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ABSTRACT

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The Ameroro Dam was built by the Sulawesi IV River Basin Center (BWS), Directorate General of Water Resources of the Ministry of PUPR with a storage capacity of 44.44 million m3 in order to increase the Irrigation Area (DI) in Konawe Regency. The Ameroro Dam is designed with the urugan type which has a peak height of 82 meters, a dam length of 324 meters, and a width of 12 meters. The spillway building has a threshold elevation of 122.50 meters with the Ogee type, a dodger channel in the form of double concrete conduits, and a Submerged Intake Tower retrieval building type. This study aims to analyze the slope stability of the Ameroro dam. This research studies slope stability using several methods; (a) *Spencer* Method (b) Finite Element Method. This research takes a research case study in Ameroro Dam, Konawe Regency, Southeast Sulawesi Province, Indonesia. The primary data from this study is in the form of documentation of conditions in the field. The results of this study state that from the results of the slope stability analysis, it was found that the safety factor on the slopes contained in the Ameroro Dam was 1.79. Slope conditions are relatively stable. And from the results of the comparison of slope stability analysis with the spencer method and finite element method, the safety factor value of the spencer method was 1.347, while the safety factor value of the finite element method with PLAXIS 2D software analysis was 1.67. So the lower bound SoF value = 1.347 from the spencer method calculation and the upper bound SoF value = 1.67 from the PLAXIS 2D software analysis calculation.

Keywords: stability; slope; ameroro DAM

1. INTRODUCTION

Slopes are geotechnical structures that can occur by nature or man-made. Slopes are structures made of geotechnical materials in the form of soil and rock. In the stability analysis, slopes must follow provisions based on geotechnical engineering which is generally studied in the field of soil and rock mechanics. However, considering that geotechnical materials generally have weaker resistance to shear, the application of soil mechanics is more in conducting slope analysis and engineering. (Abdul Hakam:2010)

Slopes that collapse are technically said to have lost their stability. Before the collapse, the slope can certainly have a low safety value. While slopes that are in stable condition are considered not to experience movement either downward or upward slopes. But a stable slope can also have a small safety value so that at some point it will be able to collapse.

According to Irving S Dunn et al, (1990) The factors that cause instability can be generally classified as factors that cause voltage rise and factors that cause strength drop. Factors that cause increased stress include increased weight of soil units due to wetting, additional external loads such as buildings, increased slope steepness due to natural erosion or due to excavation, and working shock loads. Loss of strength can occur in the presence of water adsorption, increase in pore pressure, shock loads or repeated loads, the influence of freezing and thawing, loss of material cementation, weathering processes, loss of strength due to excessive strain in sensitive clays. The presence of water is a factor in most slope collapses, because the presence of water causes both voltage and strength drops.

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For this reason, it is necessary to conduct research on the stability of a slope to avoid collapse on a slope that can damage infrastructure buried by landslides and infrastructure buildings that are above the slope so that it is carried away by landslides when landslides occur.

In conducting the analysis, please note that some slopes cannot be analyzed easily. Where the slope has a complex geology or a very weathered slope where variations in material and strength cannot be easily identified. The slopes of consolidated clay are highly exaggerated and firm clay cracks are difficult to analyze, for example, the Waco Dam Avalanche. (Beene, 1967)

The slopes that can be analyzed are natural slopes, slopes formed by natural material excavation, and artificial banks.

The most common slope stability analysis method is based on the balance limit. In this type of analysis the safety factor regarding the stability of the slope is estimated by testing the equilibrium conditions at the time of the exact collapse beginning along a originally defined collapse plane, and then comparing the forces required to maintain balance against the forces of the ground. All boundary equilibrium problems are static, indeterminate and since the voltage-voltage relationship along the approximate collapse plane is unknown, it is necessary to make sufficient assumptions so as to make possible using only one principal difference in various methods of equilibrium boundary analysis.

The second slope analysis method is based on the use of elasticity and plasticity theory to determine shear stresses at critical places within a slope for comparison with shear strength. Finite element computer techniques are being developed lately.

This research studies slope stability using several methods; (a) *Spencer* Method (b) Finite Element Method. "AMERORO DAM SLOPE STABILITY ANALYSIS", is a study of the Ameroro Dam Project, Konawe Regency, Southeast Sulawesi Province (Package II).

