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Stability Analysis of Cantilever-Type Soil Retaining Wall Using Plaxis Method on Waipia-Saleman Road Section of Seram Island

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ABSTRACT

The Waipia-Saleman road section is a national road that has undulating topographic conditions, natural conditions in the form of hills and valleys, this results in several road segments being on slopes. Most sides of the sp. Waipia- Saleman is a steep slope so there is a way point that experiences a landslide, avalanche occurs at Sta. 34+990 – 35+020 damages the roadside along 30 meters of avalanche depth variations of 5-7 meters. The design of the cantilever soil retaining wall structure was planned with a height of 4 meters and the design of the bored pile foundation was designed to withstand the load of the structure as much as 20 points with a distance of 1,5 meters. with a pile depth of 14 meters. This study aims to analyze the safe number of slopes by strengthening cantilever type soil retaining walls using the plaxis 8.2 program and modeling slope element nets using the plaxis 8.2 program. The results of manual calculations on slopes with cantilever DPT reinforcement using Rankine theory with external stability reviews obtained safe numbers SF_{Geser} = 1,72 > 1.5 (safe), SF_{Guling} = 2,58 > 1,5 (safe), and $SF_{Daya\ dukung\ terhadap\ runtuh}$ = 4,406 > 3 (safe). The results of calculating the safe number on the slope with the reinforcement of cantilever soil retaining walls using the plaxis 8.2 program obtained a safety factor value (SF) = 1,5803 > 1,5.

1. INTRODUCTION

The soil needs to have good carrying capacity to maintain stability, feasibility, and construction life. However, in areas with poor soil carrying capacity such as the Waipia-Saleman road section where most of the sides are steep slopes, there is a risk of landslides that have the potential to endanger and disrupt community activities. Hardiyatmo [1] defines the landslide of a soil as a result of an increase in soil shear stress or a decrease in the shear strength of a soil mass. Research by Setyanto et al [2] on slope stability and avalanche mitigation using the plaxis V. 8.2 method on the Liwa – Simpang Gunung Kemala road, precisely sta. 263+650 found that soil characteristics and parameters on slopes have a significant impact on slope stability analysis results. After planning slope handling with the Plaxis method, an analysis result of 1.3548 was obtained.

In Wibowo and Wulandari's research [3] using Rankine theory and paxis software tools. The results of the calculation of stability against bolsters using the rankine method have a safety factor value of 2.54 >1.50 for stability against bolsters while stability against shear has a safe factor value (SF) of 2.447 >2.0. Based on the results of analysis with Plaxis software, deformation during the installation process of retaining wall spun pile and excavation is declared safe. The safety factor for the first excavation is 1.81, for the second excavation it is 1.82, and for the third excavation it is 2.95. From this calculation data, it can be concluded that the soil retaining wall using the Rankine method and Plaxis 8.6 software has a high capacity and is safe from possible collapse. Isdianto & Agustina's research [4] the safety factor showed a critical condition with a value of 1.066 but after being given reinforcement using soil retaining walls, the safety factor value increased to 2.213 so that it can be said that the slope conditions are safe and stable. Based on the results of analysis through the Plaxis program, it can be concluded that the slope is in a stable condition if given retaining wall reinforcement.

Figure 1. Avalanche in 2022, Waipia-Saleman.

Most sides of the sp. Waipia-saleman is a steep slope so there are some road points experiencing landslides and very dangerous for traffic and community activities. The avalanche that occurred at Sta. 34+990 – 35+020 caused damage to the roadside along 30 meters, the depth of the avalanche varied between 5-7 meters. The design of the cantilever soil retaining wall structure has a height of 4 meters, while the design of the bored pile foundation is designed to support the load of the structure as many as 20 points, with a distance between the poles of 1.5 meters and a pile depth of 14 meters.

This study aims to analyze slope safety figures by strengthening cantilever type soil retaining wall structures using the plaxis 8.2 program and modeling slopes and element nets using the plaxis 8.2 program.
The content of the paper will then be explained successively with a review of literature, methodology, results and discussion, as well as conclusions and suggestions.

2. LITERATURE REVIEW

Soil investigation aims to find out information about the soil including soil layers, rocks, groundwater table, physical and mechanical properties of the soil, from the information obtained can be derived soil parameters for simulating the location of foundations or other building construction.
Soil retaining walls are structural buildings that function to hold loose or natural soil and prevent collapse on unstable slopes or potential landslides and maintain the stability of slopes or landfills or landfills.

