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Slope Stability Analysis for Landslide in Road Preservation Working Packages Ende - Wolowaru and Junction – Kelimutu Sta 10+475

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ABSTRACT

The National Road Construction Agency (BPJN) in East Nusa Tenggara Province through the Satuan Kerja IV (Satker) has repaired some landslide points in the Ende – Wolowaru and Junction – Kelimutu Road Preservation working package. One of the landslide points that need treatment is at STA. 10+475. Based on survey and planning results from the Satker P2JN BPJN NTT, the most dominant factors that trigger landslides are geological conditions and high rainfall. Data from soil investigations at the landslide location at STA 10+475 after the landslide occurred showed that the soil was dominated by sandy clay. However, in their planning report, rainfall data was not found, therefore, it is needed to see whether there is an influence of rainwater infiltration at the location for causing landslides. This research aims to determine the causes of landslides including whether there is an influence of rainwater infiltration at the research location and the simulation results with the SLOPE/W and SEEP/W porgrams are proven to be correct. After simulating with the SEEP/W program, the slope safety factor which was 1.586 before the landslide occurred dropped to 0.883.

Keyword : road asset management, landslide, SLOPE/W, SEEP/W

INTRODUCTION

The Public Works Infrastructure is one of the assets to improve the prosperity of a region. Therefore, Public Works Infrastructure, especially National Roads, must always be in good working condition if the infrastructure is planned, constructed, operated, and maintained properly (Soemitro and Suprayitno, 2020). A landslide in one place indicates that there is the potential for a similar incident to occur at that location. This indicates that there must be risk mitigation in the future so that the buildings being built are not damaged by landslides. Muka and Wibowo (2021) state that risk is a measure of vulnerability, susceptibility, and consequences. The goal of risk management is to create mitigation and protection measures that can reduce vulnerability to threats and the potential for failures or accidents. In managing the risk of landslides that will occur, an evaluation is needed of infrastructure that have existed during their operational period or life span. Suprayitno et al (2020) state during the service life of an infrastructure, periodic evaluations should be conducted to assess the condition and quality of it.

The Kelimutu Lake area can be reached from Ende Regency only via the national road. If accessed via H. Hasan Aroeboesman Ende Airport, the journey to the location passes through the foot of Mount Kelimutu. In fact that a road network is a primary need for a region or country, the road network must always be in good quality (Babo and Suprayitno, 2019) but, the road locations that pass through mountainous or hilly topography usually have common problems. In infrastructure development, adjusting building elevations is necessary because many structures are constructed in hilly or valley areas. This condition poses a risk of collapse for infrastructure built on embankment slopes or excavation slopes. The existing inclinations, whether on embankment slopes, excavation slopes, or natural slopes, must be designed to be stable and safe. (Shoffiana et al, 2022). The control method applied involves arranging the slope by limiting the slope height to 5 meters and regulating the slope inclination to be at a ratio of 1 horizontal unit to 1 vertical unit (1H:1V). (Syah, 2022). Using another method, Ramadhan et al (2020), also mentioned in their analysis that if the Retaining Wall constructed does not intersect with the sliding plane located far below the slope, it may be necessary to add reinforcement in the form of mini piles.

Figure 1. Landslides points

Since the road to Kelimutu was upgraded to a National Road in 2015, work has been carried out to widen it to standard, where previously the road width was only 4.5 meters and now it is 7 meters. As previously explained above, this section of the national road from 2015 to 2023 will be the only access to the Lake Kelimutu area and only recently have there been many landslides. The National Road Construction Agency (BPJN) of East Nusa Tenggara Province through Satker PJN IV has planned to handle these two landslide points in the Ende - Wolowaru and Junction - Kelimutu Road Preservation work package. The landslide points that need treatment are STA. 8+425 and STA. 10+475, as shown in **Figure 1**. The length of handling on the Junction – Kelimutu section is as follows.

a. at STA 8+425 87 meters long; and
b. at STA 10+475 80 meters long.

LITERATURE REVIEW

Safety Factor

Sebayang et al (2022) stated that slope stability analysis is widely used in construction planning, such as: embankments for highways, excavation of slopes for roads, and so on. Slope stability itself is also often linked to land sliding. Generally, the safety factor for slope stability in relation to soil shear strength is taken to be greater than or equal to 1.2-1.5. Bowles (in Sebayar et al. 2022) revealed the value of the safety factor based on landslides as in **Table 1** below.

