(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Volume 4, Issue 2, August 2022

Comparison of Embankment Reinforcement Requirements with Geotextile on Soft Soil with 2D and 3D Slope Stability Analysis Methods

Nur ‘Arfiati Shoffiana[1,a)], Yudhi Lastiasih[2,b)] & Trihanyndio Rendy Satrya[2,c)]

[1)]Magister Student, Civil Engineering Dept, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2)]Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Correspondent : [a)]nurarfiatis11@gmail.com, [b)]yudhi.lastiasih@gmail.com & [c)]trendysatrya@its.ac.id

ABSTRACT

Slope stability analysis is very important in slope design so it can manage and maintain the infrastructure assets. If the slope is unstable, it can damage the infrastructure around the slope. The method commonly used in slope stability analysis is 2D modeling which assumes the length of the landslide area is not limited or continuous. Landslides that occur in the field are limited and not continuous, so 3D modeling is more suitable than 2D modeling. 3D slope stability analysis has been developed by various researchers. Most of the results of previous studies stated that the 3D and 2D factor of safety ratio were more than one for cohesive soils and less than one for non-cohesive soils. This safety factor affects the amount of reinforcement needed. Differences in 2D and 3D safety factors will cause differences in the amount of reinforcement needed. Therefore, this study was conducted to determine the differences in the 2D and 3D slope stability analysis result. Slope stability analysis was carried out using LEM, where the 2D slope stability used the Fellenius method while the 3D slope stability used the Hovland method. Calculate the required reinforcement amount using geotextiles with Tilt = 250 kN/m. The results obtained from this study are the 2D safety factor is smaller than the 3D safety factor. The 3D and 2D safety factor ratios range from 1.09 – 1.397. While the amount of reinforcement required in the 3D analysis is less than in the 2D analysis with the ratio of 3D and 2D reinforcement requirements ranging from 0.5 to 0.955 depending on the width and height of the embankment.

Keywords: Infrastructure asset management, slope stability, 2D analysis, 3D analysis, safety factor, geotextile reinforcement

INTRODUCTION

Nowadays, infrastructure is developed massively in Indonesia. Based on the Infrastructure Asset Management (IAM), infrastructure must be well managed through all stages of its life cycle from infrastructure idea, planning design, construction, operation, maintenance, and infrastructure disposal when it’s no longer needed (Suprayitno & Soemitro, 2018). Examples of infrastructure are dams, roads, bridges, irrigation, etc. Each infrastructure has its particular function but the most important thing is the infrastructure must have a sustainable function (economic, social, environmental) (Suprayitno & Soemitro, 2018; Suprayitno et al 2020).

In infrastructure development, elevation adjustments are needed because there are a lot of infrastructures to be built on hills and valleys. This condition causes the infrastructure to be built on an embankment slope or an excavation slope. A slope, both embankment slope, excavation slope, and natural slope must be designed to be stable and safe. Unstable embankment slopes can potentially lead to landslides that can cause damage to the infrastructure built on it. Likewise with the slope of an excavation. If the slope of the excavation is unstable, it can cause the infrastructure in the excavation to be damaged by landslides. Slope stability analysis is an analysis that can estimate the stability and safety of a slope by calculating the factor of safety (SF) of the slope. On artificial slopes (embankment and excavation), slope stability analysis will be easier to do than on natural slopes which need to pay attention to changes in slope angle in one form of height (Wardani et al, 2019). The safety factor can be influenced by changes in groundwater level, river water level around the slope, and scouring on the slope (Sugiarto et al, 2022). Based on SNI 8460:2017, the slope safety factor required for soil slope stability analysis is 1.5. Therefore, slope stability analysis is very important in embankment and excavation slope design so it can maintain the infrastructure assets.

Slope stability analysis can be carried out using several methods, such as the Limit Equilibrium Method (LEM), Finite Element Method (FEM), Finite Difference Method (FDM), and others. The most popular and frequently used method is the LEM. Slope stability analysis is generally carried out using 2D modeling. This model assumes that the landslide area that occurs has an unlimited or continuous length. But in fact, the landslides that occur in the field are local and not continuous so the 2D modeling becomes less suitable. Based on this, 3D modeling becomes more suitable for use in planning.

