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Slope Stability Assessment Using Limit Equilibrium Method With Deterministic and Probabilistic Approach (Case Study : Mota'ain-Motamasin National Road, East Nusa Tenggara, Indonesia

Muhammad Zakki[1,a)], Ria Asih Aryani Soemitro[2,b)], Trihanyndio Rendy Satrya[2,c)] & Andria Muharami Fitra[3,d)]

[1)]Students of Superspecialist Masters in Ministry of Public Works and Housing (PUPR), Department of Civil Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.
[2)]Civil Engineering Department, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.
[3)]Division of Planning and Supervision of the National Road of the Province of East Nusa Tenggara, The National Road Construction Agency for East Nusa Tenggara Province, Directorate General of Highways, Ministry of Public Work and Housing, Indonesia.

Correspondent : [b)]ria@ce.its.ac.id

ABSTRACT

The Mota'ain-Motamasin road section is a road section that was built in the realization of infrastructure development in the border area in East Nusa Tenggara which borders Timor Leste. On this section, road construction has been completed, but at several points there are landslides that need to be addressed. Research conducted includes modeling and testing in the laboratory. Physical, mechanical, suction and XRD tests were carried out on the samples. Back analysis was carried out to obtain soil parameters during landslides. Then analyzed the stability of the slopes Sta 149+140 with deterministically and probabilistically and analyzed the sensitivity of soil parameters to the value of Safety Factor. Bobonaro soil is classified as Cohesive Soil and has a value of Liquid Limit = 80.823% and Plasticity Index value = 58.747%, classified as CH (High Plasticity Clay) soil. Bobonaro soil has kaolinite content of 3.4%-17.9%, illite 16.6%-42.6%, and montmorillonite 9.6%-30.6%. The combination of small amount of kaolinite and high montmorillonite accompanied by high changes in water content is the cause of frequent landslides on the mota'ain-motamasin roads. At Sta 149+140, the value of Safety Factor = 1,249 at GWT 0 m becomes SF = 1,254 at GWT -5 m probabilistically 10,000 iterations. The value of SF = 1,254 without suction becomes SF = 1,263 when there is suction at GWT -5 m probabilistically 10,000 iterations. The most sensitive soil parameter on the Safety Factor is cohesion, followed by the internal shear angle and unit weight. Handling of Sta 149+140 landslides used bore piles with SF=1.808 > SF=1.5.

Keyword : Slope stability, Safety Factor, Limit Equilibrium, Monte Carlo Probabilistic, Sensitivity analysis.

INTRODUCTION

Indonesia is a country that has borders with other countries. Indonesia's large area means that there are many countries that are neighbors with Indonesia. East Nusa Tenggara (NTT) is a province in Indonesia which is directly adjacent to the State of

Timor Leste, which has become one of the areas that has experienced rapid infrastructure development in recent years. This can be seen from the construction of the National Border Crossing Center (PLBN), followed by the construction of the Indonesia-East Timor border road. The map of East Nusa Tenggara and the location of the Mota'ain-Motamasin road section can be seen in Figure 1.

Figure 1. Map of East Nusa Tenggara and the Mota'ain-Motamasin Road Section

The Mota'ain-Motamasin road section is one of the roads that have been built in the framework of the realization of infrastructure development in the border area in East Nusa Tenggara. On this segment, road construction has been completed, but at several points it has experienced landslides. Photos of the landslides that occurred can be seen in Figure 2.

Figure 2. Sliding Slope on the Mota'ain-Motamasin Road Section

In addition, there is still a lack of research on the types of soil in East Nusa Tenggara. Several previous researchers have defined that the type of soil on the roads in East Nusa Tenggara is problematic soil.

The calculation of the slope factor of safety usually uses the limit equilibrium method. The existence of uncertainty in the limit equilibrium method causes the need for supporting calculations, one of which is the calculation using a probabilistic approach. El-Ramly et.al (2003) said that the use of a probabilistic approach in the analysis of slope stability for problematic soils such as clay shale is still limited. There is still little use of the probabilistic approach in slope safety applications, making the probabilistic method used in the analysis of slope stability in this study other than the deterministic approach.

Landslides generally occur during the rainy season, so the influence of the water level in the soil needs to be considered in this study. Pratama (2021) said, in the design of clay shale slope stability, groundwater table control plays an important role in maintaining slope stability. Groundwater table modeling is modeled in this study to see the effect of the groundwater table in the calculation of slope stability. In unsaturated soils, the suction value affects the slope shear strength parameter. And in this study will also be taken into account the effect of suction on the stability of the slopes to the ground water level being modelled.

With more than one boring data and laboratory data, it can be used to approach safety factor with deterministic and probabilistic. So, based on this background, this research is important to do.

RESEARCH METHOD

The research to be carried out is modeling research accompanied by research in the laboratory. The data obtained is primary data (from research conducted in the laboratory) and secondary data from the field. From Figure 3, this research start with literature review, and then the data will be collected from the field which can be divided into primary data dan secondary data. After that, the primary data will be tested at the laboratorium to get physical and mechanical parameters, suction, and clay minerals from the sample. After that, parameters data from primary and secondary data will be analyzed in the assist program (Geoslope) to do back analysis to get parameters of momentary conditions during a landslide. Also, to get safety factor value with deterministic approach, and safety factor value with probabilistic approach. Then, conclutions and recommendations will be proposed. And that is the end of the research.

