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Slope Reinforcement Design for Balikpapan-Samarinda Toll Road Landslide Section 28+000 To 28+100.

Siti Nurlita Fitri[1,2] and Marbono Widya Diputra[3]

[1]UNS Geoscience Research Group, Civil Engineering Department, Universitas Sebelas Maret, Jebres, Surakarta 57126, Indonesia.
[2] Disaster Research centre, Universitas Sebelas Maret, Jebres, Surakarta 57126, Indonesia
[3] PT. Wijaya Karya, Balikpapan Samarinda Toll Road Project, Samboja, East Borneo 75272, Indonesia

[a)] Corresponding author: sitinurlitafitri@staff.uns.ac.id

Abstract. The Balikpapan - Samarinda Toll Road is a new infrastructure project that connects two capital cities in East Borneo. Landslides occur in sections 28+000 to 28+100, necessitating the terrace design to prevent unstable conditions. As a result, a new proposed design is required to ensure safety in this area. This study aims to offer further slope reinforcement in this location to prevent landslides. This research utilizes secondary data from Standard Penetration Test (SPT) results to determine the soil properties. First, the lateral earth pressure was conducted to calculate the sheet pile and retaining wall structure. The other reinforcement is geogrid with geotextile combine. The Finite element model carried out all the overall stability with Plaxis calculation. The results show that all new proposed to generate the safety factor value >1.3. Sheet pile variations present the CCSP type W-600 with a total length reaching 17m, which offers a safety factor 1.31. The second variation is a retaining wall with a full height of 5m and combined in sheet pile design, which reaches the safety factor in the overall stability of 1.498. the internal strength of the retaining wall is divided into three categories: overturning, sliding, and bearing capacity with 1.55, 2.44, and 2.88, respectively. Meanwhile, the geogrid type described the SF 1.32 with three step slope design and spacing of 0.3m, 0,5m, and 1,0m, respectively.

Keywords: landslides, sheet pile, retaining wall, geogrid, safety factor

INTRODUCTION

The need for infrastructure connecting two major cities in East Borneo, Balikpapan and Samarinda, led to the development of a toll road construction project. Balikpapan – Samarinda Toll Road was designed to address transportation problems, including reducing travel distances, shortening travel durations, and providing well-designed highway geometry. These circumstances encouraged the project to build several hill areas, which led to several common problems, such as a landslide. The research location around this area is presented in Figure 1.

Balikpapan - Samarinda Toll Road Project was constructed in terraces design with 18m height slopes in stationing 28+000 to 28+100, preventing the landslide. Although this strategy sometimes produces safety conditions [1], [2], the design offers the opposite situation on this site. This section presents several cracks in the slope body after heavy rainfall, which leads to mass material movement downhill. Moreover, the water runoff covers and stagnates in specific locations, which causes issues for heavy equipment movement. As a result, a new reinforcement design is required to solve the landslide problem. The general view of this slope is shown in Figure 2.

This paper describes several methods to cope with landslide issues, which are analyzed with the finite element method based on Plaxis. This method was successfully applied in several landslide investigations, such as in India, Vietnam, and Canada [3]– [5]. The general slope reinforcement, such as sheet pile, retaining wall, and geogrid, was designed in this paper, considering the stiff consistency of the subgrade. This analysis has generated the safety conditions in another Toll Road project [6]– [12]. Consequently, this study aims to determine the proposed design that appropriates site conditions.