Research on 3D slope stability has been carried out by many researchers. The researchers developed the basic theory of 2D slope into the 3D slope. Most of the results of previous studies stated that the 3D and 2D factor of safety ratio was more than one (SF 3D > SF 2D) for cohesive soils and less than one (SF 3D < SF 2D) for non-cohesive soils (Sari et al, 2020). Research conducted by Chen and Chameau (1982) stated that the ratio of the 3D and 2D safety factors was between 0.98 – 1.5. A similar study was conducted by Gens and Hutchinson (1988) and resulted in a safety factor ratio ranging from 1 to 1.7. Another study was conducted by Bahsan and Fakhriyyanti (2018) and the average safety factor ratio obtained was 1.44. Dana et al (2018) conducted a comparative analysis of the 3D and 2D safety factor values in the open-pit mines area and produced a ratio of 1.17 for gentle slopes and 1.29 for steep slopes. The difference in the results of each previous study is caused by differences in soil types, assumptions of landslide fields, and slopes used. The summary of the results from previous studies is presented in **Table 1.**

The safety factor obtained from previous studies is only a minimum safety factor so research on the comparison of 2D and 3D slope stability analysis has not been completed. This is because the safety factor (SF) obtained from the slope stability analysis will affect the planning of slope reinforcement requirements. In planning the need for slope reinforcement, the safety factor used is not the smallest or the most critical factor of safety but must be calculated for each possible landslide area with various safety factor values. This is because the smallest safety factor does not guarantee getting the largest amount of reinforcement needed.

2D and 3D safety factors may be different, thus allowing for differences in the number of reinforcement requirements. The method used to calculate the amount of reinforcement in the 3D analysis is the same as that used in the 2D analysis. In the same way, the comparison of the amount of reinforcement needed between 2D and 3D is not directly proportional to the comparison of the value of the safety factor. This is because other factors affect the amount of reinforcement needed, such as the resisting moment and the center point of the landslide.

Research on the comparison of the amount of reinforcement needed between 2D and 3D has previously been carried out by Shoffiana et al (2021). The research was conducted using two soil conditions, namely homogeneous soil conditions and heterogeneous subgrade conditions (layered soil). The results obtained from this study are the number of requirements for geotextile reinforcement for homogeneous soil conditions is relatively the same between the results of 2D and 3D analysis. While the results obtained for heterogeneous subgrade conditions are uncertain where under certain conditions, the amount of need for 2D reinforcement is more than 3D, and in other conditions, the amount of need for 2D reinforcement is less than 3D. The uncertainty of the results obtained is because the subgrade data used is soil at a certain location so it cannot be used in general.

Given the uncertainty of the results on heterogeneous soils, it is not clear how far the difference in the amount of reinforcement required between 2D and 3D analyzes of the layered subgrade is. Therefore, it is necessary to analyze the difference in safety factors between the results of the 2D and 3D modeling analysis on the amount of reinforcement needed in general layered soil conditions, namely soft soil so that it can be seen which slope stability model is best used.

Table 1. The Summary of The Safety Factor Ratio for the 3D and 2D Slope Stability Base on Previous Studies

Procedure	Theoretical Basis	SF 3-D/SF 2-D
Chen dan Chameau (1983)	Spencer (1967)	> 1 for cohesive soil; < 1 for non-cohesive soil
Thomas dan Lovell (1988)		> 1 for cohesive soil not always for non-cohesive soil
Chen et al (2003)		>1
Jiang dan Yamagamu (2004)		>1
Baligh dan Azzouz (1975)	Fellenius (1922)	>1
Hovland (1977)	Fellenius (1927)	> 1 for cohesive soil; < 1 for non-cohesive soil
Ugai (1988)	Fellenius (1936)	> 1 for cohesive soil; < 1 for non-cohesive soil
Gen et al (1988)	Fellenius (1922)	>1
Xing (1988)	Fellenius (1927)	>1
Hungr (1987)	Bishop (1955)	>1
Ugai (1988)		> 1 for cohesive soil; < 1 for non-cohesive soil
Hungr et al (1989)		>1
Huang dan Tsai (2000)		>1
Cheng dan Yip (2007)		>1
Anagnosti (1969)	Mogenstern and Price (1965)	>1
Hungr (2001)		
Sun et al (2012)		
Cheng dan Yip (2007)		
Hungr et al (1989)	Janbu Simplified (1965 and 1973)	>1
Huang et al (2002)		
Cheng dan Yip (2007)		

source: Sari et al (2020)

RESEARCH METHOD AND LITERATURE REVIEW

2D Slope Stability Analysis

The 2D slope stability analysis in this study used one of the Limit Equilibrium Methods (LEM), namely the Fellenius method (1936) or the ordinary method. The plane of failure in this method is a circular arc. The plane surface and the forces acting on the n^{th} slice can be seen in **Figure 1**. The factor of safety by Fellenius (1936) can be calculated using the following equation:

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

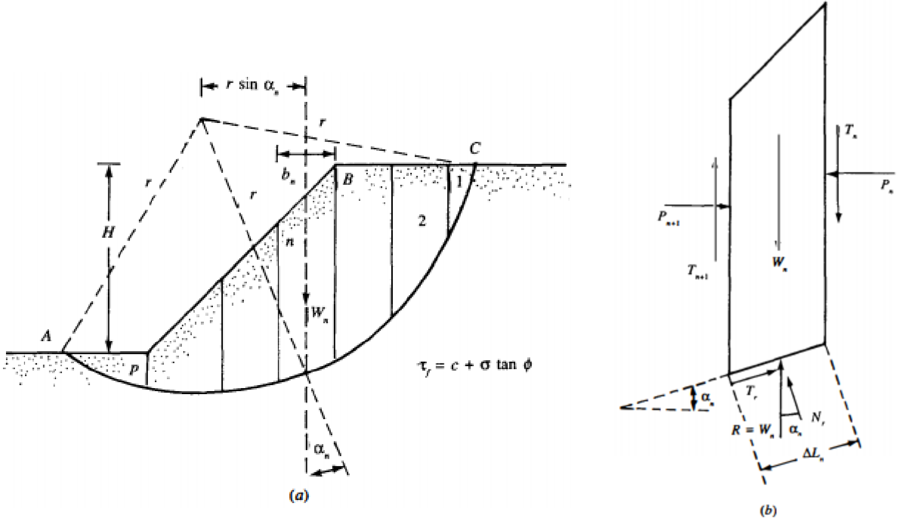
$$F = \frac{\sum_{n=1}^{n=p}\left(c.\frac{(b_n)}{\cos\alpha_n} + W_n.\cos\alpha_n.\tan\phi\right)}{\Sigma W_n.\sin\alpha_n} \qquad \ldots(2)$$

The equation when the slope is affected by the groundwater table:

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

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



Source: Braja M. Das volume 2 (1936)

Figure 1. Ordinary method slope stability analysis; (a) Plane surface; (b) The force acting on the nth slice

3D Slope Stability Analysis

Analysis of 3D slope stability in this study used the equation proposed by Hovland (1977). This method is a development of the ordinary method. The analysis is carried out by dividing the failure surface into several vertical soil columns like the 2D method. Calculation of the 3D safety factor used the following equation:

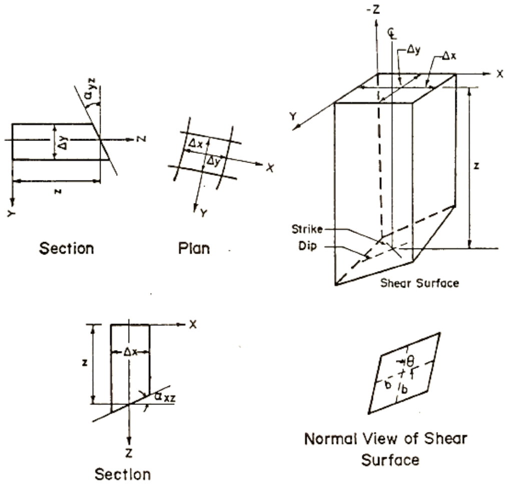
$$F_3 = \frac{\Sigma_x\Sigma_y\left\{\frac{c.\Delta x.\Delta y\sin\theta}{\cos\alpha_{xz}\cos\alpha_{yz}} + \rho.z.\Delta x.\Delta y\cos(DIP)tan\phi\right\}}{\Sigma_x\Sigma_y\,\rho.z.\Delta x.\Delta y\sin\alpha_{yz}} \qquad \ldots(4)$$

$$\cos(DIP) = \left(1 + tan^2\alpha_{xz} + tan^2\alpha_{yz}\right)^{-1/2} \qquad \ldots(5)$$

$$\sin\theta = \left(1 - sin^2\alpha_{xz}\,.sin^2\alpha_{yz}\right)^{1/2} \qquad \ldots(6)$$

Where:

F_3 : 3-D safety factor
c : soil cohesion
ϕ : angle friction
Δx : column width
Δy : column length
z : column height
α_{xz} : angle of slip surface in the x direction
α_{yz} : angle of slip surface in the y direction
ρ : soil density



Source: Chen (1981)

Figure 2. The cross-sectional shape and three-dimensional view of one soil column

Geotextile Reinforcement

The calculation of the geotextile reinforcement needs is influenced by the tensile strength of the geotextile in receiving or carrying shear forces that occur during landslides. The ultimate strength of the geotextile (Tult) used in this study is 250 kN/m. The tensile strength can be calculated using the following equation:

$$T_{all} = T_{ult}\left(\frac{1}{FS_{ID}.FS_{CR}.FS_{CD}.FS_{BD}}\right) \qquad \ldots(7)$$