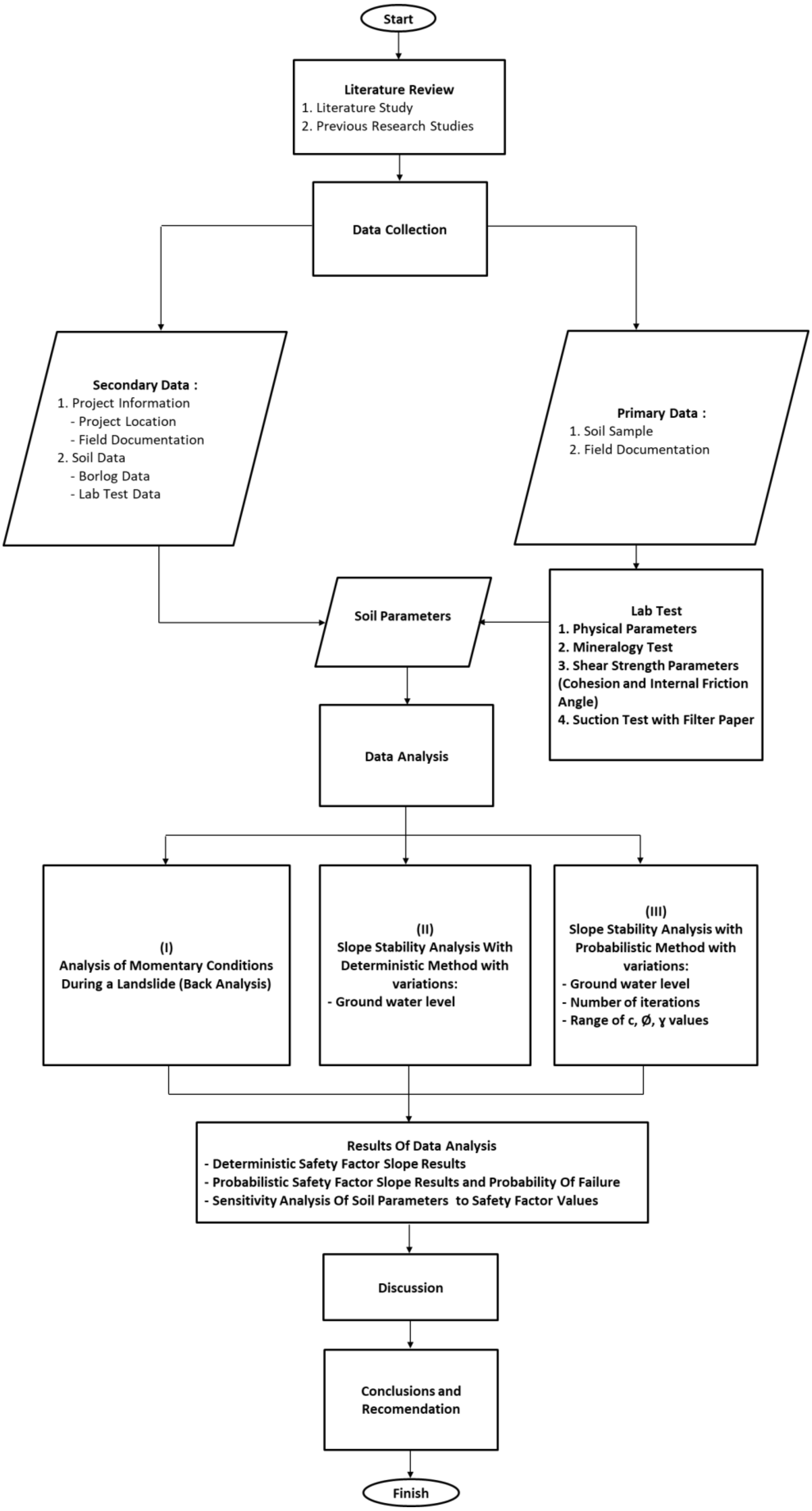

Figure 3. Flowchart

DATA COLLECTION

The point for taking soil samples for testing in the laboratory is at Sta 149+140 as deep as ±1 m from the soil surface which is then taken to the soil mechanics laboratory of the Sepuluh Nopember Institute of Technology Surabaya and becomes the primary data for this study. As for secondary data, obtained from Public Works and Public Housing data from the East Nusa Tenggara National Road Implementation Center (PUPR BPJN NTT). Figure 4 shows sampling location and landslide location in this paper.