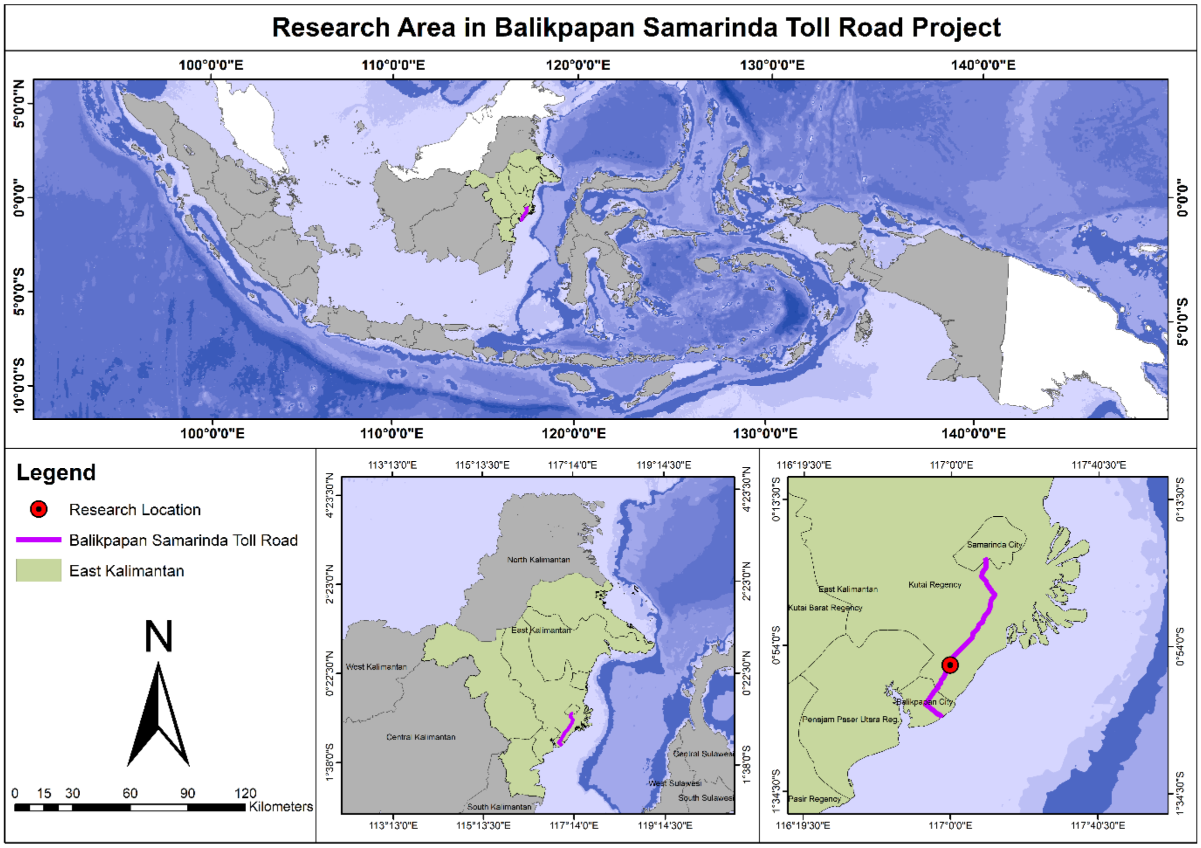

FIGURE 1. Research location

FIGURE 2. Landslide in sections 28+000 to 28+100

RESEARCH METHODOLOGY

This research uses secondary data supporting geotechnical software based on the finite element model, which was decided because of two approach analyses based on [13]. The detail of this information is described as follow:

Soil Properties

This report utilizes soil properties by secondary data based on the Standard Penetration Test (SPT) in-depth 2-8m. According to the boring log site and laboratory results, the soil parameter depicts the silt clay category from 0-20m. The specific parameters are described in Table 1.

Table 1. Soil Properties based on SPT result

Depth (m)	Thickness (m)	NSPT	Soil type	γ(kN/m3)	Gs
0-2	2	10	Silty clay	18.3	2.52
2-18	16	31	Silty sand	17	2.62
18-20	2	13	Silty clay	17.3	2.595
20-30	10	80	Silty clay	16.58	2.596

Sheet pile

This research was carried out by sheet pile calculation with type Corrugated Concrete Sheet Piles (CCSP) type W-600. The first step to designing earth-retaining structures is analyzing the lateral earth pressure, which considers the soil properties. Next, the finite element analysis (FEM) with the Plaxis model have conducted to model the whole site, which assumes the result of a previous study in sheet pile analysis[14]. The simulations of calculations geometry and soil parameters are depicted in Figure 3.