Where:

Tall : geotextile strength based on specification
Tult : ultimate strength of geotextile
FS_{ID} : safety factor due to installation error
FS_{CR} : safety factor due to creep
FS_{CD} : safety factor due to chemical effect
FS_{BD} : safety factor due to biological effect

Besides the tensile strength of geotextiles, in calculating the required amount of geotextile reinforcement also requires data such as the safety factor (SF), the resisting moment (MR), the center point of the landslide, and the radius of the slide (R). The amount of reinforcement required is obtained from the calculation of the moment that will be resisted by the geotextile (ΔMR) with the following equation:

$$M_D = \frac{M_{R\ eksisting}}{SF} \qquad \ldots(8)$$

$\Delta M_R = M_{R\ design} - M_{R\ eksisting}$ …(9)

$\Delta M_R = (SF_{design} x\ M_D) - M_{R\ eksisting}$ …(10)

Where:

M_D	: driving moment
MR	: resisting moment
SF	: safety factor existing
SF design	: safety factor design= 1,5
ΔM_R	: a moment that will be resisted by the geotextile

Calculation of the number of geotextile requirements is carried out in stages until the total moment of the geotextile (ΣMgeotextile) is equal to or greater than ΔM_R with the following equation:

$\text{Mgeotextile} = \text{Tall x Ti}$ …(11)

$\Sigma\text{Mgeotextile} \geq \Delta M_R$ …(12)

$\Sigma(\text{Tall x Ti}) \geq \Delta M_R$ …(13)

Where:

Ti : the vertical distance of each geotextile to the center of the slide

DATA AND MATERIAL

Ground Layers Data

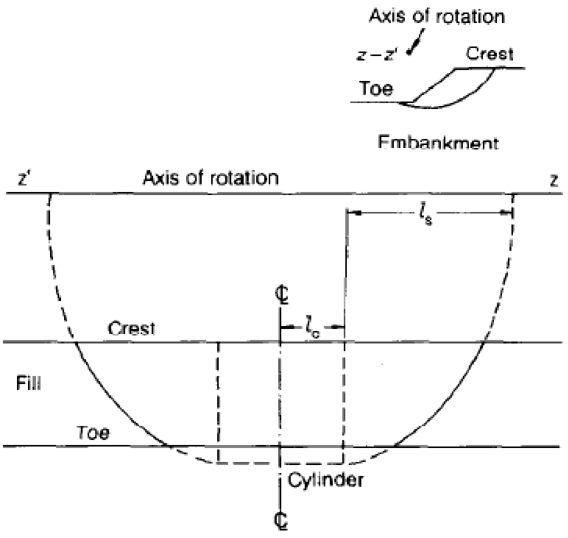
The ground layers data used the soil data that refers to the thesis of Septiandri R.A., et al (2021) entitled “Metode Cepat Untuk Menentukan Besar Pemampatan Konsolidasi (Sc) Pada Timbunan Di Atas Tanah Lunak dan Perencanaan Perkuatannya Untuk Kondisi Dengan dan Tanpa Pemasangan Prefabricated Vertical Drain (PVD)” as shown in **Table 2**. The soil data was obtained based on Ardana and Mochtar (1999). The ground layers data is soil data with very soft, soft, and medium consistency. The thickness of the ground layer used was 30 m with details of 3 m very soft, 14 m soft, and 13 m medium consistency.

Embankment Data

The embankment soil used in this study is granular. The embankment soil parameters include volume weight (γ) is 19 kN/m^3 dan angle friction is 40°.

3D Landslide Field Dimensions

The 3D landslide field used in this study was a cylinder at the center and an ellipsoid at the tip. The total length of the cylinder is 2lc, while the length of the right and left ellipsoids are ls each as shown in **Figure 3**. The dimensions of the 3D landslide field used in this study are lc/H = 0.5 and ls/H = 4 where H is the height of the embankment.