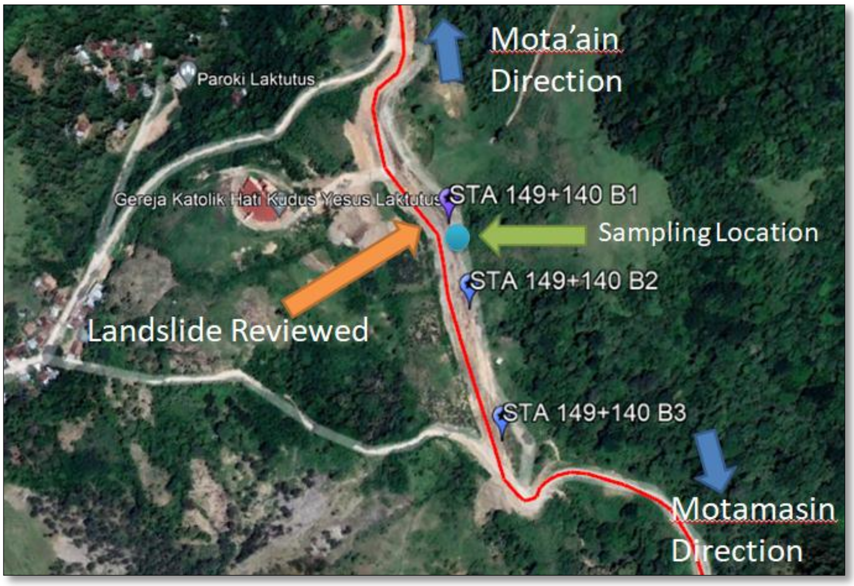

Figure 4. Sampling Locations and Landslide Locations

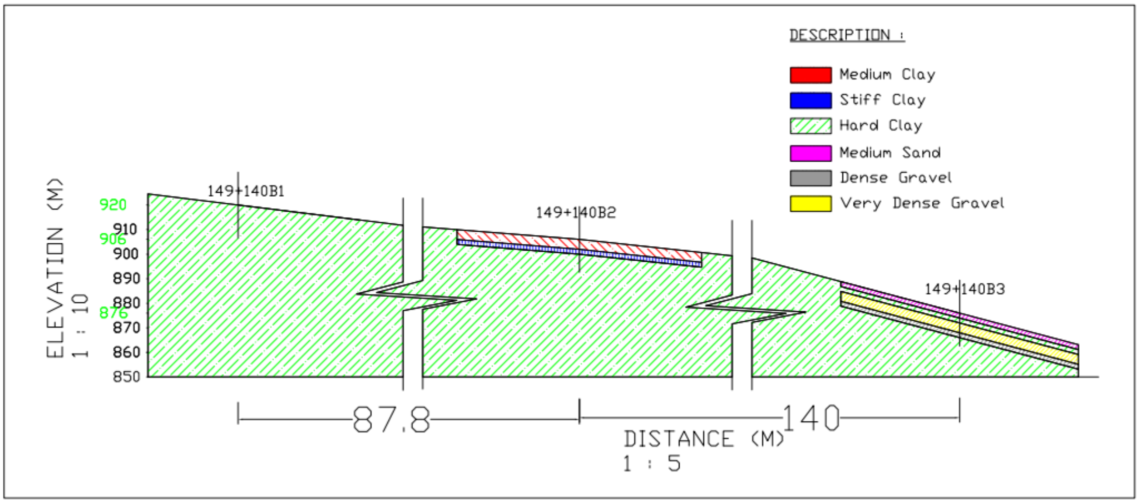

Figure 5. Soil Stratigraphy

Secondary data is processed so that soil stratigraphy is made. Based on the results of soil stratigraphy in Figure 5, with 3 boring data and laboratory test result and also the result of laboratory test from primary data, it used in deterministic and probabilistic calculations in this paper.

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RESEARCH ANALYSIS

Laboratory Test

Laboratory test such as physical properties, mechanical properties and suction test conducted at Soil and Rock Mechanics Laboratory, Civil Engineering Department Sepuluh Nopember Institute of Technology, Surabaya. And XRD mineralogy tests were carried out at the Materials and Metallurgical Engineering Laboratory of the Sepuluh Nopember Institute of Technology, Surabaya, with 2 samples. Table 1 shows the results of testing.

Table 1. Results of Physical dan Mechanical Properties Testing of Bobonaro Soil At a depth of ±1 m

No	Lab Test	Unit	Result Value
1	**Soil Physical Properties Test**		
a	Grain distribution analysis		
	- Gravel	%	-
	- Sand	%	2.130
	- Silt	%	39.247
	- Clay	%	58.623
b	Atterverg Limit		
	- Liquit Limit	%	80.828
	- Plastic Limit	%	22.081
	- Plasticity Index	%	58.747
c	Gravimetric-volumetric		
	- Water Content	%	19.769
	- Spesific Gravity		2.593
	- Volume Weight	gr/cm^3	1.631
	- Pore Value		0.509
	- Porosity		37.077
2	**Soil Mechanical Properties Test**		
	Unconfined Compression Test		
	- q_u	kg/cm^2	1.324
	- $C_u = q_u / 2$	kg/cm^2	0.662

From testing the physical properties it is known that the Bobonaro clay sample consists mostly of silt and clay, as seen from the silt fraction of 39.247%, and the clay fraction of 58.623%, so it is classified as cohesive soil. From its Liquid Limit value of 80.828%, and its Plasticity Index value of 58.747%, Bobonaro clay is classified as a soil that has high plasticity. Based on USCS, Bobonaro clay is classified as CH, and based on AASHTO, it is classified as A-7-6. The Bobonaro clay tested has a qu value of 1.324 kg/cm2 and a Cu value of 0.662 kg/cm2. Based on the value of qu, the Bobonaro clay samples tested were of stiff consistency.

