	0,574	0,765
	1:2	0,879	0,492	0,879

The ratio of the difference in the amount of reinforcement for Plaxis LE and Geostudio is 0.446 to 0.879. After calculating using statistical methods, the ratio of these differences is relatively the same so that an average value can be taken, and it can be concluded that the need for Plaxis LE reinforcement = 0.7 Geostudio Reinforcement Requirement for all variations with soft, layered soil conditions.

CONCLUSION

Based on the outcomes of the slope stability analysis utilizing the Limit Equilibrium method, the following conclusions can be drawn:

1. The 2D safety factor derived from Plaxis LE for all embankment variations is consistently less than 1.5 (SF 2D < 1.5), falling within the range of 0.439 to 0.960.
2. The 2D Moment Resistance value produced from Plaxis LE for all embankment variations ranges from 1332 kNm – to 18560 kNm.
3. The amount of geotextile reinforcement required with the Plaxis LE application = 0.7, which is the amount of reinforcement required with Geostudio for all variations with layered soft soil conditions

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