The Improvement of Existing Slope Reinforcement System and The Design of Alternative Slope Reinforcements Case Study: Lainea-Awunio Road Section Km 98+050 South Konawe Regency, Southeast Sulawesi Province

Nadia Kamila[1, a)], Mohamad Khoiri[2, b)] & Freddy Siagian[3)]

[1)]Magister Student, Department of Civil Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.
[2)]Department of Civil Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.
[3)]National Road Implementation Agency of Southeast Sulawesi Region, Directorate General of Highways, Ministry of Public Works and Housing

Correspondent : [a)]nadiakamila011@gmail.com & [b)]mkhoiri@ce.its.ac.id

ABSTRACT

The landslide that occurred on the Lainea-Awunio KM 98+050 national road in South Konawe Regency, Southeast Sulawesi caused a partial collapse on the road and disrupted traffic flow. For this reason, slope rehabilitation has been carried out using the construction of retaining walls. Based on the Geological Map and test results, it was found that the soil at the location has a high soil bearing capacity, but in reality, landslides occur during the rainy season and cracks are found on the slopes, therefore it is necessary to analyze slope stability using a cracked soil approach. In this research, slope stability analysis was analyzed using authentic soil data and with a cracked soil approach, slope stability analysis was analyzed using using the GEO5 auxiliary program and reinforcement planning was calculated using manual calculations. After the analysis, it was discovered that the slope that was initially predicted to be safe (SF>1) turned out to be a collapse (SF<1), and the reinforcement system that had been implemented in the field after being evaluated turned out to be not stable enough and required additional reinforcement. The additional reinforcement is designed using bored piles with a diameter of 1 meter to a depth of 13 meters to increase the safety factor from SF=0,66 to SF=1,60. Meanwhile for slopes without reinforcement bored piles with a diameter of 0,8 meters to a depth of 16 meters was used to increase the safety factor from SF=0,51 to SF=1,65.

Keyword : Slope Stability, Retaining Wall, Bored pile, Cracked soil

INTRODUCTION

In Indonesia nowadays, Infrastructure and Facility Asset Management become a requirement for Public Infrastructure. Infrastructure and Facility Management is knowledge, sciences, and practices to Manage Infrastructure and Facility along its life span (Suprayitno et al 2020). Public Works Infrastructure is asset for the good life of a region and a country. Hence, the Public Works Infrastructure must always be in good functioning condition. This can be preserved if the infrastructure is properly planned, designed, constructed, operated, and maintained; Operation and maintenance must be based on infrastructure conditions or infrastructure performance (Babo & Suprayitno 2019; Soemitro & Suprayitno 2020; Maulidha et al 2022).

The Lainea-Awunio road section is one of the national roads in Southeast Sulawesi Province in South Konawe Regency, one of the slopes on the Lainea-Awunio road section, precisely at KM 98+050, location of the landslide are shown in Figure 1, has experienced a landslide in 2021 during the rainy season that caused almost half of the road to collapse and block the flow of traffic for this reason slope rehabilitation has been carried out using the construction of retaining walls as high as 8.5 meters. A slope, both embankment slope, excavation slope, and natural slope must be designed to be stable and safe because unstable slopes can potentially lead to landslides that can cause damage to the infrastructure built on it (Shoffiana et al 2022). The condition of the slope before and after the landslide can be seen in Figure 2 and the condition of the slope after the reinforced is shown in Figure 3.