Table 2. Volumetric Water Content vs Suction

Kondisi	vwc	Suction
Jenuh	0.539	49.98
Initial	0.372	156.34
75%	0.350	362.66
50%	0.316	5191.30
25%	0.283	10096.48
0%	0.245	69.203.01

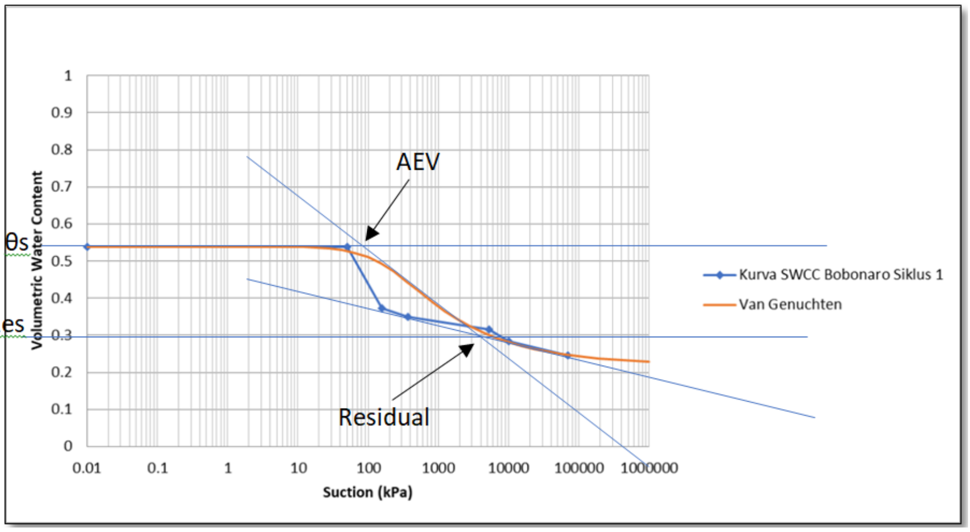
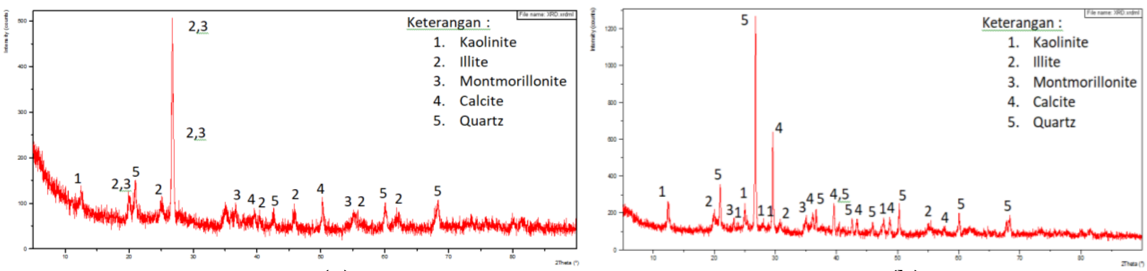


Figure 6. Lab Result SWCC Curve vs Van Genuchten's SWCC

From the results of matching with Van Genuchten's SWCC as can be seen at Table 2 and Figure 6, the unsaturated parameter values were obtained, namely a = 200, n = 1.42, and m = 0.296. Low value suction occurs in saturated soil, and no water has come out of the soil pores. Along with the start of drying, the suction value increases, and air begins to enter, seen in the Air Entry Value (AEV) position. The volumetric water content value decreases, and the suction value increases. At a certain position, that is, as the volumetric water content decreases to the residual position, the suction value will increase. In the SWCC curve, it can be seen that the maximum value of volumetric water content (saturated) is 0.53. Residual water content is at a value of 0.22. This unsaturated parameter will later be used in calculating the safety factor both deterministically and probabilistically for Bobonaro soil, especially at Sta 149+140.



(a) (b)

Figure 6. Graph of XRD Results (a) Sample 1 (b) Sample 2

In the Bobonaro clay samples at Figure 6, calcite minerals were found with levels of 15.4% -20.9%, and there was also quartz with levels of 8.1% -35%. The mineral content of kaolinite clay found is in the range of 3.4% -17.9%. Furthermore, the mineral content of illite clay is in the range of 16.6% -42.6%, and the mineral content of montmorillonite clay is in the range of 9.6% -30.6%. The combination of the relatively small content of the mineral kaolinite and the presence of the mineral montmorillonite which is relatively high accompanied by the change of season from dry season to rainy season, is indicated as the cause of the frequent occurrence of landslides on the Mota'ain-Motamasin roads.

Back analysis

Modeling in the geoslope assist program begins with making a slope model, then analyze the stability of the slopes by paying attention to the water level and suction. The water level applied to the model is -5 m, -2.5 m, and 0 m (saturated) from the subgrade surface.