Based on Figure 2, the subgrade in the calculation model is three layers, which is the depth of the embedded sheet pile, and the upper geometry of CCSP is 6m. Therefore, the result of the calculation is the embedded sheet pile, which will be input into the Plaxis model to generate the safety factor (SF). All safety factor values (SF) ought to be in a safe condition, which requires more than 1,2 value[15].

The conventional calculation uses the lateral earth pressure, which is described in equations as follows[16]:

two captwo$Ka = tan^2\,(45 - \frac{\varphi}{2})$ (1)

$$Kp = tan^2\,(45 + \frac{\varphi}{2}) \qquad (2)$$

$$\sigma_v = \gamma\, h$$

(3)

$$\sigma_h = \sigma_v\ ka - 2\, c\, ka^{0.5} \qquad (4)$$

Where ka is the active coefficient of lateral earth pressure, kp is the passive coefficient, γ is unit weight, φ is friction angle, h is the thick layer of soil, σ_v is the vertical pressure and σ_h is horizontal pressure.

Retaining Wall

The retaining wall was designed in specific geometry that considers the appropriate shape. The calculation stage is similar to sheet pile analysis, where the initial step is calculating the lateral earth pressure based on formulas 1-4. However, if the upper subgrade had a sloping layer, the active coefficient would be calculated in the Rankin equation in equation 5[17]. Later, the Plaxis model was run to show the safety factor analysis. The material is concrete reinforcement with in situ types. The height of the retaining wall was designed at 5,0 m, which observed the whole condition of the soil layer. The combination of sheet pile and retaining wall was applied in this category because retaining walls with numerous heights provide an ineffective structure as a retainer. The retaining wall structure details are shown in Figure 4, while Figure 5 shows the retaining wall with a soil properties model.

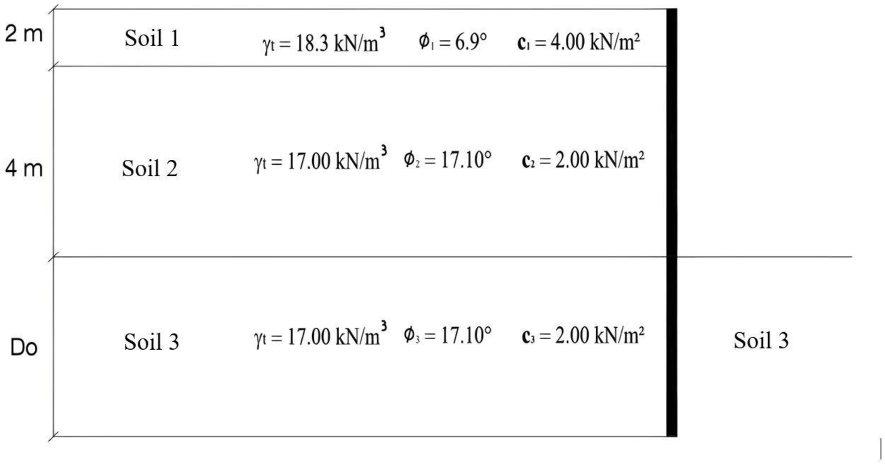

FIGURE 3. Sheet pile calculation model

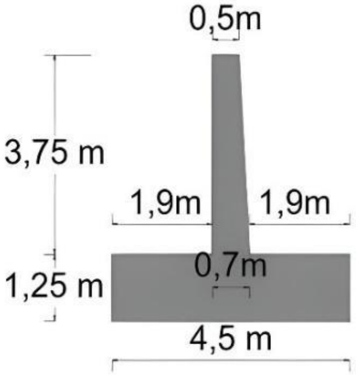

FIGURE 4. Retaining wall geometry

$$Ka = cos\alpha\ (\frac{cos\alpha-(cos\alpha^2-cos\varphi^2)^{0.5}}{cos\alpha+(cos\alpha^2-cos\varphi^2)^{0.5}}) \qquad (5)$$

Where α is the angle of top subgrade.