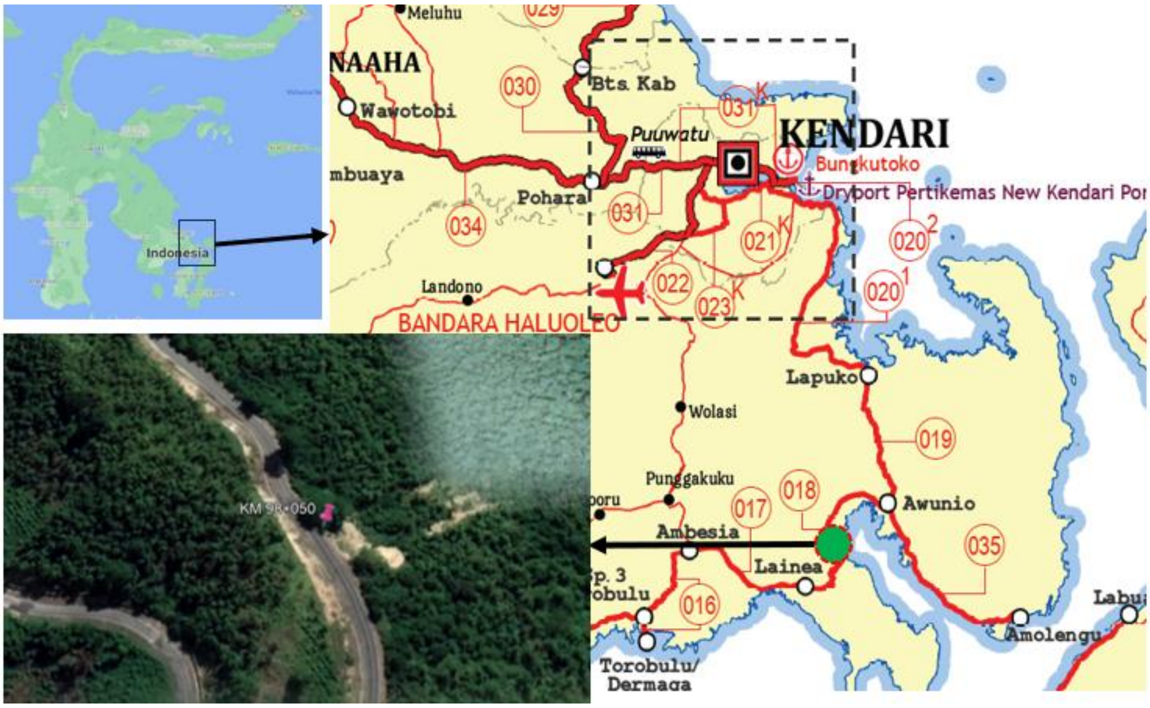


Figure 1. The location of the landslide on Lainea-Awunio Road Section KM 98+050

Figure 2. Slope condition before and after landslide
(PPK 2.1, 2021)

Figure 3. Condition of slope after the reinforcement

Amalia et al (2018) in her research of slopes in the construction area of the East Kalimantan Police Criminal Investigation building, Balikpapan which has slopes with fairly stiff soil shows that the analysis of slope stability in saturated conditions due to rain with original soil data that is predicted to be safe (SF>1) turns out to be a landslide (SF<1) when analyzed for slope stability with the crack soil approach, where the condition of the landslide is in accordance with the conditions that have occurred in the field. The cracked soil approach is a theory of landslides that occur due to cracks on the slope surface. To accommodate the property of cracks that can drain water easily, the soil strength along the cracks should be considered equal to the soil shear strength in the drained condition, where the cohesion value (c) = 0 and the internal friction angle (ϕ) $\neq$ 0; regardless of the original condition of the soil (Amalia et al 2018). Based on the Geological Map and test results, it was found that the soil at the location has a high soil bearing capacity, but in reality, landslides occur in the field during the rainy season and cracks are found on the slopes (Figure 4) therefore it is necessary to analyze slope stability using a cracked soil approach.

Figure 4. Cracks on the slope
(PPK 2.1, 2019)

In this study, an analysis will be carried out to determine whether the existing slope reinforcement system is stable to anticipate potential landslides that occur if the cracked soil approach is used and how alternative reinforcement can be applied in the field on slopes that have not experienced landslides so that they can anticipate potential landslides that may occur on the Lainea-Awunio road section in the future.

RESEARCH METHOD

In this study slope stability analysis was carried out using the GEO5 auxiliary program and reinforcement planning was carried out using manual calculations. The research steps for this paper can be seen in Figure 5.