Table 3. Soil parameter values Sta 149+140 (Zone I)

No	Soil Layer	Used parameters		
		$\gamma_{average}$ (kN/m3)	Ø $_{average}$ (^{0})	C $_{average}$ (kPa)
1	Layer of Bobonaro Clay	19.53	0	44.13
2	Layer of CH- Hard	20.77	6.64	128.32

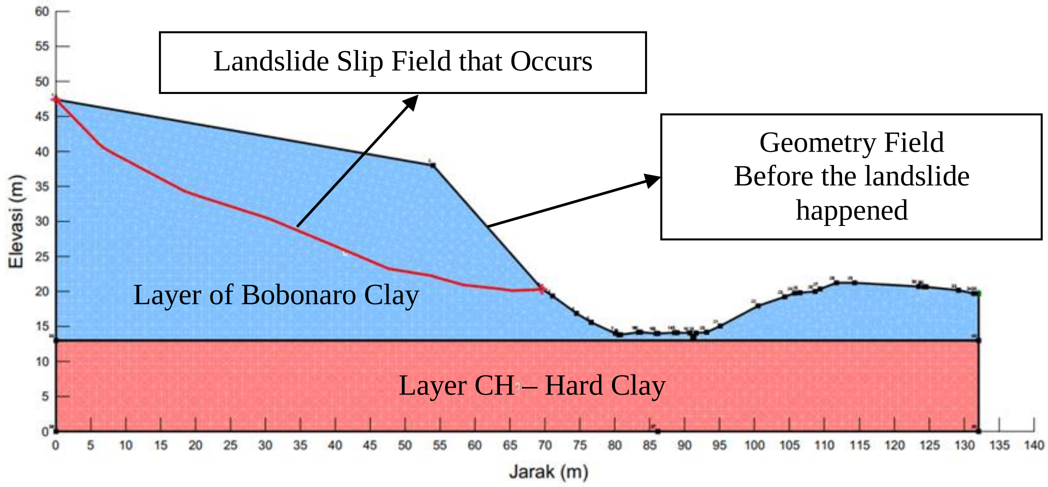


Figure 7. Geoslope Modeling Back analysis Sta 149+140 B1

Table 3 and Figure 7 show the geometry and layer of soil that applied to the model for Sta 149+140. The calculation done to get the parameters when landslides. In the calculation results obtained SF value of 0.741 < SF = 1. This shows that with the parameters that occur, the slope has experienced a slide. Thus, the existing soil parameters become parameters that play a role when landslides occur, namely Ø' = 0^0 and C' = 44,133 kPa.

Safety Factor For Existing Condition

<u>STA 149+140</u>

Slope stability is calculated using a deterministic and probabilistic approach. With deterministic approach, it is calculated using average values of soil parameters. And with probabilistic approach, it is calculated using range data of soil parameters that calculated with statistical component such as mean of data, standart deviation and covariance of the data.

Following are the results of statistical calculations on the CH-Hard soil parameter data in Sta 149+140 and the shape of the data distribution.

$\gamma_{average}$ = 20.769 kN/m3 γ_{min} = 19.790 kN/m3
Stdev γ = 0.547 kN/m3 γ_{max} = 21.620 kN/m3
COV γ = 0.026

The COV γ value is still in the range of 0.00-0.1 according to Schneider H.R and Schneider M.A (2013).

$\text{Ø}'_{average}$ = 6.6430 $\text{Ø}'_{min}$ = 4.5000
Stdev Ø' = 1.4470 $\text{Ø}'_{max}$ = 9.5000
COV Ø' = 0.219

The COV Ø' value is still in the range of 0.037-0.29 according to Kim (2001).

$C'_{average}$ = 128.322 kPa C'_{min} = 77.885 kPa
Stdev C' = 54.609 kPa C'_{max} = 299.343 kPa
COV C' = 0.426

The COV C' value is still in the range of 0.1-0.5 according to Duncan (2000).