Source: Chen and Chameau (1982)

Figure 3. The front view of the 3D landslide

The Variations of Embankment Dimensions

The embankment slope used in this study is 1:1. The variations used in this study are the height of the embankment and the width of the top of the embankment as follows:

- The height of the embankment = 4 m, 6 m, dan 8 m
- The width of the top of the embankment = 7 m, 10 m, dan 13 m

Table 2. Ground Layers Data

Depth (m)	e0	γsat (t/m3)	Cu (kg/cm2)	Cu (kPa)	Cu (t/m2)	Consistency
1	1.8	1.571	0.0991	9.906	0.991	Very Soft
2	1.783	1.575	0.1072	10.720	1.072	
3	1.766	1.579	0.1154	11.539	1.154	
4	1.748	1.582	0.1236	12.363	1.236	Soft
5	1.731	1.586	0.1319	13.192	1.319	
6	1.714	1.590	0.1403	14.027	1.403	
7	1.697	1.593	0.1487	14.867	1.487	
8	1.679	1.597	0.1571	15.712	1.571	
9	1.662	1.601	0.1656	16.563	1.656	
10	1.645	1.605	0.1742	17.419	1.742	
11	1.628	1.609	0.1828	18.281	1.828	
12	1.610	1.613	0.1915	19.148	1.915	
13	1.593	1.617	0.2002	20.021	2.002	
14	1.576	1.621	0.2090	20.901	2.090	
15	1.559	1.625	0.2179	21.786	2.179	
16	1.541	1.630	0.2268	22.677	2.268	
17	1.524	1.634	0.2357	23.574	2.357	

Table 2. Continued…

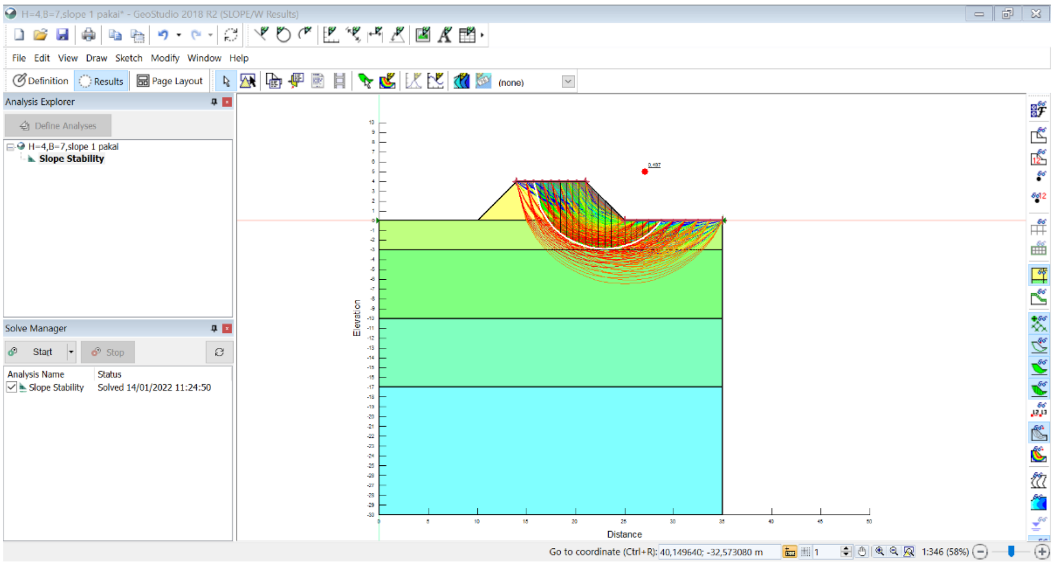
Depth (m)	e0	γsat (t/m3)	Cu (kg/cm2)	Cu (kPa)	Cu (t/m2)	Consistency
18	1.507	1.638	0.2448	24.477	2.448	Medium
19	1.490	1.643	0.2539	25.386	2.539	
20	1.472	1.647	0.2630	26.302	2.630	
21	1.455	1.652	0.2722	27.224	2.722	
22	1.438	1.656	0.2815	28.153	2.815	
23	1.421	1.661	0.2909	29.088	2.909	
24	1.403	1.666	0.3003	30.030	3.003	
25	1.386	1.671	0.3098	30.979	3.098	
26	1.369	1.675	0.3193	31.934	3.193	
27	1.352	1.680	0.3290	32.897	3.290	
28	1.334	1.685	0.3387	33.867	3.387	
29	1.317	1.690	0.3484	34.843	3.484	
30	1.300	1.696	0.3583	35.828	3.583	

RESEARCH ANALYSIS

2D Slope Stability Analysis

2D Slope Stability Analysis Results

2D slope stability analysis was carried out using the GeoStudio program, using the Fellenius method (1936), or the ordinary method. Modeling is carried out for all variations of the height and width of the top of the embankment. The output from this 2D modeling is several possible landslide areas accompanied by safety factors, landslide center points (X and Y), radius (R), and resisting moment (Mres). **Figure 4** shows an example of GeoStudio's output in the form of all possible landslide fields.