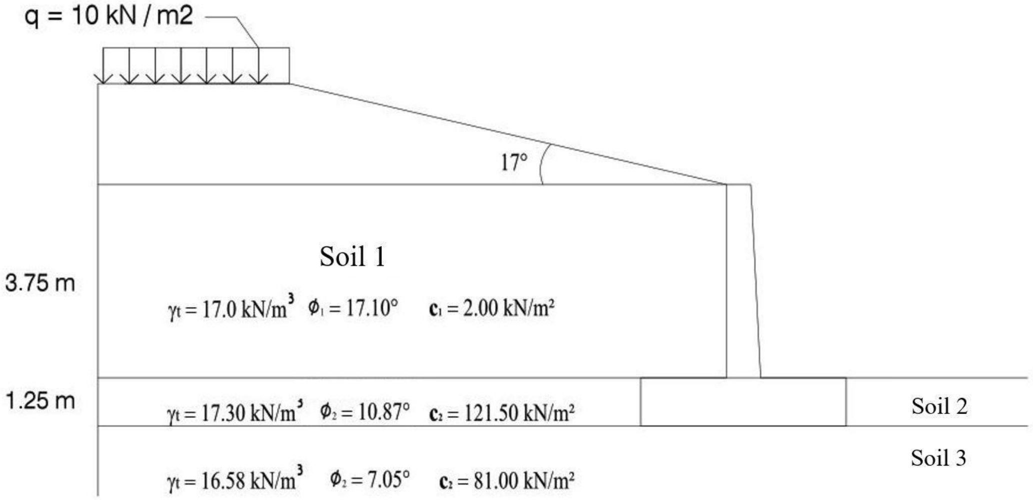

FIGURE 5. Retaining wall calculation model

Geogrid

The calculation of Geogrid reinforcement was carried out with many steps. Firstly, determining the spacing between two geogrid layers provides the total layer of required geogrid. Another aspect is the length of geogrid, which influences the need for reinforcement. Next, the calculation was done by FEM with Plaxis to analyse the SF value. Finally, the formula to calculate the geogrid parameters has been presented as follows[18]:

$$Sv = \frac{T_{allowable\,C_r}}{\sigma h\ SF} \tag{6}$$

$$T_{allowable} = \frac{T_{ultimate}}{RF_{id}\ RF_{cr}\ \ RF_{cbd}} \tag{7}$$

$$L = Lr + Le \tag{8}$$

$$Le = \frac{Sv\ Ka\ SF}{2\ Cr\ Ci\ tan\varphi} \tag{9}$$

Where Sv is distance between the geogrid, T allowable is the tensile strength of the geotextile, which reduce by several factors, Sf is safety factors, T ultimate is the tensile strength based on specification products, Rf is the reduction factor, Lr is the length from slide mass, Le is empirical length of geogrid, Cr is upper cohesion soil layer, Ci is cohesion in lower layer.

RESULT AND DISCUSSION

Sheet Pile

The lateral earth pressure for sheet pile calculation is shown in Figure 6. Based on Figure 6, the active and passive force was conducted to determine the length of the embedded pile. Ea means active pressure, while Ep is passive. The exact value of each layer calculation is shown in Table 2.

According to Table 2, the equation relationship between active and passive pressure generates the embedded pile (Do), which determines the result of Do is 11m. However, the outcome should consider the upper pile. Thus, the total length of the sheet pile is 17m.

Regarding FEM analysis, this second step calculates the safety factor analysis based on the Plaxis outcome. The result has shown in Figure 7. The outcome shows that a sheet pile with a total length of 17m generates a safety factor 1.32. Based on Bowles[15], this condition offers the safety condition for slope stability analysis. The CCSP design was appropriate to apply in road construction. According to Fadilah [19], to stop further lateral earth movements brought on by the weight of moving vehicles on the road, precast concrete sheet piles were created to support the road embankment. The sheet pile system is described together with its analysis and design.