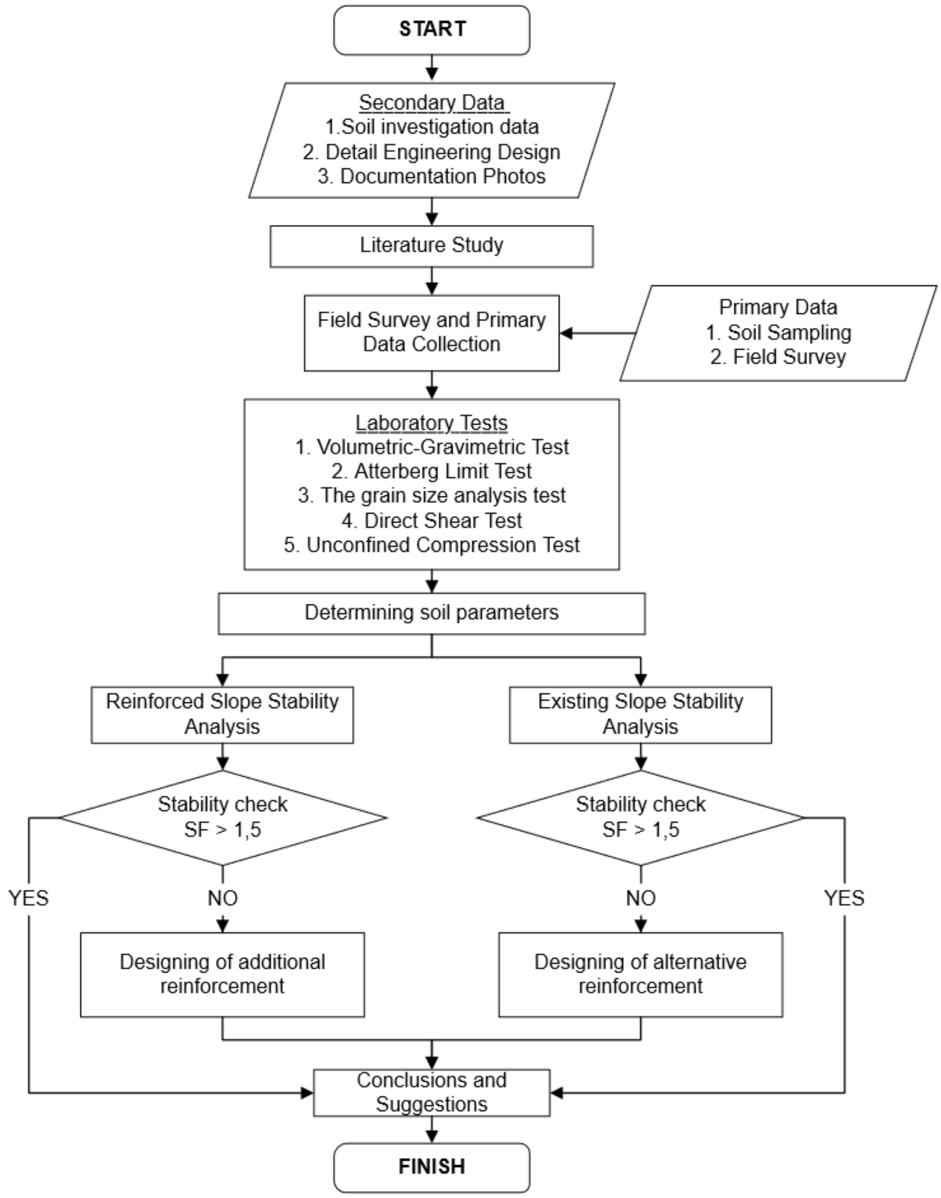


Figure 5. The research steps

RESEARCH ANALYSIS

Soil Data

Soil properties in these studies is determined by correlation, boring test, and laboratory test results based on primary and secondary data. The soil parameters are shown in Table 1, and slope statigraphy for modelling are shown in Figure 6 and Figure 7.

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6, Special Issue 2, January 2024

Table 1. Soil parameters

Depth (m)	γ (kN/m3)	γ Sat (kN/m3)	c (kPa)	ϕ (°)
0 – 5	18,00	18,00	50,25	28,00
5 – 8	17,66	17,66	7,26	26,18
8 – 30	22,68	23,81	134,00	36,00