H=4,B=7,slope 1 pakai* - GeoStudio 2018 R2 (SLOPE/W Results)

H=4,B=7,slope 1 pakai
Slope Stability

Analysis Name	Status
☑ Slope Stability	Solved 14/01/2022 11:24:50

Go to coordinate (Ctrl+R): 40,149640; -32,573080 m

1:346 (58%)

Figure 4. GeoStudio's output on the embankment with H = 4 m and W = 7 m

Calculation of Reinforcement Requirements for 2D Slope Stability

In planning for slope reinforcement requirements, the factor of safety used is not the smallest or most critical safety factor. The safety factor used is the safety factor that has the highest number of reinforcement requirements. Therefore, it is necessary to calculate the amount of reinforcement needed for each possible landslide area and choose the safety factor with the highest amount of reinforcement. After calculating the number of reinforcement requirements in each landslide area, 10 factors of safety were obtained with the highest number of reinforcement requirements as shown in **Table 3**. The recapitulation of the calculation of the amount of reinforcement needed is presented in **Table 4**.

Table 3. Recapitulation of 10 Safety Factors with the Most Required Geotextile Reinforcement for H = 4 m and B = 7 m

SF	Center X (m)	Center Y (m)	Radius (m)	Resistance Moment (kNm)	Geotextile Reinforcement (layer)
0.584	23.657	4.435	8.793	1453.775	9
0.59	23.1947	4.457	9.206	1642.849	10
0.606	24.247	4.466	9.384	1727.4077	10
0.607	23.788	4.488	9.8	1931.4905	12
0.625	24.385	4.519	10.398	2240.155	13
0.63	24.842	4.498	9.979	2020.271	12
0.64	25.3	4.475	9.562	1813.295	10
0.645	24.986	4.551	11	2573.147	14
0.654	25.441	4.529	10.578	2337.549	13
0.67	25.896	4.507	10.158	2112.995	11

Table 4. Recapitulation of 2D Safety Factor and Geotextile Reinforcement Requirements

Variation of Embankment Height (m)	Variation of Embankment Width (m)	SF 2D	Reinforement Requirements (layer)
4	7	0,645	14
	10	0,639	18
	13	0,657	22
6	7	0,438	23
	10	0,422	29
	13	0,427	36
8	7	0,365	31
	10	0,34	39
	13	0,333	48

Based on **Table 4**, it is known that the 2D safety factor is less than 1.5. It can be seen that the 2D safety factor has no relationship with the height and width of the embankment. This is because the 2D safety factor used is the safety factor that has the highest number of reinforcement requirements. However, when viewed from the amount of reinforcement needed, the wider the embankment, the more geotextile reinforcement needs will be. Likewise for the same width and slope of the embankment, the higher the embankment, the more the need for geotextile reinforcement.

The results of the research conducted by Septiandri et al (2021) about the analysis of the geotextile reinforcement needed for varying embankment heights on soft soil indicate that the relationship between embankment height and the need for the amount of geotextile shows a linear correlation, which means that as the height increases, the need for geotextile reinforcement increases. These results are following the results in this study.

3D Slope Stability Analysis

3D Slope Stability Analysis Results

3D slope stability analysis was carried out using the Hovland (1977) formulation which was the development of the Fellenius method (1936). The 3D landslide field is described using the Autocad program by dividing the soil mass into several vertical soil columns. The basis for making 3D landslide fields is 2D landslide fields which have the highest number of reinforcement requirements. The dividing of the column in the y-axis direction is based on the dividing of the columns in the 2D landslide plane, while the dividing of the column in the x-axis direction is 1.5 m wide. The modeling of the 3D landslide field is only in half because the landslide area is assumed to be symmetrical as shown in **Figure 5.** The summary of the results of the 3D slope stability analysis is presented in **Table 5**. After calculating the 2D and 3D slope stability analysis, a comparison of the safety factors obtained is carried out by calculating the ratio of the two factors of safety. **Table 6** presents a recapitulation of the comparison of 2D and 3D safety factors.

Based on **Table 6**, it is known that the ratio of the 3D and 2D safety factors is more than 1 for all variations of embankment dimensions. These results are the same as most of the previous studies which stated that the 3D and 2D safety factor ratio was more than 1. Based on **Table 1**, research conducted by Hovland (1977) stated that the ratio of the 3D and 2D safety factors is more than 1 for cohesive soils, while for non-cohesive soils the ratio is less than 1. The subgrade data used in this study is soft soil which is cohesive soil, so the results of this study are following the results of research conducted by Hovland (1977). This result indicates that the 3D safety factor is greater than the 2D safety factor. In other words, the 2D safety factor is more critical than the 3D safety factor, so it can be concluded that the 2D safety factor already represents the 3D landslide field.