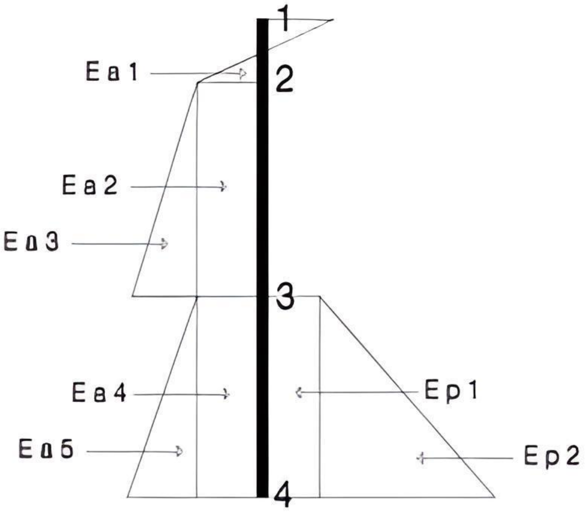

FIGURE 6. Lateral earth pressure for sheet pile calculation

TABLE 2. Lateral earth pressure for sheet pile

Pressure	Force (kN)	Distance (m)	Moment (kNm)
Active pressure	Ea1=16.32	4.5+Do	73.46 +16.32 Do
	Ea2=57.54	2+Do	115.09 + 57.54 Do
	Ea3=73.65	1.33+Do	98.21 + 73.65 Do
	Ea4=51.21 Do	0.5 Do	25.61 Do^2
	Ea5=4.60 Do^2	0.33 Do	1.53 Do^3
Passive pressure	Ep1=5.44 Do	0.5 Do	2.72 Do^2
	Ep2= 15.69 Do^2	0.33 Do	5.23 Do^3

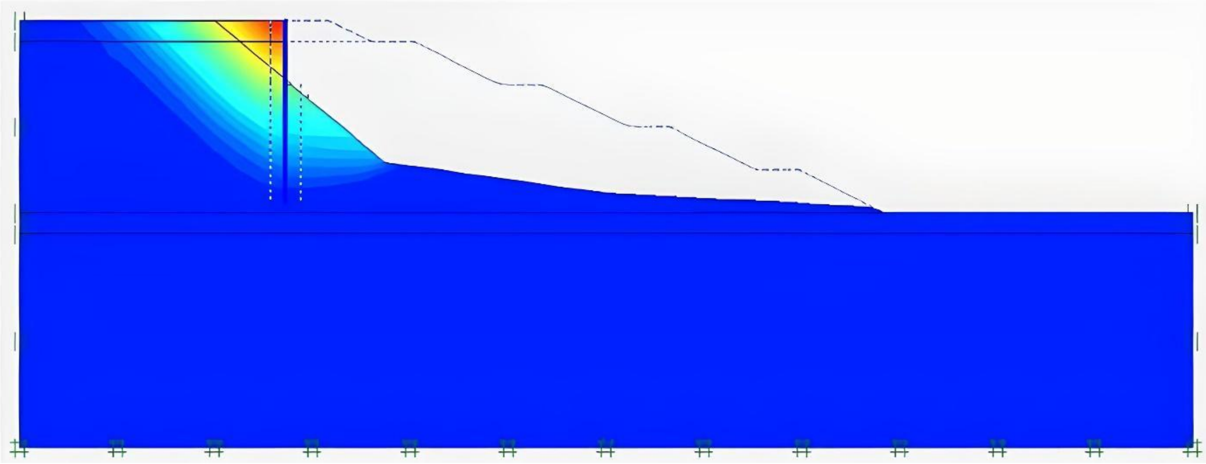

FIGURE 7. Sheet pile analysis output from Plaxis

Retaining Wall

The retaining wall analysis was carried out by calculating the lateral earth pressure of soil and structure, as seen in Figure 8. The next step is checking the internal stability of the retaining wall structure, which is the exact value shown in Tables 3 and 4. Ea is active pressure while Ep is passive. Note 1 until 4 is the piece of structure to convenience calculation.