2. METHOD

Location and Time of Research

This research takes a research case study in Ameroro Dam, Konawe Regency, Southeast Sulawesi Province, Indonesia.

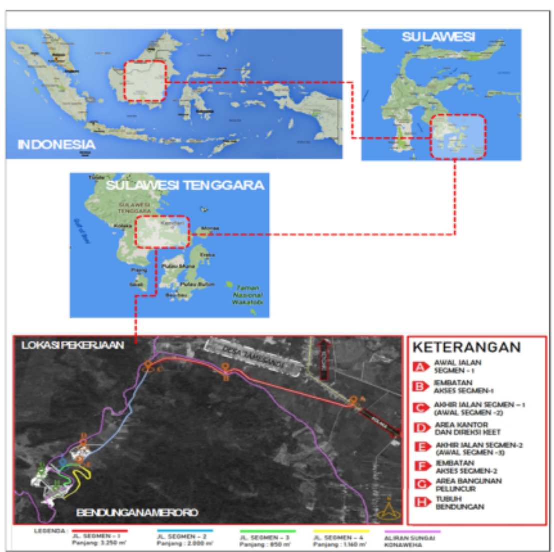


Figure 1. Research Location of Ameroro Dam, Konawe Regency

Data Collection

The primary data from this study is in the form of documentation of conditions in the field. Meanwhile, according to some secondary data for research obtained from various sources, including:

a. SNVT Construction of BWS Sulawesi IV Kendari Dam for the Ameroro Dam Construction project, Konawe Regency, Southeast Sulawesi Province (Package II), in the form of field test results data (*Bor Log*) and laboratory test data.
b. HUTAMA – ADHI KSO for the Ameroro Dam Construction project, Konawe Regency, Southeast Sulawesi Province (Package II), which is in the form of slope geometry plan drawing data at the Ameroro Dam (*spillway*).
c. Google Earth, data obtained from *Google Earth* in the form of images of slope conditions at the Ameroro Dam (*spillway*) research location.

Design Drawings

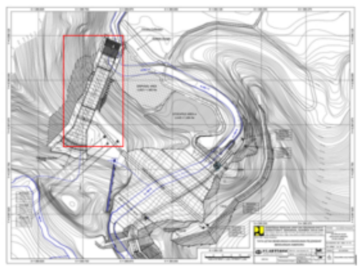


Figure 2. Dam Layout &; Auxiliary Buildings of Ameroro Dam

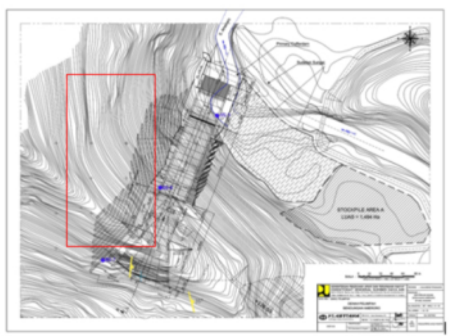
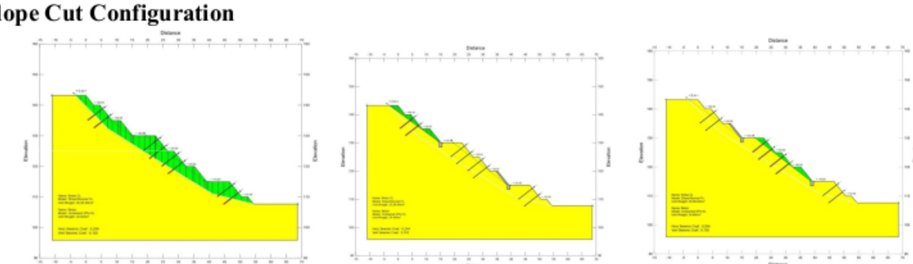


Figure 3. Ameroro Dam Spillway Plan

Slope Cut Configuration



(a) (b) (c)

Figure 4. (a) Slope Cut 1, (b) Slope Cut 2, (c) Slope Cut 3,

Field Work (Secondary Data)

Field work (secondary data) carried out by researchers is drilling, *in-situ testing* and laboratory tests, then engineering geological mapping, *seismic surveys* and laboratory tests (secondary data).