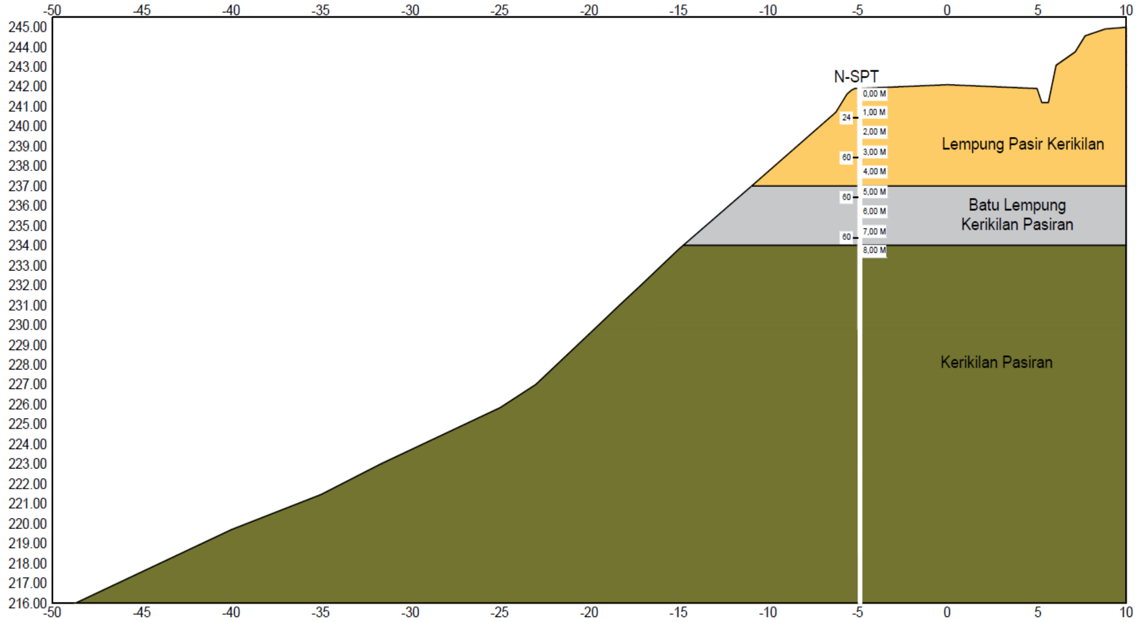


Figure 6. Existing slope statigraphy

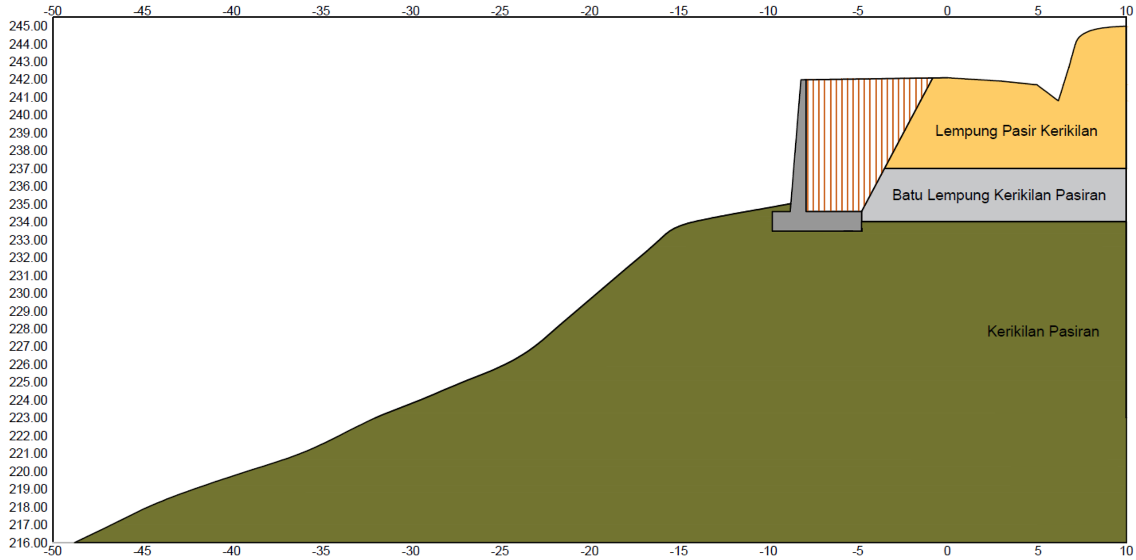
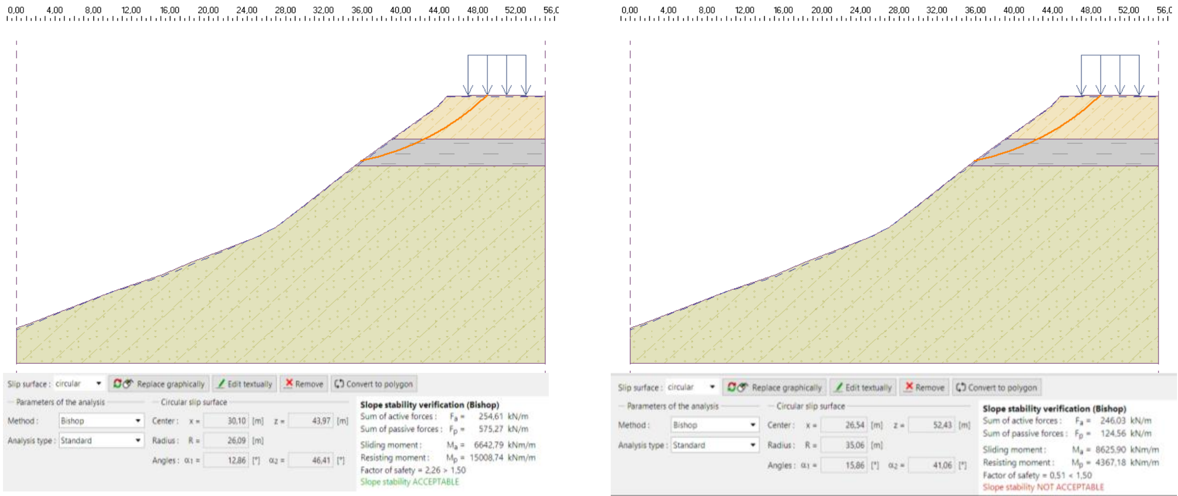