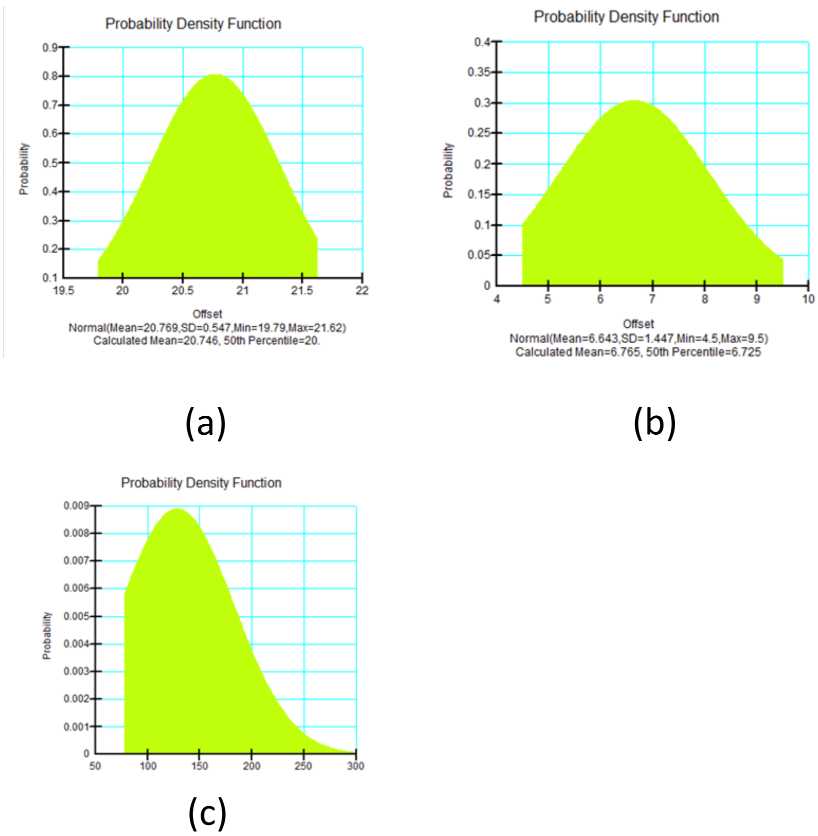


Figure 8. *Probability Density Function*
(a) γ, (b) Ø, (c) C, at Sta 149+140

Then the slope stability analysis is carried out using the Monte Carlo method using the geoslope, by entering the parameters above. And obtained the value of SF for each location. The Monte Carlo probabilistic calculation process is assisted by the geoslope aid program to then be calculated with iterations of 2000, 5000, and 10,000 calculations with conditions without suction and with suction, as well as with GWT variations of 0 m, -2.5 m , and -5 m from the ground level.

Table 4. Safety Factor Values For Sta 149+140 B1 Deterministic and Probabilistic

No	Condition	Deterministikk		Probabilistik N= 2000				Probabilistik N= 5000				Probabilistik N= 10000			
		No Suction	With Suction	No Suction		With Suction		No Suction		With Suction		No Suction		With Suction	
		FS	FS	FS	Pf	FS	Pf	FS	Pf	FS	Pf	FS	Pf	FS	Pf
1	GWT 0 m	1.249	1.249	1.249	0.000%	1.249	0.000%	1.249	0.000%	1.249	0.000%	1.249	0.000%	1.249	0.000%
2	GWT -2.5 m	1.253	1.254	1.253	0.000%	1.254	0.000%	1.253	0.000%	1.254	0.000%	1.253	0.000%	1.254	0.000%
3	GWT -5 m	1.254	1.263	1.254	0.000%	1.263	0.000%	1.254	0.000%	1.263	0.000%	1.254	0.000%	1.263	0.000%

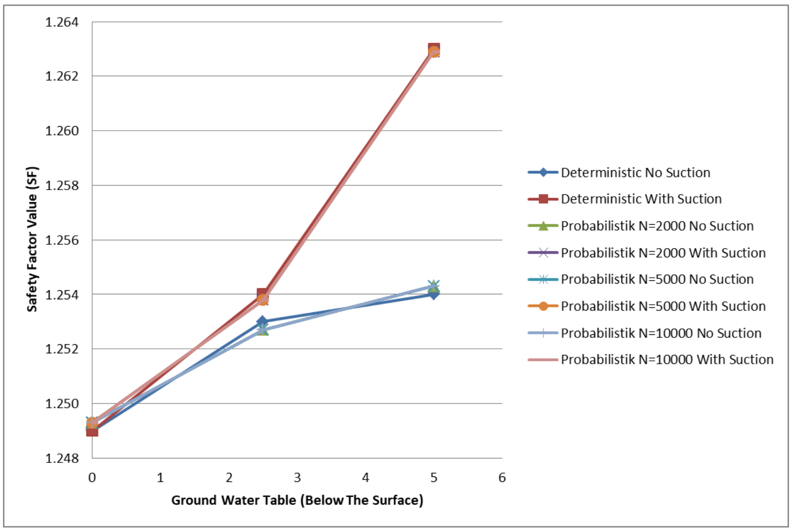
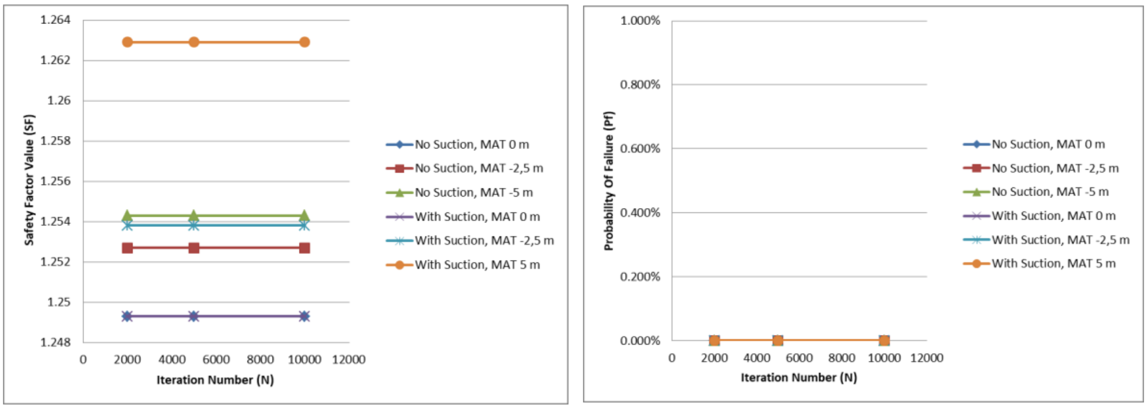