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Slope stability analysis with the help of *plaxis software*

The following will explain the ways in which the project is modeled into an analytical model that Plaxis can calculate. The steps include *input* data, c*alculation* and o*utput*.

Research Flow Chart

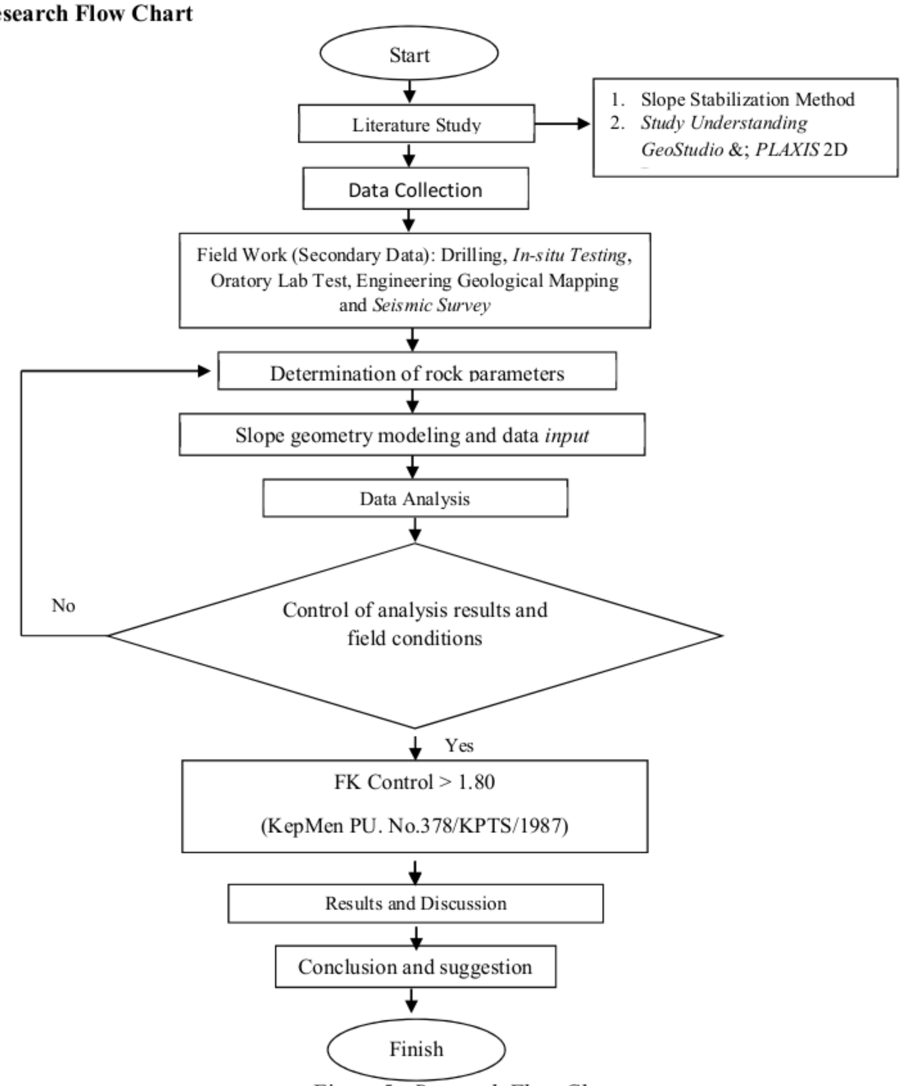

Figure 5. *Research Flow Chart*

3. RESULTS AND DISCUSSION

***Assessment* of Analysis Results and Field Conditions**

At this stage, calculations and determination of several parameters needed as input parameters for the *GeoStudio* program will be carried out. After that, using the input parameters obtained, slope stability analysis was carried out using the *GeoStudio* program so that it could be known whether the data used was appropriate to represent the conditions at the research site.

The data used for this study was located in the Ameroro Dam Construction project, Konawe Regency, Southeast Sulawesi Province (Package II). The data obtained from SNVT BWS Sulawesi IV Kendari Dam Construction is in the form of field test results data *(Bor Log)* and laboratory test data. This data is expected to represent slope conditions at the point of research review.