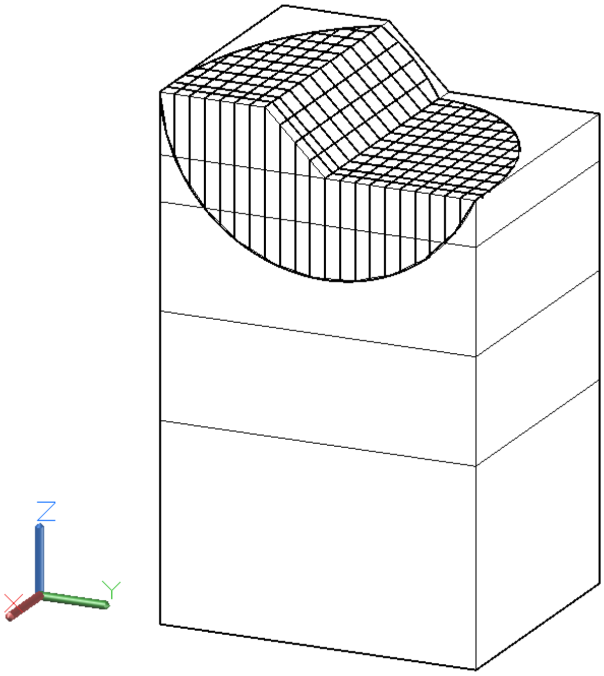


Figure 5. 3D landslide plane and column division for H = 4 m, W = 7 m

Table 5. Recapitulation of the 3D Slope Stability Analysis

Variation of Embankment		SF 3D
Height (m)	Width (m)	
4	7	0,741
	10	0,795
	13	0,918
6	7	0,483
	10	0,497
	13	0,538
8	7	0,400
	10	0,404
	13	0,421

Calculation of Reinforcement Requirements for 3D Slope Stability

In the 3D slope analysis, there is no calculation of the resisting moment that occurs so it is assumed that the retaining moment that occurs in the 2D and 3D methods is the same. When viewed from the safety factor, the 3D safety factor is greater than the 2D safety factor. So, with the same resisting moment in general, the amount of geotextile reinforcement for 3D slopes is less than the amount of geotextile reinforcement for 2D slopes.

Research on the comparison of the amount of geotextile reinforcement required between 2D and 3D has previously been carried out by Shoffiana et al (2021). The results obtained on soils with heterogeneous layers are uncertain because under certain conditions the amount of 2D geotextile reinforcement required is more than 3D and in other conditions, the need for 2D reinforcement is smaller than 3D. These results cannot be used in general because the soil data used is data at a certain location. These problems are answered by current research using soft soils in general. So for subgrade in the form of soft soil with a very soft, soft, and medium consistency, the required 3D geotextile reinforcement is less than the 2D geotextile reinforcement needed with a ratio of about 0.5 to 0.955 (see **Table 7**).

Table 6. Recapitulation of the Comparison of 2D and 3D Safety Factor

Variation of Embankment		SF 2D	SF 3D	SF 3D / SF 2D
Height (m)	Width (m)			
4	7	0,645	0,741	1,149
	10	0,639	0,795	1,244
	13	0,657	0,918	1,397
6	7	0,438	0,483	1,103
	10	0,422	0,497	1,179
	13	0,427	0,538	1,259
8	7	0,365	0,400	1,096
	10	0,34	0,404	1,187
	13	0,333	0,421	1,264

Table 7. Recapitulation of the Comparison of 2D and 3D Geotextile Reinforcement

Variation of Embankment		SF 2D	2D Reinforcement Requirement (layer)	SF 3D	3D Reinforcement Requirement (layer)	Ratio of 3D and 2D Reinforecement
Height (m)	Width (m)					
4	7	0,645	14	0,741	9	0,643
	10	0,639	18	0,795	13	0,722
	13	0,657	22	0,918	11	0,5
6	7	0,438	23	0,483	21	0,955
	10	0,422	29	0,497	23	0,793
	13	0,427	36	0,538	25	0,694
8	7	0,365	31	0,4	29	0,935
	10	0,34	39	0,404	32	0,821
	13	0,333	48	0,421	35	0,729

CONCLUSION

Based on the calculation and comparison of 2D and 3D slope stability analysis, the following conclusions were obtained:

- The 2D and 3D safety factors are less than 1.5 for all embankment variations which means the embankment will collapse. For the same height and width, the 2D and 3D safety factors have different values. The 3D and 2D factor of safety ratio is more than 1, which means that the 3D factor of safety is greater than the 2D factor of safety for all variations. The difference ratio of the 3D and 2D safety factors ranges from 1.09 to 1.397. Therefore, the 2D safety factor can be said to be representative of the 3D landslide field.
- The number of geotextile reinforcement for 2D analysis ranges from 14 to 48 layers. The number of reinforcement requirements with geotextiles for 3D analysis is less when compared to 2D analysis with a ratio ranging from 0.5 to 0.955. So, in planning embankment slopes, it is necessary to pay attention to avoid overestimating or underestimating design.