Figure 7. Reinforced slope statigraphy

Stability Analysis of Existing Slope

Slope stability analysis was conducted using the Geo5 auxiliary program, using the bishop method. The groundwater table was modeled above the slope surface because the landslide occurred during the rainy season. This modeling uses a surcharge load of 10 kPa in accordance with SNI 8460:2017 and the landslide plane is estimated according to the landslide that has occurred in the field.

The results of the slope stability analysis using the authentic soil data obtained a value of SF = 2.26, while the slope stability analysis with the crack soil approach (c = 0) resulted in SF = 0.51 (Figure 8). The slope is said to landslide when the resulting SF is less than SF = 1 (critical), so it can be deduced that the slope stability analysis with the crack soil approach illustrates the condition of the landslide in the field.



(a) slope stability analysis using the authentic soil data

(b) slope stability analysis with the crack soil approach (c = 0)

Figure 8. Slope stability analysis of existing slope

Stability Analysis of Reinforced Slope

In the field, it is known that the slope that collapsed has been handled with 8,5 meter cantilever type retaining wall. In accordance with SNI 8460: 2017, the design of retaining walls must meet safety criteria for stability towards overturning, lateral sliding, bearing capacity and global stability. However, these requirements have been replaced with new ones, where stability against overturning does not need to be reviewed if stability against sliding/tilting is already secure because based on field observations, it is found that almost 99% of failures in retaining walls are caused by overall stability issues (90%) and sliding/tilting (9%), so the overturning stability does not need to be reviewed as the stability against sliding/tilting already represents it. Therefore, the stability analysis of the retaining wall was performed with the following results:

Table 2. The safety factor analysis toward lateral sliding

No	Conditions	Lateral Sliding	
		Requirement	Result
1	Retaining wall with authentic soil data	≥ 1,5	2,32
2	Retaining wall with with the crack soil approach	≥ 1,5	1,11