Figure 9. Graph Safety Factor Sta 149+140 B1 Deterministic and Probabilistic

Table 4 and Figure 9 show SF for deterministic and probabilistic approach. From the graph in Figure 9, probabilistically calculated SF for sta 149+140 shows that the SF value is the same/close to the deterministically calculated SF.



(a) (b)

Figure 10. (a) Graph Safety Factor and Sta 149+140 B1 Probabilistic vs Iteration Number,
(b) Graph Probability of Failure Sta 149+140 vs Iteration Number

If we compare SF value with the number of trials conducted in Figure 10, it can be seen that SF value will approach the flat line, so that the change in value will be stable. This means that the more the number of trials given, the more stable SF value will be. The probability of failure is 0.00%, this means that there is no value of SF < 1.

Safety Factor After Reinforcement

STA 149+140

At Sta 149+140, the slope that occurs is the result of excavation of the existing soil. The soil condition indicated as Bobonaro clay, based on laboratory results that have been analyzed, is prone to a decrease in shear strength due to exposure to water. In addition, the relatively high nature of montmorillonite clay minerals, causes the need for handling to prevent significant changes in water content. Handling on existing slopes due to excavations, at the location of the Mota'ain-Motamasin border road, the other that has been carried out, namely the use of gabions and retaining walls, has experienced many failures. Therefore, the authors suggest strengthening with Bore Pile on the slope of Sta 149+140. Planned bore pile with a diameter of 60 cm as deep as 9.5 m. After modeling, the SF value is 1.808 > SF = 1.5. Seen in Figure 11 below.

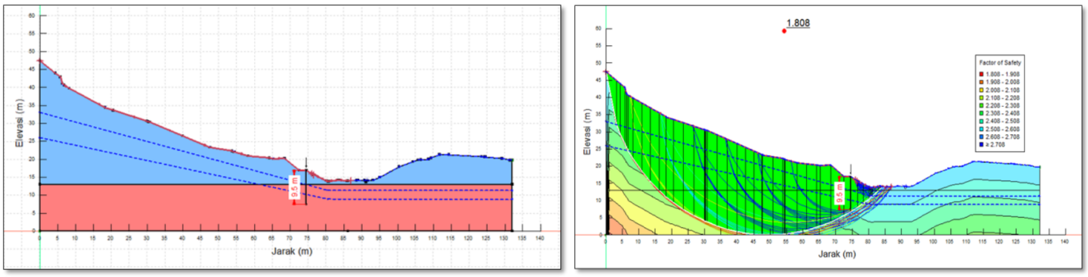


Figure 11. Bore Pile and SF Results After Bore Pile Strengthening At Sta 149+140

Sensitivity Analysis

Sensitivity analysis was carried out to determine the effect of changing the parameter values applied to the soil on a value, in this case the SF value. In this study, a sensitivity analysis of the value of the parameter ɣ, the value of the parameter C (cohesion), and the value of the parameter Ø to the value of SF was carried out. In this study, sensitivity analysis was conducted in Sta 149+140. At Figure 12, we can see that changes in the cohesion value gives significant change in the safety factor.