Note. This paper has been presented in ICIFAM #1 2022, Surabaya, 21-22 June 2022, organized by Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. ICIFAM – International Conference on Infrastructure & Facility Asset Management.

REFERENCES

Bahsan, E. & Fakhriyyanti, R. (2018). "Comparison of 2D and 3D Stability Analyses for Natural Slope". *International Journal of Engineering & Technology* 7 : 662-667

Chen, R.H. (1981). *Three-Dimensional Slope Stability Analysis*. IN: Purdue University. West Lafayette. Indiana.

Chen, R.H. & Chameau, J.L. (1982). "Three-dimensional Limit Equilibrium Analysis of Slopes". *Geotechnique* 32(1): 31-40.

Dana, H.Z, Kakaie, K.R., Rafiee, R., & Bafghi, A.R.Y. 2018. "Effects of Geometrical and Geomechanical Properties on Slope Stability of Open-Pit Mines Using 2D and 3D Finite difference methods". *Journal of Mining & Environment* 9 (4) : 941-957.

Das, B.M. (1985). *Mekanika Tanah (Prinsip-prinsip Rekayasa Geoteknik) Jilid II*. Diterjemahkan oleh Mochtar N.E., dan Mochtar I.B. Erlangga. Jakarta

Gens, A., Hutchinson, J.N., Cavounidis, S. 1988. “Three-dimensional analysis of slides in cohesive soils”. *Geotechnique* 38(1) : 1-23.

Sari, P.T.K, et al. (2020). “The Comparison Between 2-D and 3-D Slope Stability Analysis Based on Reinforcement Requirements”. *Advanced Science Engineering Information Technology* 10(5) : 2082-2088.

Septiandri, R.A, et al. (2021). Metode Cepat Untuk Menentukan Besar Pemampatan Konsolidasi (Sc) Pada Timbunan Di Atas Tanah Lunak dan Perencanaan Perkuatannya Untuk Kondisi Dengan dan Tanpa Pemasangan Prefabricated Vertical Drain (PVD). *Tesis Pasca Sarjana*. Institut Teknologi Sepuluh Nopember (ITS) Surabaya

Septiandri, R.A., et al. (2021). “Analisis Kebutuhan Perkuatan *Geotextile* untuk Tinggi Timbunan Badan Jalan yang Bervariasi di atas Tanah Lunak pada Kondisi dengan dan tanpa Pemasangan PVD (*Prefabricated Vertical Drain*)”. *Jurnal Aplikasi Teknik Sipil* 19 (3) : 283-294.

Shoffiana, N.A., et al. (2021). Perbandingan Hasil Analisa Stabilitas Lereng 2-D dan 3-D terhadap Jumlah Kebutuhan Perkuatannya. *Tugas Akhir*. Institut Teknologi Sepuluh Nopember (ITS) Surabaya.

SNI 8460:2017. *Persyaratan Perancangan Geoteknik*. Badan Standarisasi Nasional. Jakarta.

Sugiarto et al (2022). “Analisis Penyebab dan Mekanisme Keruntuhan Lereng Sungai Konaweha, Studi Kasus Ruas Bts. Kab. Konawe Utara/Kab. Konawe – Pohara Km 29+750”. *Jurnal Manajemen Aset Infrastruktur & Fasilitas - JMAIF 6(Khusus1) Januari 2022.*

Suprayitno, H. & Soemitro, R.A.A. (2018). “Preliminary Reflexion on Basic Principle of Infrastructure Asset Management”. *Jurnal Manajemen Aset Infrastruktur & Fasilitas – JMAIF 2(1) Maret 2018.*

Suprayitno, H. et al (2020). “Preliminary Reflection on Performance Indicator and Performance Factor for Infrastructure Asset Management”. *Journal of Infrastructure & Facility Asset Management - JIFAM 2(1), March 2020.*

Wardani, M.K. et al (2019). “Evaluasi Potensi Kelongsoran Pada Lereng Alam Akibat Perubahan Sudut Kemiringan Menggunakan Metode Fellenius”. *Jurnal Manajemen Aset Infrastruktur & Fasilitas.* Vol. 3, Edisi Khusus 2, Juni 2019.