Table 1. Correlation of safety factor and landslide incident

Safety Factor	Incident
SF < 1,07	Landslides Commonly Occur
1,07 < SF < 1,25	Landslides Have Occurred
SF > 1, 25	Landslides Rarely Occur

Source: sebayang et al, 2022

Rain Instesity

The daily rainfall data obtained will first be converted into hourly rainfall data using the Mononobe formula (Atikah et al, 2017), as follows:

$$i = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{2/3} \quad \ldots(1)$$

where:
i : rain intensity (mm/hr; m/hr)
t : time (duration) of rainfall (hr)
R_{24} : maxium rainfall height at 24 hours (mm)

Atikah et al (2017) stated that the intensity of rain that occurs in Indonesia has a duration of 5-7 hours, so the middle value of this interval is often used as a reference in calculating hourly rainfall derived from daily rainfall data. To determine Debit, using formula such as:

$$Q = 0{,}278 \times C \times I \times A \quad \ldots(2)$$

where:
1. I is rain intensity
2. C is the value of the flow coefficient
3. A is catchment area

Analysis of Stability

Slope stability analysis is generally based on the concept of limit plastic equilibrium (Hardiyatmo, 2010), which are:
a. Slope failure occurs along a specific sliding plane and can be considered a two-dimensional surface problem;
b. The sliding soil mass is considered as a passive object;
c. Shear resistance from the soil mass at each point along the sliding plane is independent of the orientation of the sliding surface, or in other words, the soil shear strength is considered isotropic;
d. The safety factor is defined by considering the average shear stress along the potential sliding plane and the average shear strength along the sliding surface.

Slope stability analysis is intended at obtaining safety factors for a particular slope shape. Knowing the safety factors makes it easier to build or strengthen slopes to determine whether the slopes that have been formed have a risk of landslides or are stable enough. Increasing the level of certainty in predicting landslide threats can be useful for the following things:
a. To understand the development and forms of natural slopes and the processes that lead to the formation of different natural shapes.;
b. To assess the stability of slopes in the short term (usually during construction) and under long-term conditions;
c. To assess the likelihood of landslides involving natural or man-made slopes.

d. To analyze landslides and understand the failure mechanisms and the influence of environmental factors;
e. To redesign failed slopes and plan and redesign prevention measures, as well as reassessment;
f. To study the effects or influence of seismic loads on slopes and embankments.

RESEARCH METHOD

The slope topography will be redrawn in the AUTOCAD program to speed up the process of drawing slope conditions. Images from the AUTOCAD program will be exported to SEEP/W to simulate rainwater infiltration and to SLOPE/W to calculate slope stability. The data that will be entered into the SEEP/W and SLOPE/W programs is the data mentioned in data collection section. Inputting soil properties for slope stability analysis. It is planned to simulate rainwater infiltration with three models. Rain model I (without rain), rain model II (existing rain before and after the landslide with a duration of seven days, rain model III (annual rain). From each model a relationship will be obtained between safety factors and rain duration. Meanwhile for conditions Before the landslide occurs, back analysis will be carried out. The simulation results can be used to analyze the causes of landslides with a Safety Factor value of less than 1 (one), whether influenced by rain infiltration or not with back analysis. The effect of rain on slope stability based on the slope safety factor.

DATA COLLECTION

Based on soil investigation data at STA 10+475, conclusions can be drawn regarding the type of soil at the study location as in **Table 2**.

Table 2. N-SPT value on STA 10+475 landslide point

Depth (m)	Thickness (m)	Type of Soils	N-SPT	Consistency (*Lambe and Whitman)
0 -2,5	2,5	Brown sandy silty clay	13	*Stiff*
2,5 -4,5	2	Fine brown clayey sand	18	*Very Stiff*
4,5 -6,5	2	Red silty clay	21	*Very Stiff*
6,5 -8,5	2	Red silt clay, brown sandy clay, tuff, Boulders	39	*Hard*
8,5 -10,5	2	Coarse, clayey sand, layered with sandstone	60	*Hard*
10,5 -12,5	2	Brown clayey sand	39	*Hard*
12,5 -14,5	2	Brown clayey sand	52	*Hard*
14,5 -16,5	2	Brown clayey sand	40	*Hard*
16,5 -18,5	2	Brown clayey sand	60	*Hard*
18,5 -20,5	2	Brown argillaceous sandstone, Boulders, Gravel	60	*Hard*
20,5 -22,5	2	Clayey sand, sandstone with Boulder, Gravel	60	*Hard*
22,5 -24,5	2	Coarse, clayey sand with pivoted boulder	60	*Hard*