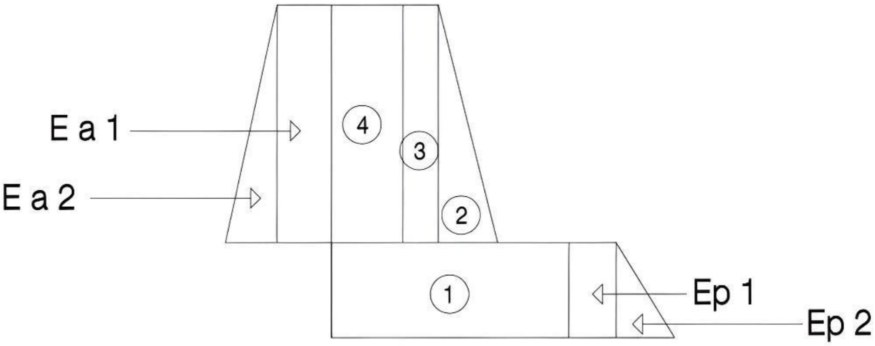

FIGURE 8. Lateral earth pressure for sheet pile calculation

Based on the whole internal stability calculation, the safety factor shows three types: overturning, sliding, and bearing capacity. All the numbers ought to be> 1.5 to provide safe conditions. The outcome indicates that the safety factor in this analysis is 1.55, 2.44, and 2.88, respectively.

The overall stability calculation was conducted by Plaxis analysis. The outcome is shown in Figure 9. The combined reinforcement between the sheet pile and retaining wall offers the FEM analysis with 1.498, representing a value > 1.5. This variation describes fewer cut areas in the hill than sheet pile analysis. However, this category provides a more significant material need for slope reinforcement than the last variety.

TABLE 3. Lateral earth pressure for retaining wall

Pressure	Force (kN)	Distance (m)	Moment (kNm)
Active pressure	Ea1=18.55	3.13	57.96
	Ea5=102.39	2.5	255.97
Passive pressure	Ep1=367.63	063	229.77
	Ep2= 19.8	0.42	8.25

TABLE 4. Force calculation of retaining wall

Note	Force (kN)	Distance x(m)	Distance y (m)	Moment (kNm)
1	135	0		0
2	9	0.43		3.9
3	45	-0.05		-2.25
4	130.6875	1.23		160.09
q	76.875	1.23		94.17
Ea1	18.55		3.13	57.96
Ea2	102.39		2.5	255.97
Ep1	367.63		0.63	229.77
Ep2	19.8		0.42	8.25