Slope Stability Analysis with *Spencer Method*

Spencer Slices Method of Slices is one of the most theoretically rigorous wedge methods because it satisfies the force and moment equilibrium of its collapse mass, which gives the calculation of the safety factor – *Factor of Safety* (F) slope stability. *Spencer's* method F calculation using an excel program can assign the F value of each slice. For Factor of *Safety* verification, the *Spencer* method is checked at each slice of the SF value of the $_{slice}$ based on *the condition of imminent failure.*

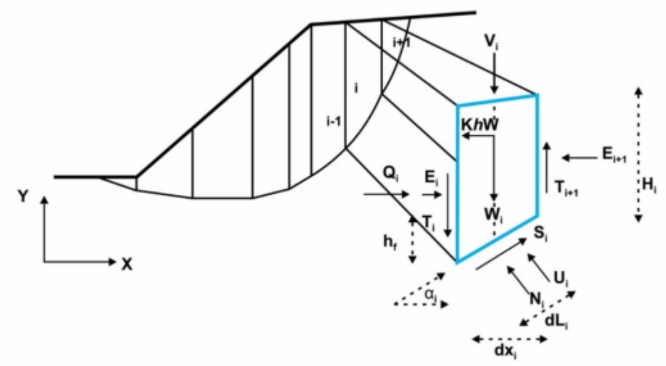

Figure 6. *Static scheme - Spencer method*

Where:

W	= sliced weight
Kh	= horizontal seismic coefficient
H_i	= slice height
α_i	= angle of inclination of the base of the slice
h_f	= height of left-side *interslice* force
v_i	= external addition
N_i	= effective normal force
U_I	= water pore force/strength
S_i	= mobilized shear force
E_i	= left *interslice* style
E_i+1	= right *interslice* style

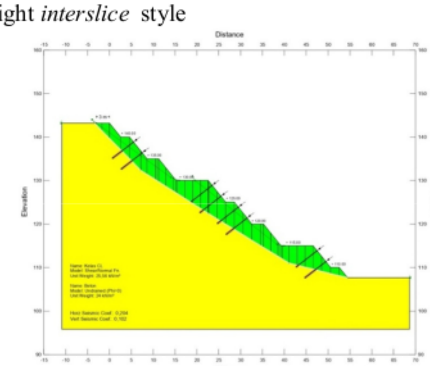

Figure 7. *Static scheme - Spencer method*

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Where:

W	=	sliced weight
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v_i	=	external addition
N_i	=	effective normal force
U_I	=	water pore force/strength
S_i	=	mobilized shear force
E_i	=	left *interslice* style
E_i+1	=	right *interslice* style

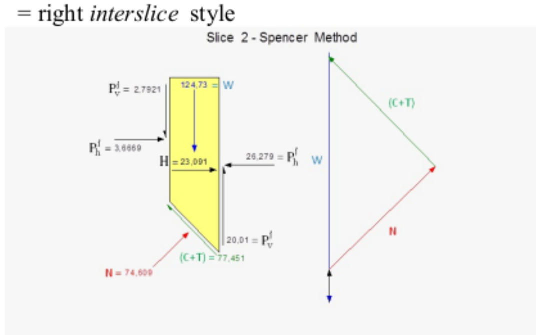

Figure 8. *Typical* Slicing Slope Calculation Spencer Analysis *Method*

Where:

W	=	sliced weight
H	=	normal force of the slice
P_h^i	=	normal force on the left side of the slice
P_v^i	=	sliding force on the left side of the slice
P_h^j	=	normal force on the right side of the slice
P_v^j	=	shear force on the right side of the slice
(C+N)	=	shear force at the base of the wedge
N	=	normal force at the base of the slice

Slice 2 - Spencer Method

Factor of Safety	=	1,79
Phi Angle	=	57,502 °
C (Strength)	=	8,8613 kPa
Pore Water Pressure	=	0 kPa
Pore Water Force	=	0 kN
Pore Air Pressure	=	0 kPa
Pore Air Force	=	0 kN
Phi B Angle	=	0 °
Slice Width	=	1,6935 m
Mid-Height	=	2,6149 m
Base Length	=	2,4304 m
Base Angle	=	-45,829 °
Anisotropic Strength Mod.	=	1
Applied Lambda	=	0,76144
Weight (incl. Vert. Seismic)	=	124,73 kN
Base Normal Force	=	74,609 kN