Source: Anonym (P2JN), 2022

From **Table 2** above, can be seen that the soil has a very hard consistency starting from a depth of 6.5 meters. This is also reinforced by the service provider having difficulty drilling holes for the Borepile. The Geostudio software requires at least 3 (three) main parameters to be included in the calculation. Namely unit weight, cohesion, and angle friction. After viewing and comparing the data in the Geotechnical Planning Report and correlating between parameters, the input parameters that will be used in the analysis can be seen in **Table 3**.

Table 3. Paremeter Input for programs

Depth (m)	Thickness (m)	Type of Soils	N-SPT	γ	γ_{sat}	*Cohesion* (C)	*Angle Friction* (ϕ)	*Angle of Friction of Stuct-Soil*	*Poisson Ratio* (ν)
				[kN/m^3]	[kN/m^3]	[kPa]	[°]	[°]	
0 -2,5	2,5	Brown sandy silty clay	13	17	20	14,30	30,00	20,00	0,30
2,5 -4,5	2	Fine brown clayey sand	18	21	27	5,00	41,00	27,00	-
4,5 -8,5	4	Red silty clay	28	17	20	14,30	30,00	20,00	0,30
8,5 -12,5	4	Coarse, clayey sand, layered with sandstone	48	21	27	5,00	31,00	20,00	-
12,5 - 18,5	6	Brown clayey sand	55	21	35	5,00	52,78	35,00	-
18,5 - 24,5	6	Brown argillaceous sandstone, Boulders, Gravel	60	17,5	30	5,00	45,55	30,00	-

Rain data was obtained from the BMKG website, by looking for the closest station to the research location. Because Ende Regency itself does not have rain observation statistics and after searching for information regarding the existence of the nearest station to the location, it was decided to use a station from the Fransiskus Xaverius Seda Meteorological Station in Sikka Regency. The following is the rainfall data for 2022 in **Table 4** which has been adapted for calculation purposes:

Table 4. Sikka Regency 2022 rainfall

Month	Number of Rainy Days recorded	Average (mm)	Max (mm)
January	25	10,04	73,2
February	24	9,31	42,4
March	22	6,34	80,4
April	21	1,33	20,2
May	20	0,30	6
June	17	5,80	74
July	21	0,01	13
August	15	0,00	0
September	17	1,23	8,9
October	23	1,96	18,5
November	21	12,56	75,8
December	21	8,63	71,1

From the rain data obtained which is focused on 2022, it can be seen that in March there was the highest rainfall with a rainfall of 80.4 mm/day. In the information that the author obtained from BPJN NTT, the landslide incident was reported on June 21 2022 and in that month the highest daily rainfall (R24) was 74 mm/day. From this rainfall data, rain intensity can be calculated using equation (1), which is then needed to calculate the water flux value by dividing the discharge by the area.