2.1 Soil Investigation

Soil investigation aims to find out information about the soil including soil layers, rocks, groundwater table, physical and mechanical properties of the soil, from the information obtained can be derived soil parameters for simulating the location of foundations or other building construction. The type of soil research used is soil research in the laboratory which includes :

1. Testing from direct observation
2. Water content
3. Specific gravity
4. Atterberg limits consisting of liquid limit research, plastic limit to obtain plasticity index
5. Soil volume weight
6. Sieve analysis

2.2 Rankine theory

Rankine's theory assumes that the retaining wall is in a vertical position without any friction between the ground and the wall. The value of the active soil coefficient for flat soil can be expressed by equation (1):

$$Ka = tg^2 = Ka = tg^2(45^\circ - \frac{\varphi}{2}) \quad (1)$$

The total value of active pressure on the retaining wall is as high as H, when the soil is a cohesive soil, it can be expressed by equation (2):

$$Pa = \frac{1}{2}\gamma H^2 Ka - 2c H\sqrt{Ka} \quad (2)$$

The active holding moment is expressed by equation (3):

$$Ma = Pa \frac{1}{3} H \quad (3)$$

The value of the passive soil coefficient can be expressed as the comparative value between horizontal and vertical stresses under certain conditions. The passive soil pressure coefficient can be expressed by equation (4):

$$Kp = tg^2 = Kp = tg^2(45^\circ + \frac{\varphi}{2}) \quad (4)$$

The passive pressure on the retaining wall is H-level, when the soil is cohesive soil, can be expressed by equation (5):

$$Pp = \frac{1}{2}\gamma H^2 Kp + 2c H\sqrt{Kp} \quad (5)$$

The passive holding moment is expressed by equation (6):

$$Mp = Pp \frac{1}{3} H \quad (6)$$

2.3 DPT Stability Against Overthrow

Lateral soil pressure caused by urug soil behind the retaining wall tends to roll over the retaining wall with the center of rotation at the end of the front foot of the foundation plate The safe factor against rolling (Fgl) is expressed by equation (7):

$$Fgl = \frac{\Sigma Mw}{\Sigma Mgl} \geq 1{,}5 \quad (7)$$

2.4 DPT stability against swiping

The forces that shift the soil retaining wall will be restrained by friction between the soil and the foundation and passive soil pressure when in front of the soil retaining wall there is heap soil. The safe factor against shift (Fgs) is expressed by equation (8):

$$Fgs = \frac{\Sigma Rh}{\Sigma Ph} \geq 1{,}5 \quad (8)$$

2.5 DPT stability to soil carrying capacity

The equation used for the calculation of the stability of the carrying capacity of the basic soil, is the Terzaghi equation which can be seen in the equation (9 – 11).

$$q_{ult=cN_c+D_f\gamma N_\gamma+0.5\,B\gamma N_\gamma} \quad (9)$$

$$q_{un=q_{u-\gamma.Df}} \quad (10)$$

$$q_{n=q_{-\gamma.Df}} \quad (11)$$

To find the resultant forces acting on the center of weight of the foundation mat the equation (12-13) is used:

$$x = \frac{\Sigma Mw - \Sigma M_A}{\Sigma W} \quad (12)$$

$$e = \frac{B}{2} - x; B > 6 \quad (13)$$

After getting the values of qun and qn, the safety factor can be calculated in equation (14):

$$F = \frac{q_{un}}{qn} \quad (14)$$

2.6 Program Plaxis

When building is implemented in the field, the plaxis application processes the data that has been entered so that the results obtained can be close to implementation in the field, or the processed results of the plaxis program can be assumed as a reflection of actual conditions in the field. The stages of analysis using the plaxis program go through several stages that must be carried out including.

1. Input Data
The data input stages in the plaxis program include soil property data, slope geometry modeling, load specifications, then meshing, and initial conditions. After that, the analysis proceeds to the next stage.

2. Calculation
The calculation stage is a calculation or analysis stage that can be done with various conditions. The results of the calculation can be seen in the output section.

3. Output
The output of the analysis at the previous calculation stage can be observed and seen then the results of the analysis at the output stage can be presented in the form of numbers, image visualizations, and curves.

3. METHODOLOGY

3.1 Research Location
The location of this research is on the Trans Seram Waipia-Saleman STA Road 34+990 – 35+020 Seram Island, Maluku province. Location research maps are shown in figures 2 and 3.