Base Normal Stress	=	30,698 kPa
Base Shear Res. Force	=	138,66 kN
Base Shear Res. Stress	=	57,051 kPa
Base Shear Mob. Force	=	77,451 kN
Base Shear Mob. Stress	=	31,867 kPa
Left Side Normal Force	=	3,6669 kN
Left Side Shear Force	=	2,7921 kN
Right Side Normal Force	=	26,279 kN
Right Side Shear Force	=	20,01 kN
Horizontal Seismic Force	=	23,091 kN
Point Load	=	0 kN
Reinforcement Load Used	=	0 kN
Reinf. Shear Load Used	=	0 kN
Surcharge Load	=	0 kN
Polygon Closure	=	1,9722 kN
Top Left Coordinate	=	-1,693512; 143,21091 m
Top Right Coordinate	=	0; 143,21091 m
Bottom Left Coordinate	=	-1,693512; 141,46764 m
Bottom Right Coordinate	=	0; 139,72438 m

After obtaining data from the *Spencer* method, the calculation of the equilibrium of forces in each direction in the slice. The stages of analysis are as follows:

a. Describe a one-way/vector equilibrium force of the slice force, then find the values of N_i and $(C + T)_i$.

$N_1 = W \sin 45^\circ$
$N_1 = 106{,}133$
$(C+T)_1 = W \cos 45^\circ$
$(C+T)_1 = 65{,}523$

Where : 45° is used to refer to the reference that 45° is the safety limit of the slope.

Calculates the amount *of Safety Factor* (SoF) in each vector direction.

$$F_1 = SoF_1 = \frac{N_1}{(C+T)_1}$$
$$F_1 = SoF_1 = 1{,}620$$

b. Repeating steps a and b until the direction/vector of the slice is complete, as well as with the next slice, the same is treated for each vector in the slice.

$\boldsymbol{N_2 = P_v^i \sin 45^\circ}$
$N_2 = 2{,}376$
$(C+T)_2 = P_v^i \cos 45^\circ$
$(C+T)_2 = 1{,}466$
$$F_2 = SoF_2 = \frac{N_2}{(C+T)_2}$$
$F_2 = SoF_2 = 1{,}620$

$\boldsymbol{N_3 = P_v^j \sin 45^\circ}$
$N_3 = 17{,}027$
$(C+T)_3 = P_v^j \cos 45^\circ$
$(C+T)_3 = 10{,}512$
$$F_3 = SoF_3 = \frac{N_3}{(C+T)_3}$$
$F_3 = SoF_3 = 1{,}620$

$$\boldsymbol{N_4 = P_h^i \cos 45^\circ}$$
$$N_4 = 1{,}927$$
$$(C+T)_4 = P_h^i \sin 45^\circ$$
$$(C+T)_4 = 3{,}122$$
$$F_4 = SoF_4 = \frac{N_4}{(C+T)_4}$$
$$F_4 = SoF_4 = 0{,}617$$

$$\boldsymbol{N_5 = P_h^j \cos 45^\circ}$$
$$N_5 = 22{,}361$$
$$(C+T)_5 = P_h^j \sin 45^\circ$$
$$(C+T)_5 = 13{,}805$$
$$F_5 = SoF_5 = \frac{N_5}{(C+T)_5}$$
$$F_5 = SoF_5 = 1{,}620$$

$$\boldsymbol{N_6 = 77,451}$$
$$(C+T)_6 = 74{,}609$$
$$F_6 = SoF_6 = 1{,}038$$

After completing the SoF calculation of each vector per slice. Next calculate the SoF of the segment. Where the segment SoF formula is as follows:

$$SoF\ segmen = \frac{\left(\frac{\sum F_1 + \cdots + F_{n-1}}{n-1}\right) + F_n}{2}$$

Where:

$\sum F_1$ = total summation of pre-calculated per-vector SoF values

n = total data/ amount of SoF data

F_n = SoF value in the last data/vector

$$SoF\ segmen = \frac{\left(\frac{\sum F_1 + \cdots + F_{n-1}}{n-1}\right) + F_n}{2}$$

***(F=SoF) segmen* = 1,245**

Table 1. *The Spencer* method *Factor of Safety* is examined at each slice of the slice's SF value based on *imminent failure* conditions

Slice	F=SoF
1	1,494
2	1,245
3	1,224
4	1,280
5	1,301
6	1,304
7	1,314
8	1,343
9	1,350
10	1,336
11	1,273
12	1,255
13	1,253