RESEARCH ANALYSES

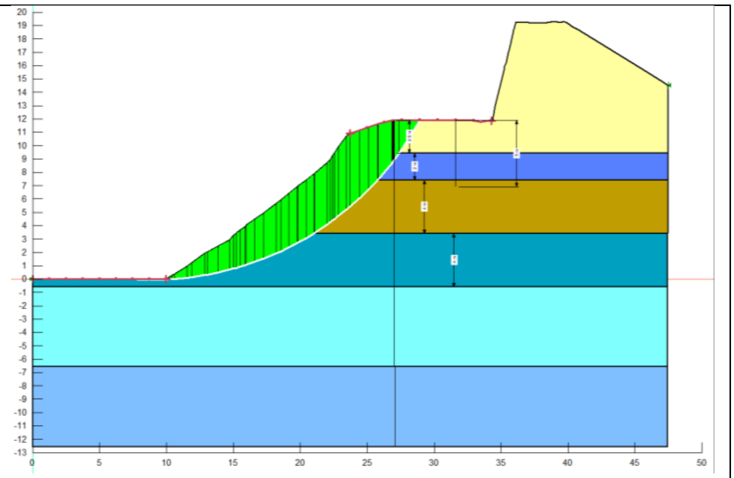
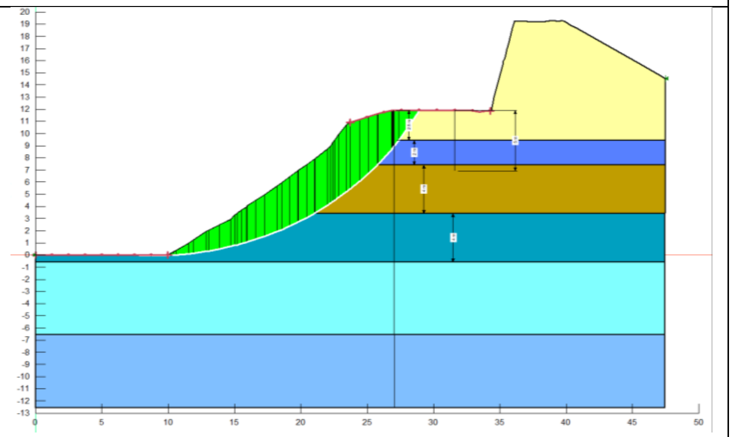
Using SLOPE/W

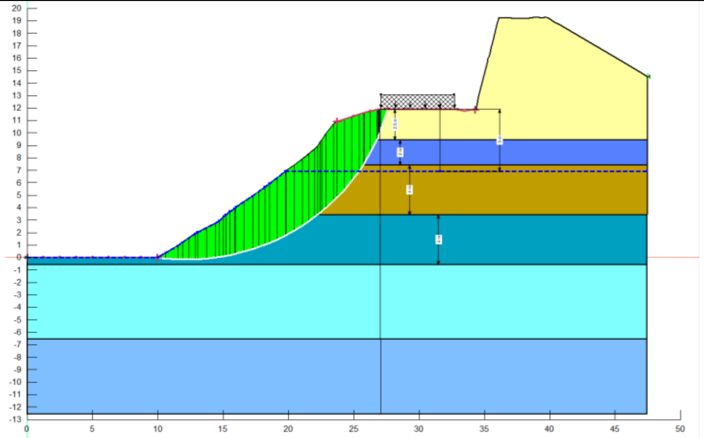
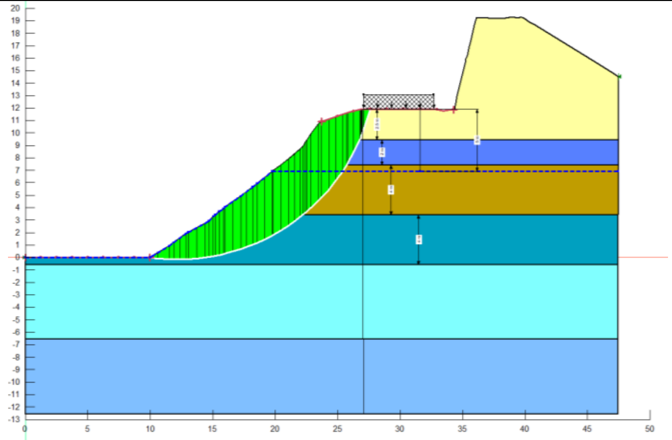
Input parameters as in table 3 will be listed. At this stage, a comparison of the safety factors of the four stages of slope conditions and the soil materials that form them is carried out. For the slip surface analysis type, the entry and exit type is used, which draws the length of the area under load and the area under it. The simulation is carried out in several stages such as:

1. Initial conditions (only soil material input)
2. Soil material parameters + ground water level
3. Soil material parameters + ground water level + vehicle load
4. Soil material parameters + ground water level + vehicle load + earthquake load

From the initial simulation results which only included the materials that make up the soil layer, the safety value for the Fellenius type was obtained at 1.586 and for the Morgenstern-Price type at 1.686. The simulation then continues with several stages to determine the cause of the landslide from the following possibilities as show at **Table 5** below:

Table 5. SLOPE/W Sliding Plane Simulations

1. Initial conditions **SF = 1,586**	
2. Soil material parameters + ground water level at 5 meters from road surface **SF =1.078**	

3. Soil material parameters + ground water level + vehicle load **SF =1.078**	
4. Soil material parameters + ground water level + vehicle load + earthquake load. **SF = 1,012**	

The pore water pressure value used is 9.807 kN/m3. The vehicle load value used is 15 kN/m2 where this value is a value based on the vehicle load value for Class I roads listed on Geotechnical Planning IV Manual. Meanwhile, for earthquake loads, horizontal earthquake load (kh) and vertical earthquake load (kv) values are used which are obtained from calculating the PGA value from the Lini application. The simulation results are summarized in **Table 6**. below.