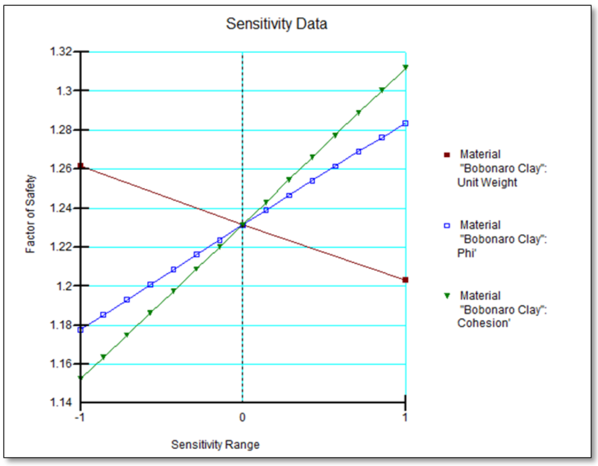


Figure 12. Results of Data Sensitivity on the Geoslope program

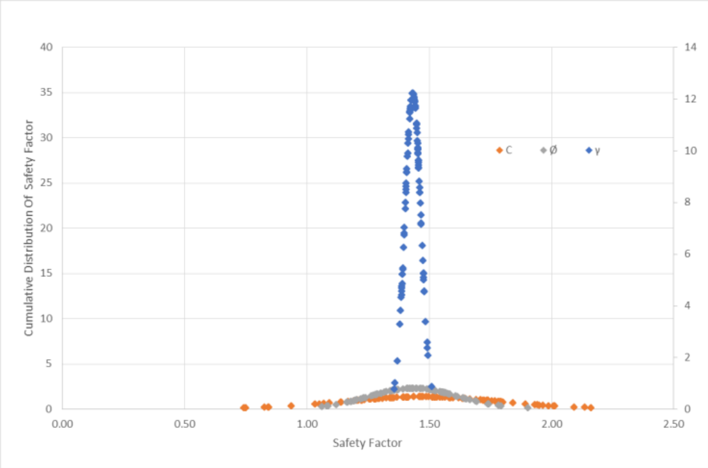


Figure 13. Sensitivity Analysis Curve

Table 5. Sensitivity Order Table

No	Parameters	Sensitivity STDV	Ranking
1	Volume Weight	0.0291	3
2	Cohesion	0.2873	1
3	Intrnal Friction Angle	0.1454	2

In Figure 13, it can be seen that a significant change in the safety factor occurs in changes in the cohesion value, compared to changes in the safety factor due to changes in the internal shear angle values and changes in the volume weight values. As can also be seen in Table 5, the standard deviation value of cohesion has the largest value compared to the standard deviation value of the internal friction angle and the standard deviation value of unit weight. This shows that the Cohesion value is the most influential factor and has the highest sensitivity to changes in the safety factor value, followed by the inner shear angle which is the most influential next and then the unit weight value of the soil.

CONCLUSION

Based on research conducted for slope stability studies using the boundary equilibrium method with a deterministic and probabilistic approach with a landslide case study on the Mota'ain-Motamasin national road section, East Nusa Tenggara, several conclusions can be drawn as follows :

1. a. The Bobonaro soil tested has a clay content value of 58.623% and a silt content of 39.247%, so it is classified as Cohesive Soil. In addition, the tested Bobonaro soil also has a high plasticity value, as seen from the LL = 80.823% and PI = 58.747%. According to USCS, Bobonaro soil is classified as CH (High Plasticity Clay) soil, and according to AASHTO, Bobonaro soil is classified as A-7-6 soil.

   b. In the Bobonaro clay samples, calcite minerals were found with levels of 15.4% -20.9%, and there was also quartz with levels of 8.1% -35%. The mineral content of kaolinite clay found is in the range of 3.4% -17.9%. Furthermore, the mineral content of illite clay is in the range of 16.6% -42.6%, and the mineral content of montmorillonite clay is in the range of 9.6% -30.6%. The combination of relatively small kaolinite mineral content and the relatively high presence of montmorillonite minerals on the slopes accompanied by significant changes in water content due to seasonal changes from dry season to rainy season, is indicated as a frequent cause of landslides on the mota'ain-motamasin roads.

2. The values of the soil parameters just before the landslide after calculating the back analysis for Sta 149+140 B1, namely the value of Ø' = 00, and the value of C' = 44.133 kPa. Significant changes in soil parameters when a momentary landslide occurs, are caused by soils that have high plasticity (classified as CH) and saturated conditions.
3. Calculation of the Safety Factor using the Probabilistic approach, namely Monte Carlo, although it has a higher SF value than the Deterministic SF calculation, it helps to show the probability of slippage, which can be used as material for consideration in determining whether an existing slope needs to be repaired as soon as possible or not. In this study, the value of the probability of sliding in all zones obtained is Pf = 0.000%. This value indicates that there is no SF value < 1, so there is no possibility of slippage with the range of existing parameter values.
4. a. The value of the safety factor on the slopes is affected by the condition of the groundwater table, as can be seen from the results of the calculation of the safety factor which changes significantly due to the position of the groundwater table applied to the calculation model. It can be seen that at Sta 149+140, the value of SF = 1,249 in the GWT condition of 0 m becomes SF = 1,254 when the GWT -5 m is applied to probabilistic calculations with 10,000 number of iterations / number of trials.
   b. The suction applied to the modeling shows that, at Sta 149+140, the SF value has increased due to suction. It can be seen that at Sta 149+140, the value of SF = 1,254 in the condition without suction becomes SF = 1,263 when suction is applied with GWT conditions -5 m in probabilistic calculations with 10,000 number of iterations / number of experiments.
5. The sensitivity of the soil parameter that plays the most role in the calculation of the Safety Factor both according to the calculation of the geoslope aid program and according to the calculation is the cohesion value. This shows that changes in the cohesion value will cause the safety factor value to change significantly. Then followed by the value of the internal shear angle as the next most sensitive parameter. While the value of ɣ, according to calculations both manually and using auxiliary programs, has the lowest sensitivity to safety factor.
6. The slope handling proposed at Sta 149+140 is using bore piles that are suitable for soil conditions with hard consistency at depths below 1 m. The choice of bore pile because the use of piles is not effective if driving is carried out at that location due to hard soil with a high N-SPT from a depth of 1 m below the ground surface. The use of other avalanche countermeasures such as gabions and retaining walls has been applied to other slope failure locations for slopes formed by excavation, but they are not effective in dealing with landslides. So that the bore pile reinforcement was chosen for handling avalanches at Sta 149+140 with a value of SF=1.808 > SF=1.5.

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