14	1,287
15	1,338
16	1,383
17	1,421
18	1,480
19	1,480
20	1,396
21	1,406
22	1,402
23	1,327
24	1,326
25	1,361
26	1,346
27	1,298
28	1,260
29	1,257
30	1,288
31	1,423
32	1,457
33	1,474
34	1,474
35	1,423
36	1,264
37	1,173
$\sum \boldsymbol{SoF}$	**49,716**

Based on Table 1, the value of the safety factor in each slice of the spencer method is found to range from 1.1-1.4.

$$SoF\ rerata = \frac{\sum_i^n SoF}{n}$$

Where:

Average SoF = average value of Safety Factor
n = total data/ amount of SoF data
$\sum_i^n SoF$ = result of the sum of SoF values in the data

$$SoF\ rerata = \frac{\sum_0^{37} 49{,}716}{37}$$

***(F=SoF) rerata* = 1,347**

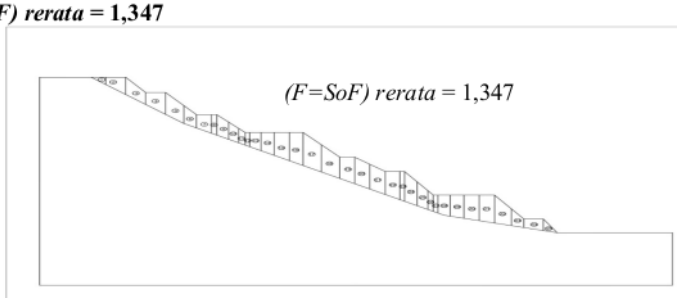

Figure 9. Spencer Slope Wedge *Method*

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Slope Stability Analysis with *PLAXIS* 2D

Slope Stability Analysis with *PLAXIS* 2D requires several input data parameters such as soil specific gravity (dry specific gravity and saturated specific gravity), deep shear angle, *Young's Modulus*, *Poisson's Ratio* and soil cohesion that can describe the properties of a soil layer and slope.

Information on rock stiffness parameters is very limited. Unit weight and permeability are not constant for different types of rocks. Therefore, it is established that the parameters are focused on rigidity and strength parameters, which have the most influence on stability.

Table 2. *Parameter Input* Data on *Plaxis*

Name	Condition	Cohesion, C (kPa)	Deep Shear Angle, φ (°)	γ_{dry} (kN/m^3)	γ_{sat} (kN/m^3)	Young's modulus, E (kN/m^2)	*Poisson's Ratio, ν*
Layer 1	Drained	>200	55	19,454	24,335	33508	0,30
Layer 2	Drained	>200	55	10,031	10,467	33508	0,25

After analysis with *PLAXIS* 2D along with existing parameters, a *Factor of Safety* result of 1.67 was obtained.

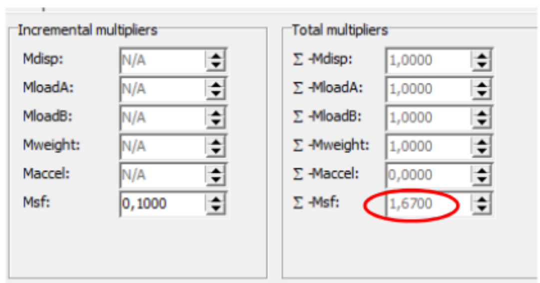

Figure 10. Spencer Slope Wedge *Method*

Here is a picture of the results of the analysis conducted with *PLAXIS* 2D:

- *Deformed Mesh*

Finite element software uses elements and nodes (nodes are one of the programming languages used to create storage blocks for various data structures and organize data in a non-sequential way) where calculations are performed. The figure below shows the result of deformation on the slope with a safety factor of 1.67

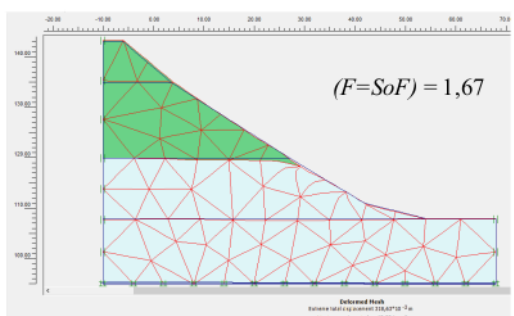

Figure 11. Deformed Mesh or Tissue of Deformed Elements on a Slope

It is shown from the figure above that the total decrease that occurred was 318.63 x 10-3 m with the safety factor number at the permit threshold of 1.67.