Figure 2. Research location

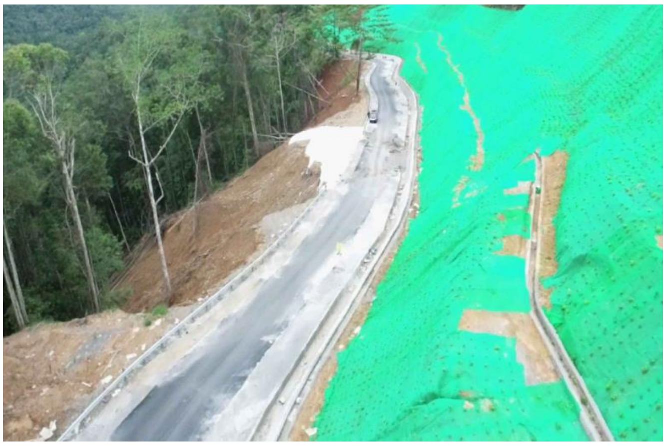

Figure 3. Existing condition of STA 34+990 – 35+020

3.2 Data Sources
There are 2 types of data used in this study, which are as follows:
1. Primary data includes data obtained from laboratory testing in the form of soil investigation results.
2. Secondary data includes initial data obtained from planning consultants (PT. Karuniya data consultant KSO PT. Ihsan Data Consultant) and contractors (PT. Sultan Anugrah KSO PT. Prima Construction) in the form of dimensional drawings of soil retaining structures.

3.3 Analysis Methods
In this study the analytical method used is a quantitative method which includes:
1. The stage of literature study is to search and study literature related to the research topic.
2. Soil investigation, in the form of laboratory testing carried out in accordance with the Indonesian National Standard (SNI) includes:
   a. Water content testing refers to (SNI 03-1965-1990)
   b. Sieve analysis testing refers to (SNI 03-1968-1990)
   c. Specific gravity testing refers to (SNI 1969-1990)
   d. Solid content weight testing refers to(SNI 03-3637-1994)
   e. Liquid limit testing refers to (SNI 03-1967-1990)
   f. Plastic limit testing refers to (SNI 03-1966-1990)
   g. Weight density testing refers to (SNI 03-1743-1989)
   h. Laboratory CBR Testing refers to (SNI 03-1744-1989)Tahap analisis dan pengolahan data, data yang didapat dari hasil pengujian di laboratorium diolah menggunakan program plaxis 2D V 8.2
3. Calculating slope stability analysis with cantilever soil retaining wall reinforcement with manual calculations using Rankine theory and 2D V plaxis program 8.2 includes stages :
   a. The first stage of data input, in the plaxis program which includes soil property data, slope geometry modeling, then meshing and initial conditions.
   b. The second stage is calculation, which is the stage of calculation and analysis that can be done with various conditions. The results of the calculation can be seen at the output stage.
   c. Output stage, which is the stage where the results of the analysis can be presented in the form of numbers, image visualization, and curves.

4. RESULT AND DISCUSSION

4.1 Analysis of cantilever soil retaining walls
Analysis of soil retaining walls is carried out to determine the strength and performance in resisting loads acting against soil retaining walls. The analysis was carried out using two methods, namely the Plaxis 8.2 program and manual calculations. The dimensions of the soil retaining wall can be seen in (figure 4).

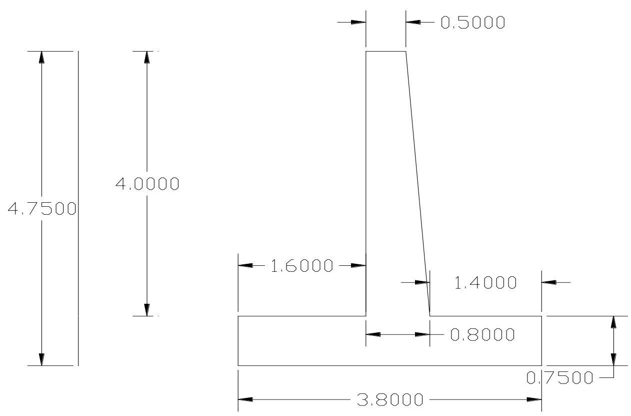

Figure 4. Dimensions of soil retaining walls

4.1.1 Active soil pressure calculation

The active pressure coefficient can be calculated using equation (1):

$$Ka = tg^2\,(45° - \tfrac{\varphi}{2})$$
$$= tg^2\,(45° - \tfrac{30}{2})$$
$$= 0{,}333$$