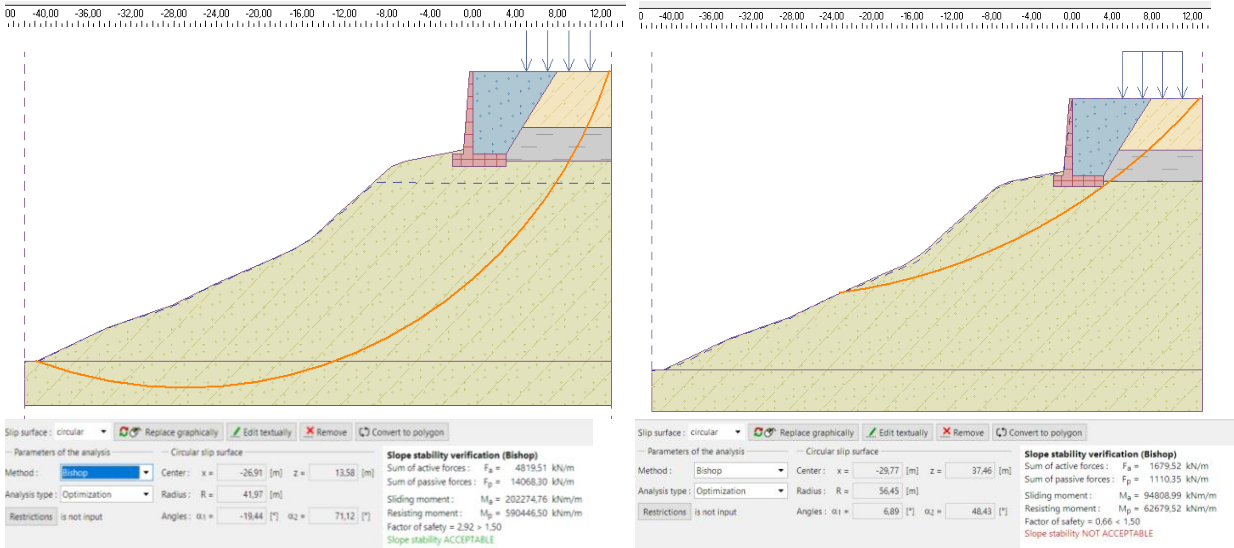
Table 3. The safety factor analysis toward tilting

No	Conditions	Tilting	
		Requirement	Result
1	Retaining wall with authentic soil data	≥ 3,0	21,14
2	Retaining wall with with the crack soil approach	≥ 3,0	4,89

Table 4. The safety factor analysis toward global stability

No	Conditions	Global Stability	
		Requirement	Result
1	Retaining wall with authentic soil data	≥ 1,5	2,92
2	Retaining wall with with the crack soil approach	≥ 1,5	0,66

From the analysis it can be concluded that for retaining walls examined with authentic soil data have a safety factor SF > 1 and meet the safety criteria, which means the stability of the slope meets the requirements and there is no landslide occured. However, when examined with the crack soil approach, the retaining wall has a safety factor of SF > 1 but does not meet the safety criteria for stability lateral sliding and global stability. As for global stability, the crack soil approach has a landslide plane with a safety factor value of SF = 0.66 (Figure 9) so additional reinforcement is needed to mitigate the landslide plane.



(a) slope stability analysis using the authentic soil data

(b) slope stability analysis with the crack soil approach (c = 0)

Figure 9. Slope stability analysis of reinforced slope

Additional Reinforcement for Reinforced Slope

After analyzing the slope reinforcement system that has been implemented in the field, it is known that using the cracked soil approach the slope safety factor is SF = 0.66, so additional reinforcement is needed to strengthen the existing retaining wall construction to prevent the possibility of future landslides. The additional reinforcement chosen is bored pile. The selection of bored piles is made with considering the hard soil layer in the field, to minimize vibration disturbance to the existing reinforcement and the process does not interfere with the flow of traffic on the road. Slope reinforcement of bored piles designed for the slope to function as reinforcements that can cut through the sliding plane of the slope to increase the bearing capacity of the soil.

The length of the bored pile is planned to cut SF=1 at a depth of 12 meters (Figure 10) so that a bored pile depth of 13 meters is required, with a bored pile length above the landslide plane of 6 meters and a bored pile length below the landslide plane of 7 meters. The parameter of slope used to calculate the number of bored piles can be seen in Table 5 while for the working bending moment (crack moment) on the bored pile is calculate using PCA Column program.