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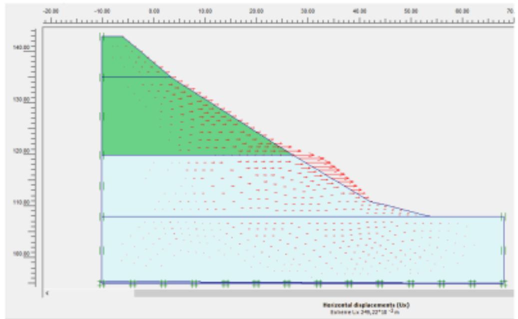
Figure 12. Horizontal deformation direction on slopes

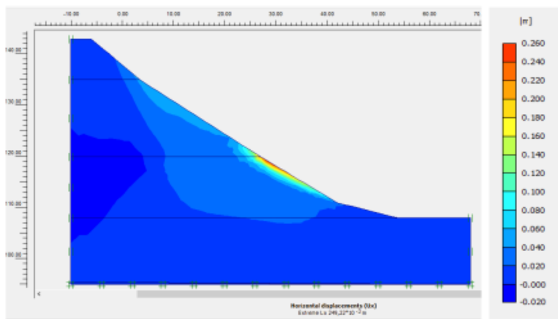

Figure 13. Horizontal deformation of slopes

From the results of slope deformation analysis, extreme horizontal deformation (Ux) of 249.22 x $^{10-3}$ m was obtained with the direction of deformation which can be seen in Figure 4.6 and 4.7 above.

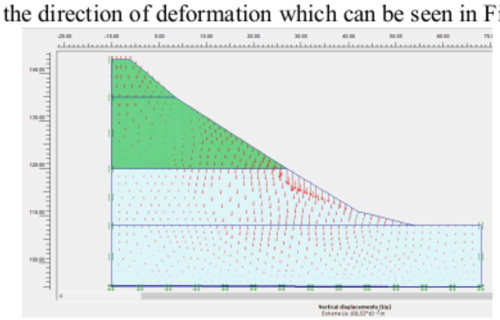
Figure 14. Vertical deformation direction on slopes

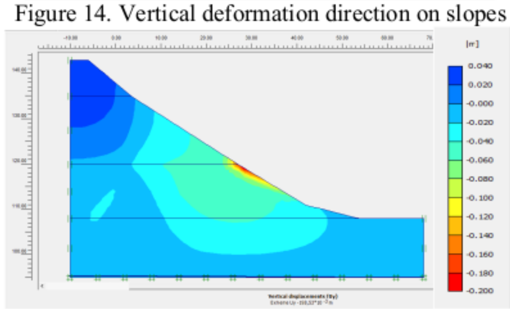

Figure 15. Vertical deformation of slopes

From the results of slope deformation analysis, extreme vertical deformation (Uy) of 198.53 x 10^{-3} m was obtained with the direction of deformation which can be seen in Figures 4.8 and 4.9 above.

1. *Total displacement* direction

Total displacement or total displacement indicates the possibility of slipping on slopes with the condition that the base layer is able to withstand loads. The stockpile is still safe but at a stable threshold.

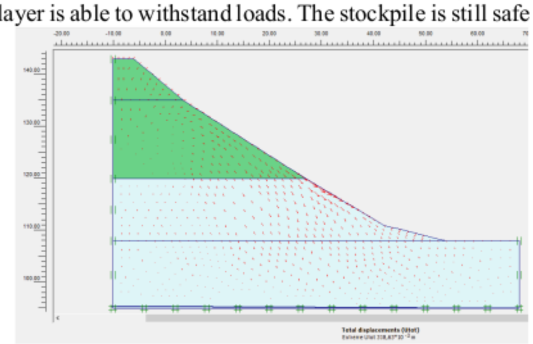

Figure 16. The total direction of displacement on the slope

The picture above shows the potential for slipping on the slope and shows the condition of whether the base layer can withstand the load. The stockpile is safe on the verge of stability.