After the active soil pressure coefficient is known, then the active soil pressure is calculated by equation (2):

$$Pa = \tfrac{1}{2} \times H^2 \times \gamma b \times Ka - 2 \times C \times H\sqrt{ka}$$
$$= \tfrac{1}{2} \times 4{,}75^2 \times 18{,}632 \times 0{,}333 - 2 \times 0{,}491 \times 4{,}75\sqrt{0{,}333}$$
$$= 67{,}302 \text{ KN}$$

The moment calculation for active soil can be calculated by equation (3):

$$Ma = Pa \times \tfrac{1}{3} \times H$$
$$= 67{,}302 \times \tfrac{1}{3} \times 4{,}75$$
$$= 106{,}455 \text{ KN.m}$$

From the calculation results obtained active soil pressure Pa = 67.302 KN and the moment for active soil Ma = 106.455 KN.m.

4.1.2 Calculation of passive soil pressure

The passive soil pressure coefficient is calculated using equation (4):

$$Kp = tg^2\,(45° + \tfrac{\varphi}{2})$$
$$= tg^2\,(45° + \tfrac{30}{2})$$
$$= 3$$

After the passive soil pressure coefficient is known, then the passive soil pressure is calculated by equation (5):

$$Pp = \tfrac{1}{2} \times H^2 \times \gamma b \times Kp + 2 \times C \times H\sqrt{kp}$$
$$= \tfrac{1}{2} \times 0{,}75^2 \times 18{,}632 \times 3 + 2 \times 0.491 \times 0{,}75\sqrt{3}$$
$$= 16{,}996 \text{ KN}$$

The moment calculation for passive soil can be calculated by equation (6):

$$Mp = Pp \times \tfrac{1}{3} \times H$$
$$= 16{,}996 \times \tfrac{1}{3} \times 0{,}75$$
$$= 4{,}244 \text{ KN.m}$$

Based on the calculation results, passive soil pressure Pp = 16,996 KN and the moment for passive soil Mp = 4,244 KN.m.

4.1.3 Self-weight calculation

Table 1. Self-Weight Calculation of Retaining Wall

No.	Formula	Description	Own weight
W1	$= b1 \,.\, h1 \,.\, \gamma beton$	0,50 x 4 x 24	48,00 KN
W2	$= \frac{1}{2} \,.\, (b3 - b1).\, h1.\, \gamma beton$	0,5 x (0,80-0,50) x 4 x 24	14,40 KN
W3	$= h2 \,.\, B.\, \gamma beton$	0,75 x 3,80 x 24	68,40 KN
W4	$= h1 \,.\, b2.\, \gamma_b$	4 x 1,60 x 18,632	119,224 KN
		$\sum_{w} =$	250,044 KN

Table 2. Calculation of Own Heavy Moments Retaining Wall

No.	Formula	Description	Own weight
M1	$= W1\left(\frac{1}{2} \,.\, b1\right) + b2$	48,00 x (0,5.0,50) + 1,60	13,60 KN.m
M2	$= W2 \,.\left(\frac{1}{3} \,.\, (b3 - b1)\right) +$ b1+b2	14,40 x (0.333 x (0,80 - 0,50)) + 0,50 + 1,60	31,67 KN.m
M3	$= W3 \,.\left(\frac{1}{2} x B\right)$	68,40 x (0,5 x 3,80)	129,96 KN.m
M4	$= W4 \,.\left(\frac{1}{2} x b2\right)$	119,244 x (0,5 x 1,60)	95,395 KN.m
		$\sum_{M_W =}$	270,625 KN.m

The amount of the building's own gravity is Σ_W = 250,044 KN and the sum of the building's own weight moments is Σ_{Mw} = 270,625 KN.m

Table 3. Recapitulation of styles and moments Cantilever Soil Retaining Wall

Uraian		Notasi	Gaya (KN)
Gaya			
1	Active pressure	Σpa	67,302
2	Passive pressure	ΣPp	16,996
3	Own weight	ΣW	250,044
Momen			**Momen (KN.m)**
1	Active moments	Σma	106,455
2	Passive moments	ΣMp	4,244
3	Own tough moments	ΣMw	270,625

4.2 Stability of retaining walls

Analysis of the stability of existing soil retaining walls with manual calculations to obtain safe values against shifting, rolling, and collapse of soil carrying capacity.