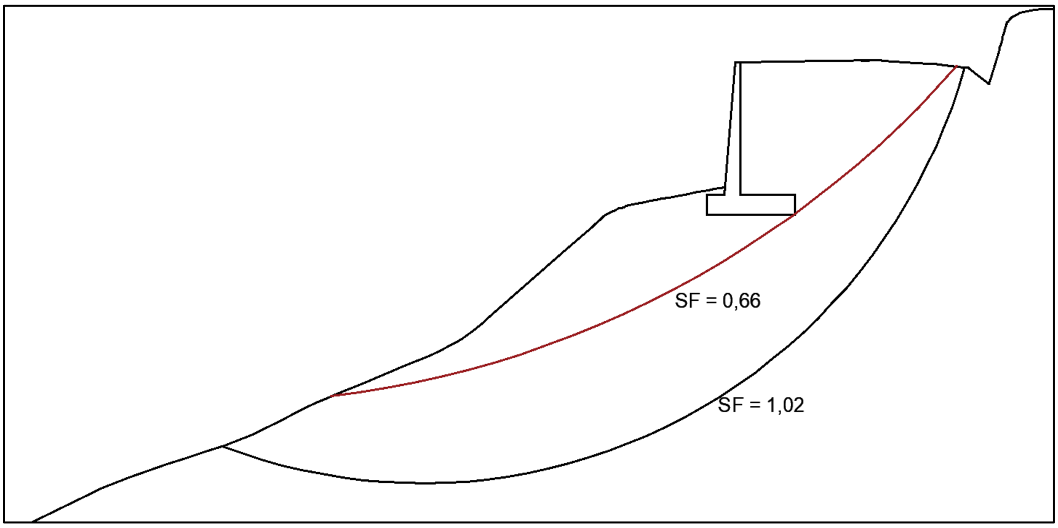


Figure 10. The landslide plane with critical SF and SF=1

Pile design is made using the PCA Column program with the following data:

Depth of pile	= 13 meter
Mounting distance	= 1,2 meter
Diameter	= 1000 mm
Fc’	= 30 Mpa
Fy	= 400 Mpa
Main rebar	= 45 D29
Mcrack	= 3.116,4 kNm

Table 5. The parameter of slope

Depth of Landslide Plane	Safety factor		Radius of Failure (R)	Resisting Moment (Mr)	Driving Moment (MD)	ΔMR
m	Existing	Design	m	kN.m	kN.m	kN.m
6,00	0,66	1,50	56,45	62.679,52	94.808,99	79.639,55

The steps for calculating the quantity of bored pile needed are as follows:

1) Bored Pile Retaining Force

Bored pile design uses dense sand soil parameters which is the soil layer where the tip of the bored pile is located. Using the NAVFAC, DM-7, 1971 chart, the soil modulus factor (f) is obtained f = 1,248 kg/ cm^3 and the relative stiffness factor (T) can be estimated.

$$T = \left(\frac{EI}{f}\right)^{\frac{1}{5}} = 200{,}00 \text{ cm} \qquad \ldots(1)$$

Then by using the NAVFAC, DM-7, 1971 chart, the moment coefficient due to lateral force Fm = 0.93 is obtained.

2) The Horizontal Force a single Pile is able to bear

$$P = \left(\frac{Mu}{Fm\ x\ T}\right) = 167.547{,}17 \text{ kg} = 1.675{,}47 \text{ kN} \qquad \ldots(2)$$

3) Calculating number of piles per meter

$$n = \frac{\Delta MR}{Pmax\ 1 \times R} = 0{,}84 \text{ pile/ meter} \qquad \ldots(3)$$

Next, the stability analysis of the slope after reinforcement is performed with the GEO5 (Figure 11), and the value of the safety factor is 1,60 > 1,5 therefore the design can be used. Illustration of the bored pile installation can be seen in Figure 12.