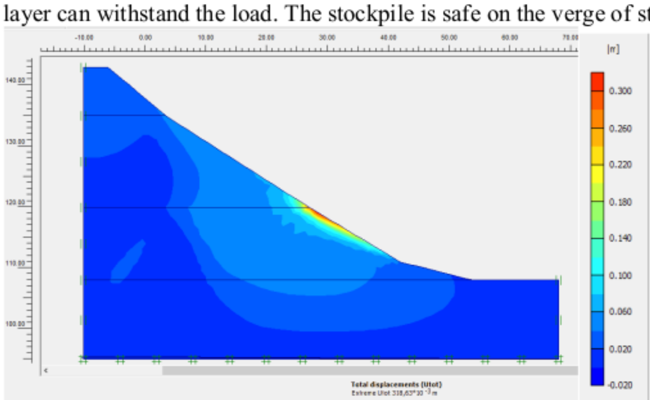

Figure 17. Total displacement on slopes

The picture above shows the condition of the slope that is disturbed due to load distribution.

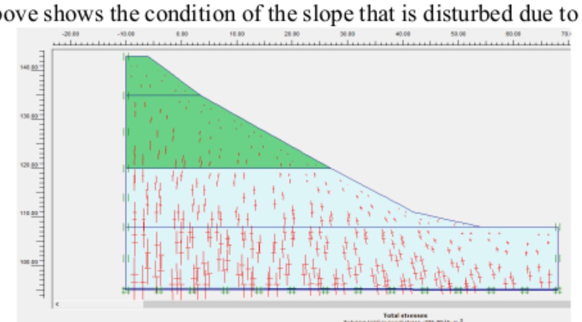

Figure 18. Total voltage on slopes

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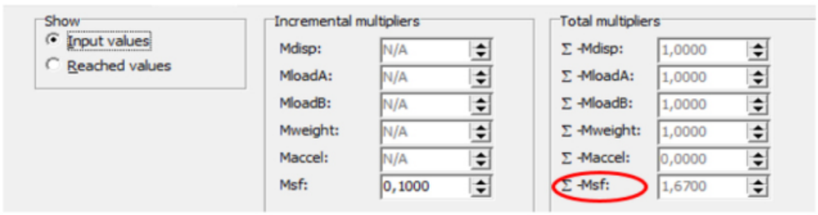
The picture above shows the slope being able to withstand the load and distribute the load evenly to all layers.

From the plastic analysis carried out, the total extreme displacement on the slope was 318.63 x $^{10\text{-}3}$ m as seen in Figure 4.5 above.

Then in the third stage select the calculation with the phi-c reduction method to get the value of the safety factor of the deformation that has occurred in the plastic analysis carried out before, then click calculate. In the phi-c reduction approach.



After deformation and safety factor analysis, a safety factor value of 1.67 was obtained. With a safety factor value of 1.67, the slope is in the relatively stable category. The results of the deformation analysis obtained an extreme horizontal displacement of 249.22 x 10-3 m, an extreme vertical displacement of 198.53 x 10-3 m and an extreme total displacement of 318.63 x 10-3 m.

The analysis of deformation and safety factors is more or less the same as conditions in the field, where the value of the safety factor obtained at 1.67 shows that the slope from the simulation results is in relatively stable condition.

Based on the results of the analysis, the soil parameter input data can be used in the next modeling simulation.

Table 2. Comparison of Safety Factor *(SoF)* values in 2 methods

SoF values **based on *Spencer's*** method	***SoF*** value **based on the results of *PLAXIS* 2D** software analysis
1,347	1,67

Based on Table 2, the value of the safety factor is obtained in 2 methods , namely:

1. Lower Bound *SonF* value = 1.347 from Spencer method calculation
2. Upper Bound *SoF* value = 1.67 from *PLAXIS* 2D software analysis calculation

4. CONCLUSION

From the results of the slope stability analysis, it was found that the safety factor on the slopes contained in the Ameroro Dam was 1.79. Slope conditions are relatively stable. From the results of the comparison of slope stability analysis with the spencer method and finite element method, the safety factor value of the spencer method was 1.347, while the safety factor value of the finite element method with PLAXIS 2D software analysis was 1.67. So the lower bound SoF value = 1.347 from the spencer method calculation and the upper bound SoF value = 1.67 from the PLAXIS 2D software analysis calculation.

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