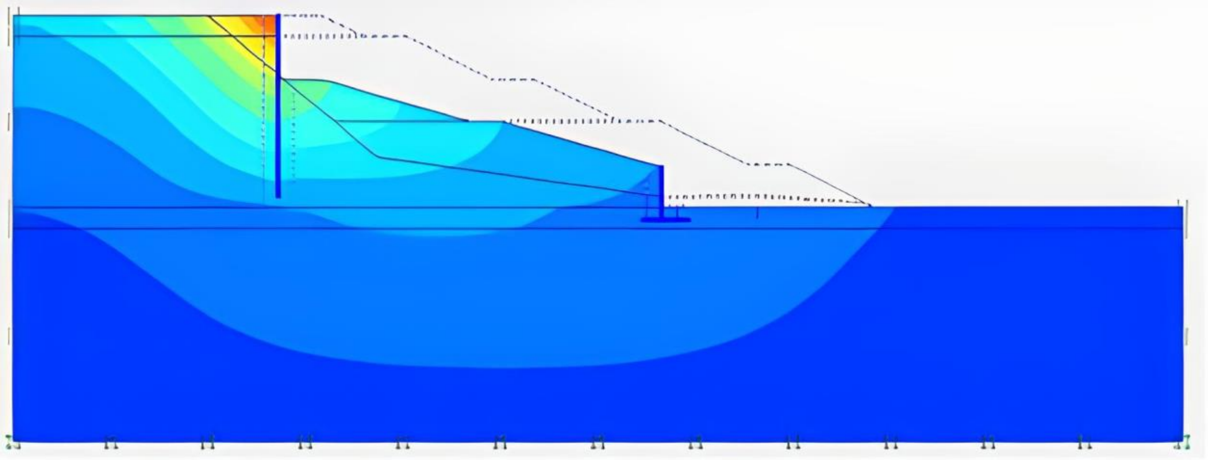

FIGURE 9. Retaining wall output from Plaxis

Regarding retaining wall design, Atencio [20] proposed an innovative technique called a generative design that can be used to optimize this iterative process to calculate the shape of the retaining wall. The designer codes the project's characteristics and constraints to ensure that the system generates the best suitable solutions to the given challenge. Moreover, the generative design was used to develop computer software that calculates the dimensions of retaining walls. Meanwhile, Sejal [21] carried out the retaining wall by Plaxis to determine the behavior of this structure. Ramulu utilized the finite element program Plaxis. As a result, it was possible to analyze numerically how the walls would behave under static loads. Unfortunately, the limit equilibrium-based current design approaches make it difficult to gather pertinent information on the mechanical behavior of the wall, while the finite-element analyses do so[22].

Geogrid

This study utilized the geogrid reinforced based on a combination of geotextile, which covers the slope area to emphasize the water absorptions and its reinforcement. Firstly, the space calculation was conducted to determine the requirement layer of geogrid. Then, the iteration method was carried out to divide all the appropriate distances. The result shows that space offers three types, namely 0.3m, 0.5m, and 1m. On the other hand, for the length of geogrid reinforcement. The slide mass length and slope stability model should be presented to determine the slip surface condition. Geogrid should be located by the slip surface to emphasize that the structures are ready to work. The outcome describes an embedded length in various categories, namely, 0.3m, 0,5m, and 1,0m, respectively. However, for easy installation, several layers have a similar length of geotextile. The detail of Geogrid has presented in Figure 10.