Table 6. Slope stability simulation with SLOPE/W

Stages of Simulation	**Safety Factors**	
	Fellenius	**Morgenstern-Price**
Soil material parameters + ground water level	1.078	1.018
Soil material parameters + ground water level + vehicle load	1.078	1.018
Soil material parameters + ground water level + vehicle load + earthquake load.	1.012	0.965

From the simulation results, can be seen that just by increasing the groundwater level, the safety factors drop much closer to critical. The simulation continued by increasing the vehicle load, can be seen that there was no change in the safety factor for the two types, but when the earthquake variable was added, the safety factor fell again and specifically for the Morgenstern Price type, it could be seen that the safety factors were below 1, namely 0.965. This shows that with this simulation slope failure occurs when all factors are added in the simulation.

Using SEEP/W

The soil material parameters used are still the same as those used in SLOPE/W but rain data is added as water flux data to calculate the effect of rainwater infiltration on the slope. The simulated conditions are the conditions before the landslide occurred and the ground water table remains at a depth of 5 meters from the road surface. The rainfall (R24) that occurred on June 21st 2022 was 74 mm/day which was used as initial data to find the water flux value required in the SEEP/W program. To illustrate the rain variables, see **Figure 2** below.

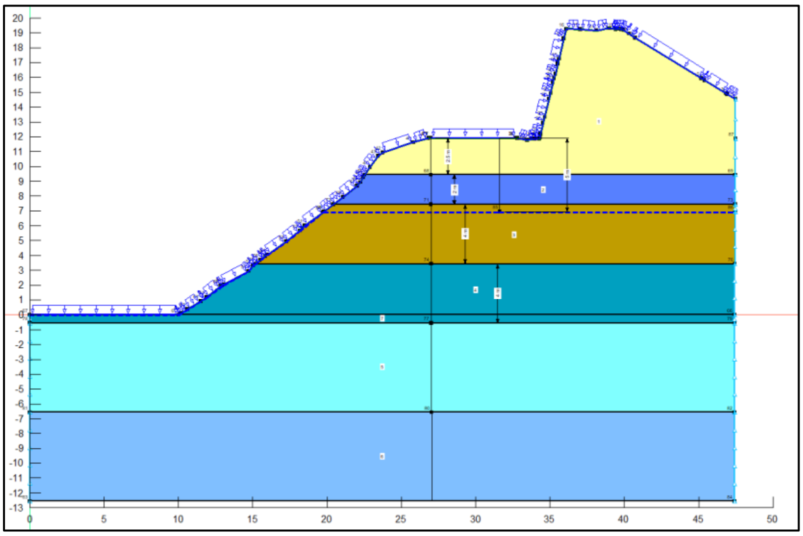


Figure 2. The slope is given a rain variable

You can see in **Figure 3** the simulation results for finding the slip area and the safety factor for the slope after adding rainwater infiltration's variable. Safety factor obtained from the simulation results is 0.951. This shows that by adding just one rainfall variable with the SEEP/W program, the slope safety number is already smaller than one so slope strengthening is needed.