Shear stability	$1{,}72 \geq 1{,}5$	OK
Stability against bolsters	$2{,}58 \geq 1{,}5$	OK

Control calculation: safety factors, shear stability and rolling stability are safe for soil retaining walls because they are greater than 1,5.

4.3 Calculation of stability against soil bearing strength.

Calculation	Result
q_{ult}	1051,036 KN/m^2
qun	1036,131 KN/m²
qn	235,138 KN/m²
Resultant forces	0,656 m
Eccentricity	1,244 ; e < B/6 (not ok)
Safe factor	4,406 > 3
q_{all}	238,546 KN/m^2
σmax	127,248 KN/m² < 238,546 KN/m^2

4.4 Analysis of slope stability by reinforcement of soil retaining walls using plaxis 8.2 program.

Analysis of slope stability with DPT reinforcement using the Plaxis program. The analysis was carried out to obtain a safe value of slope stability by strengthening the retaining wall of cantilever soil against landslides. Data on soil parameters and specifications of soil retaining walls used are presented in Table 4 and Table 5.

Table 4. Soil Parameters

Name	Unit	Basic soil	Landfill
Model		MC	MC
Jenis		Undrained	Undrained
γ Unsat	kN/m³	23.992	15.725
γ Sat	kN/m³	24.538	17.599
Kx	m/hari	0.001	0.001
Ky	m/hari	0.001	0.001
μ		0.3	0.4
E		30000	30000
Kohesi (C)	kN/m²	0.491	39.240
Sudut Geser (ϕ)	°	30	35
Sudut dilantasi (Ψ)		0	0

Table 5. Data Soil Retaining Wall Specifications

DPT Type	Cantilever	
Concrete Quality (f'c)	K300	
	24,9	Mpa
Volume weight of concrete (γc)	24	kN/m³

4.4.1 Slope modeling with retaining wall reinforcement of original condition soil on plaxis 8.2

Slope modeling with soil retaining wall reinforcement in the plaxis program was carried out by including all basic soil parameters, landfill and soil retaining wall specifications (Table 4 and Table 5) to determine the collapse that occurred on the slope.

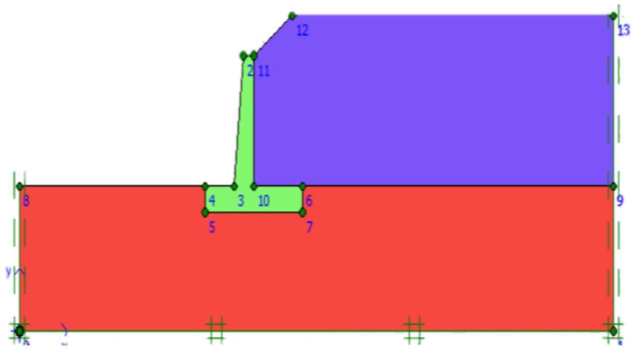

Figure 4. Slope modeling with reinforcement soil retaining wall existing condition in plaxis 8.2

4.4.2 Creation of an element network

After the modeling is in accordance with the original conditions in the field, the next step is for the geometric model to be divided into imaginary elements (meshing). The fine type was used in the meshing process in this study. The results of the webs of elements that have been created can be seen in Figure 5 below.

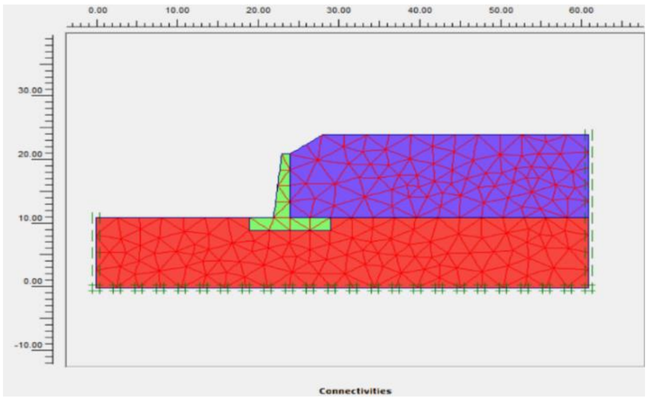

Figure 5. Nets of slope elements with reinforcement of soil retaining walls of existing conditions

4.4.3 Calculation of initial voltage

At this stage it is also referred to as gravity load. In this calculation stage, only the structure of the soil and rocks forming the slope is involved. The starting voltage can be seen in Figure 6 below.