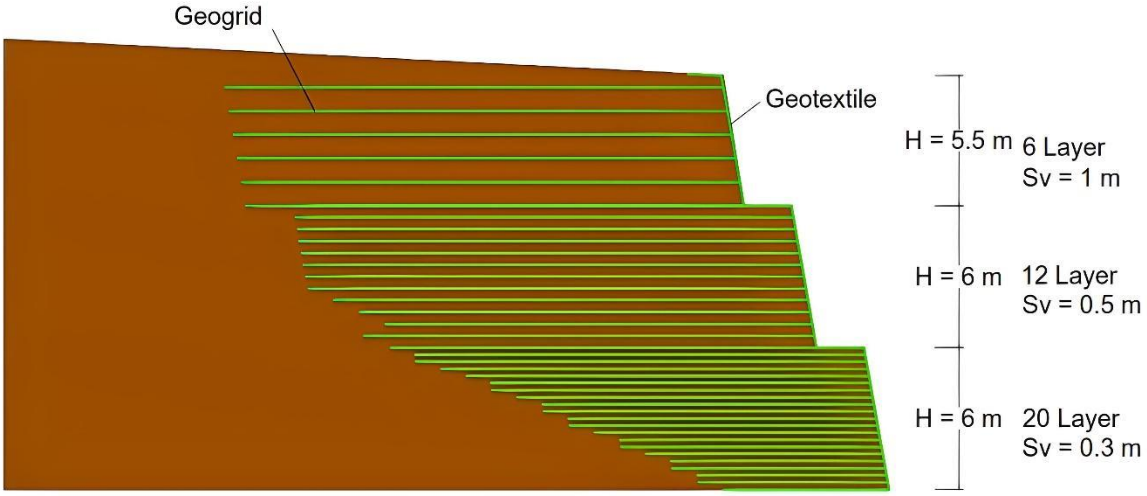

FIGURE 10. Geogrid model for Plaxis

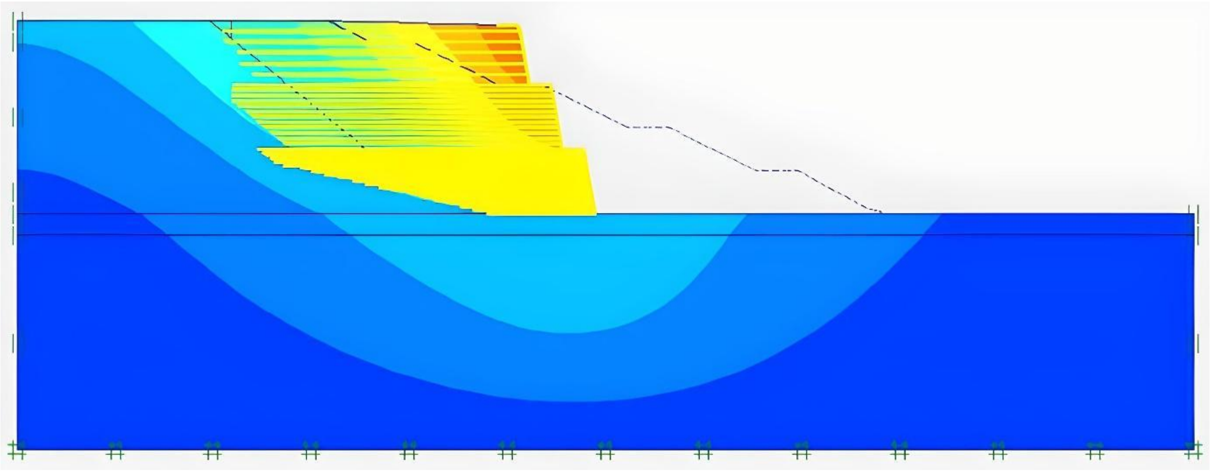

FIGURE 11. Geogrid output from Plaxis

Plaxis calculated the overall stability of geogrid. The outcome is shown in Figure 11. Based on FEM analysis, the result shows a safety factor of 1.31, which is over 1.25. The geometry is applied in 3 steps, divided into several spacing types.

Kumar [23] analyses the geogrid reinforcement to slope failure case. According to the findings of the analytical investigations, using geogrid improves slope stability. According to numerical analysis, 3.8 m-long geogrid gravity barriers are built in stages at the location of the slope failure. Different layers of geogrid packed with granular materials were positioned beneath the structure wall. Meanwhile, peak stresses in the reinforcing layers assisted in identifying possible slip surfaces. Due to the geogrid's tensile behavior, the vertical stress was redistributed, and the area close to the slope's face received the vertical stress from the soil slope. This notion increases the safety factor of the slope [24]. Furthermore, according to the calculation results of Yoo's research [25], the findings show that adding layers of geogrid to the ground can dramatically boost the bearing capacity of strip footings on sloping terrain and that the bearing capacity increase is highly dependent on the distribution of the geogrid.

CONCLUSION

Generally, the proposed design to increase the safety factor of the slope provides a value of over 1.3. The first variation is a sheet pile with CCSP type W-600. Based on the calculation, the embedded pile is 6m, and all the lengths reach 17m. The FEM analysis was carried out to determine the overall stability, showing an SF value of 1.31. The second variation is the retaining wall and sheet pile combination. The retaining wall was designed with a 3.75m body height and 1.75 pile cap, which generates a safety factor of overturning, sliding, and bearing capacity of 1.55, 2.44, and 2.88, respectively. Meanwhile, the Plaxis calculation shows the SF value of 1.498 for overall stability with combining sheet piles. The last variation is geogrid reinforcement, which gives three steep slopes with three spacing, 0.3m, 0,5m, and 1,0m, respectively. Plaxis presents the safety factor 1.32, which provides safety conditions. In summary, all the new designs offer safety conditions SF .1.3. However, the best reinforcement should consider other aspects, such as easy implementation, cost, and site condition.

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