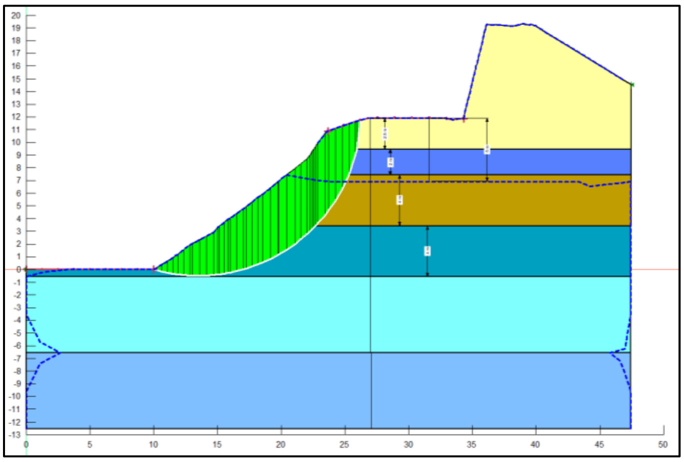
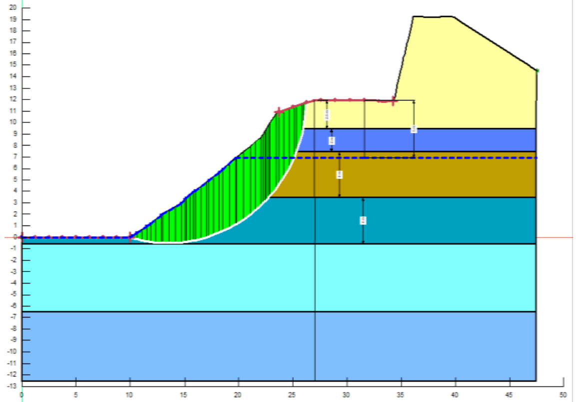
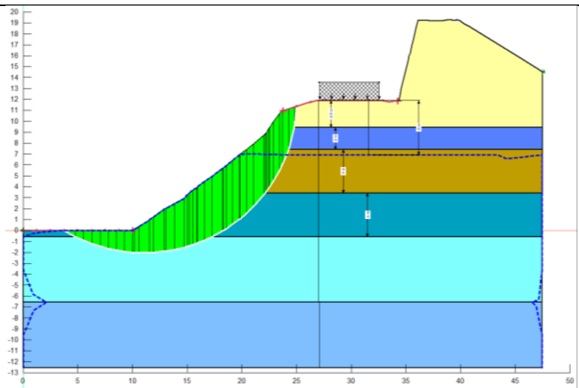
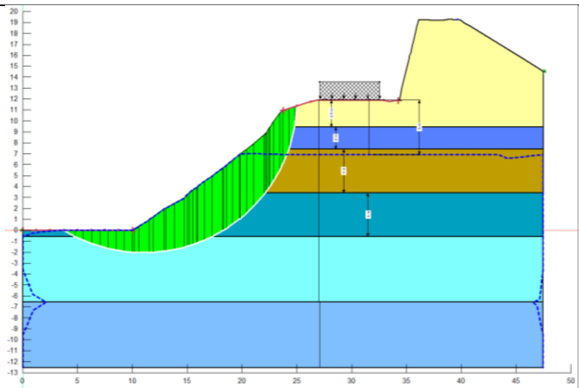


Figure 3. Slope slip area after adding the rain variable

Rain Modeling Analysis

In accordance with the research method described in Chapter 3 previously, several rain simulations were carried out with the aim of determining the effect of the magnitude of the rain on changes in slope safety scores. For Model I where there is no rainwater, simulation data from SLOPE/W can only be used. Model II with existing rain for seven days uses rain data as in the table in Appendix 3. It can be seen during the duration under review, only when a landslide occurred on June 27 2022 did rain occur, so Rain Model II uses data from the SEEP/W above before. Model III uses the highest rainfall data in 2022. More complete safety factors for the simulation results can be seen in **Table 7** below:

Table 7. SEEP/W Sliding Plane Simulations

1. Model I (without rain) **SF = 1,078**	
2. Rain model II (highest daily rainfall in the 7 day period before the landslide **SF = 0,951**	
3. Rain model III (highest daily rainfall in 1 year) **SF = 0,944**	

On the other hand which is not significantly different manner, Syah (2020) showed the results of slope stability analysis with an SF value of 1.092 in Lampung. In the context of landslide management, P2JN has planned to combine Retaining Walls with Borepile, which is considered more effective in preventing landslides compared to the Retaining Walls planned by Ramadhan et al (2020) using mini piles.

CONCLUSIONS

Based on the results of the slope stability analysis on Jalan Ende - Wolowaru and Junction - Kelimutu STA 10+475 using the Geostudio program as well as reviewing, it was concluded that rain was the cause of landslides as stated in the Geotechnical Report of the BPJN NTT P2JN Working Unit is correct. After simulating with the SEEP/W program, the slope safety factor which was 1.586 before the landslide occurred dropped to 0.883.

NOTE. This paper has been presented in ICIFAM #2 2023, Surabaya, 26-27 June 2023, organized by Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. ICIFAM – International Conference on Infrastructure & Facility Asset Management.

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