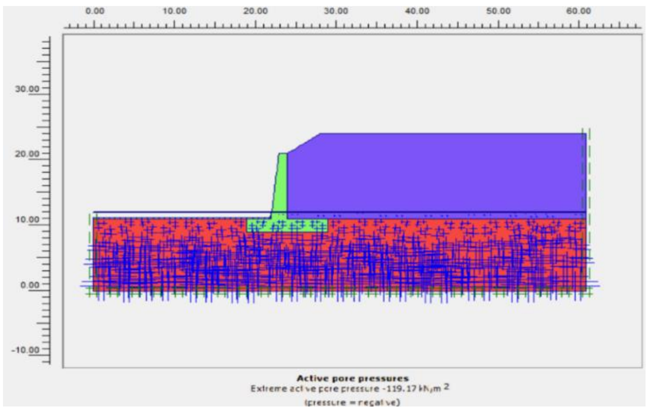

Figure 6. Calculation of the initial stress of the slope by reinforcement of the original condition soil retaining wall

4.4.4 Calculation stage

At this stage, after all parameters and data are inputted, the calculation stage is carried out. The calculation is done by entering the parameters tab with plastic analysis to find out the displacement that occurs, phi / reduction to find out the safety number and staged construction is used as loading input.

4.4.5 Output results with plaxis 8.6 program

At this stage, the safety and displacement figures that occur on the slope with the reinforcement of the cantilever soil retaining wall will be known. The results of calculations using the Plaxis 8.6 program can be seen in the following figures.

a. Deformed Mesh

The results of deformed mesh with soil retaining wall reinforcement of existing conditions obtained a total displacement of 264,39 x 10^9 can be seen in Figure 7 below.

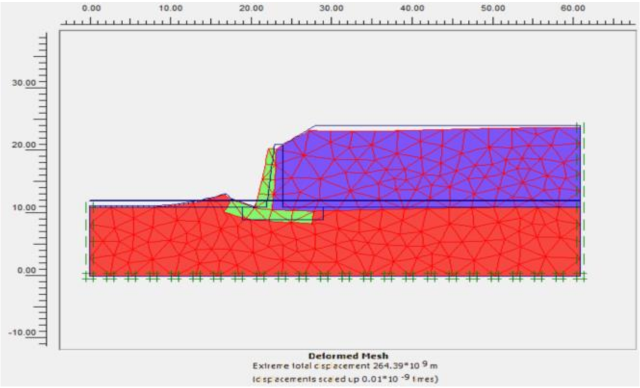

Figure 7. *Deformend mesh slope with reinforcement soil retaining wall*

b. Effective Stresses

The results of the analysis using Plaxis 8.2 on slopes with the reinforcement of soil retaining walls of the original condition found that the value of effective stresses was -851,86 kN/m². The results of effective stresses can be seen in Figure 8 below.

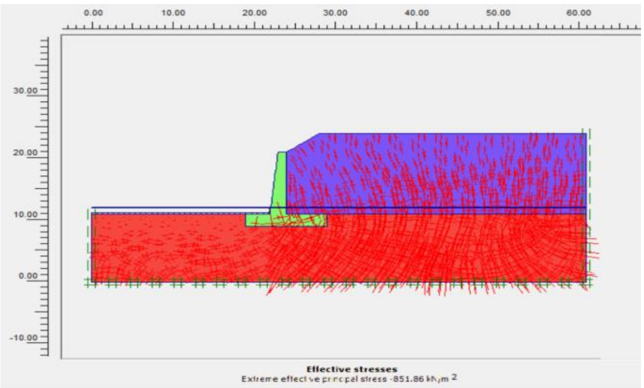

Figure 8. *Effective slope stresses with reinforcement of soil retaining walls*

c. Direction of movement and potential landslide area

The direction of movement and potential landslide areas on slopes with cantilevered type soil retaining wall reinforcement without the use of earthquake loads can be seen in Figure 9 and Figure 10.

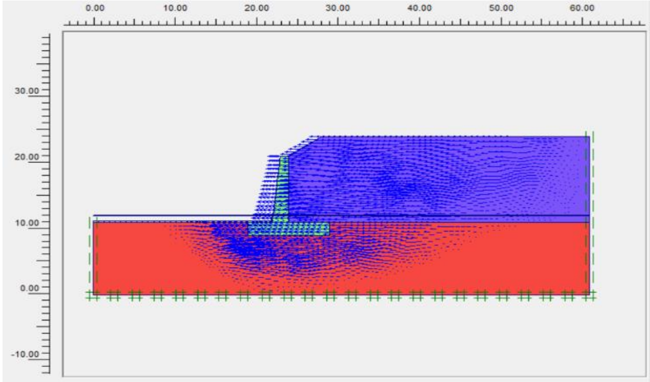

Figure 9. The direction of movement of the slope with the reinforcement of the soil retaining wall

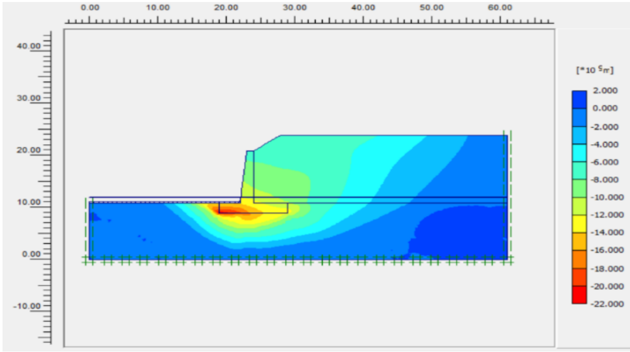

Figure 10. Areas of potential slope collapse with reinforcement of soil retaining walls

d. Safety factors

Figure 11 is the value of the safe number with reinforcement of soil retaining walls. The results of plaxis 8.2 analysis can be seen in the following figure.

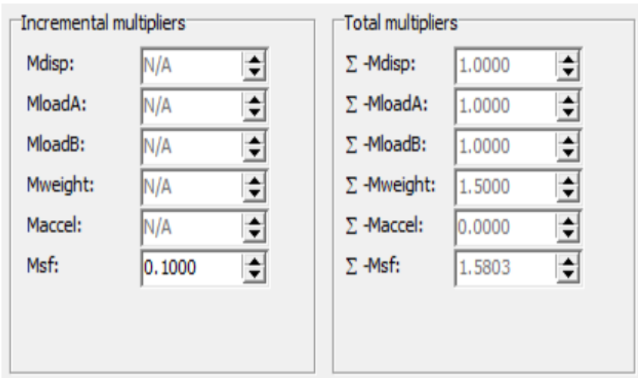

Figure 11. Ground retaining wall safety figures

The value of the safe number on the slope meets the required slope stability safety number of 1.5803 >1.5 so that slopes with soil retaining wall reinforcement are safe and stable against landslides as a whole. The Soil Retaining Wall used as a reinforcement of the soil retaining wall is able to withstand the tensile force so that the slope becomes more stable and safe against the overall landslide hazard on the slope.

5. CONCLUSIONS

The conclusions that can be presented from the results of the study based on the objectives of the study are:
The results of manual calculations on slopes with reinforcement of cantilever soil retaining walls using Rankine theory with external stability reviews obtained safe numbers SF_{Geser} = 1.72 > 1.5 (safe from shifting), SF_{Guling} = 2.58 > 1.5 (safe from rolling), and $SF_{Daya\ dukung\ terhadap\ runtuh}$ = 4.406 > 3 (safe from collapse).
The results of calculating the safe number using Plaxis 8.2 on the slope using cantilever-type soil retaining wall reinforcement were obtained 1.5803 > 1.5, so the slope is stable.
From the two results of slope stability analysis using manual calculations and the Plaxis method, different safe factor values were found, this is because the analysis using manual calculations did not include the parameters of soil elasticity modulus and poisson number and slope reviews were only reviewed in the landslide area.

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NOMENCLATURE

Ka	Active soil coefficient
Pa	Total active pressure
Ma	Active anchoring moment
Kp	Passive soil coefficient
Pp	Total passive pressure
Mp	Passive restraint moment
Fgl	Safe factor against overthrow
Fgs	Safe factor against shifting
q_{ult}	Calculation of ultimate carrying capacity
q_{un}	Calculation of net ultimate carrying capacity
qn	Net foundation pressure calculation
x	Resultant forces
e	Eccentricity at the base of the foundation
F	Safe factor calculation
Σ_W	Amount of building's own gravity
Σ_{Mw}	Number of moments of own weight of the building