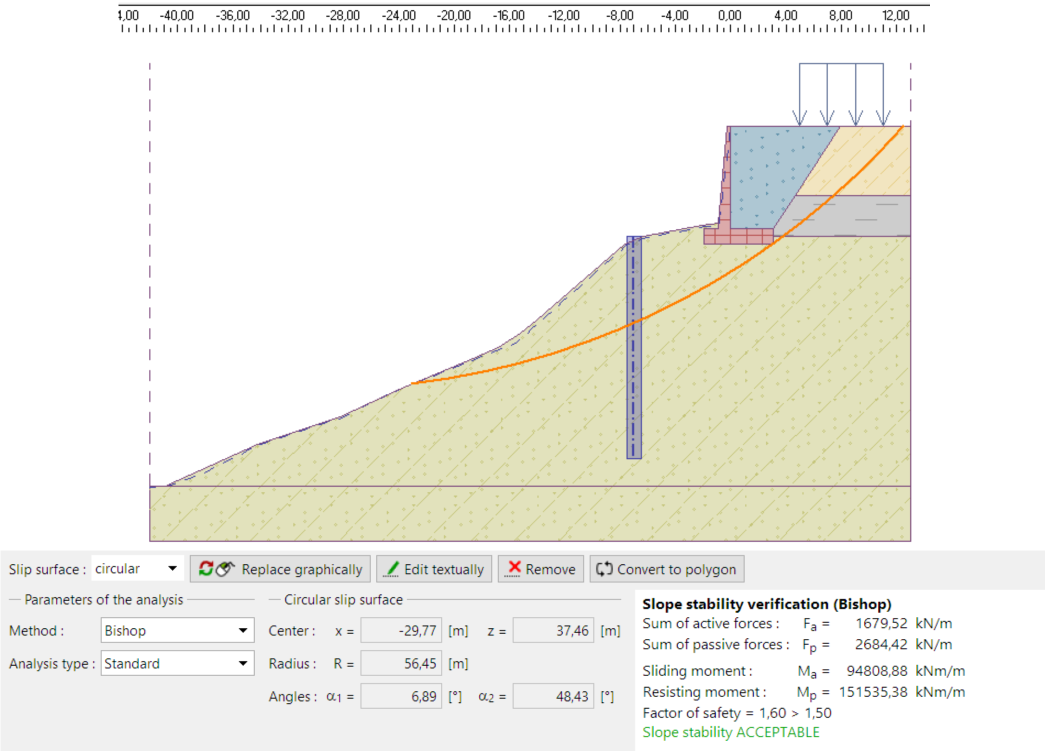


Figure 11. Analysis of slope stability after reinforcement with bored piles

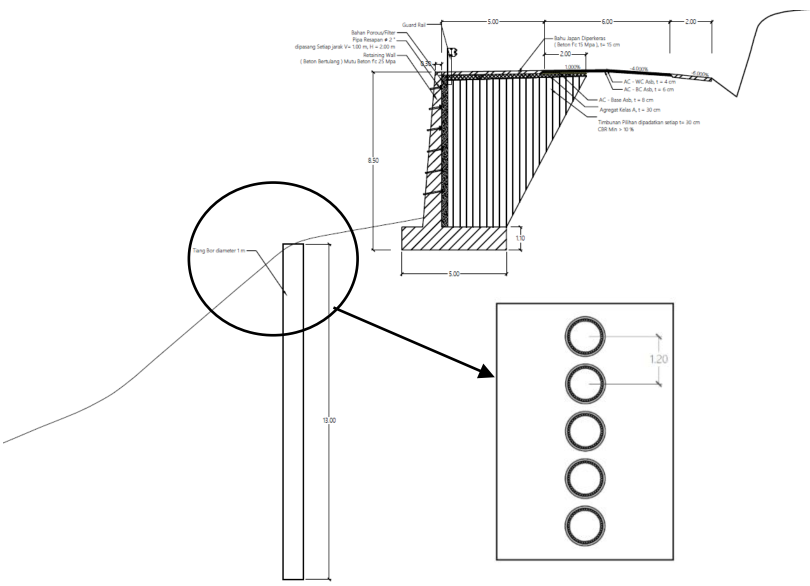


Figure 12. Illustration of the bored pile installation

Alternative Reinforcement for Existing Slopes

The reinforcement of bored piles designed for the slope acts as "stakes" that can cut through the landslide plane of the SF=1 to increase the bearing capacity of the soil (Figure 13). As a result, a bored pile depth of 16 meters is designed, with a bored pile length above the landslide plane is 3 meters and a bored pile length below the landslide plane is 13 meters. The parameter of slope used to calculate the number of bored piles can be seen in Table 6 and bored piles diameter is varied to 50 cm, 60 cm and 80 cm to get the most effective design, analysis of dimensional requirements calculation using pcaColumn program .

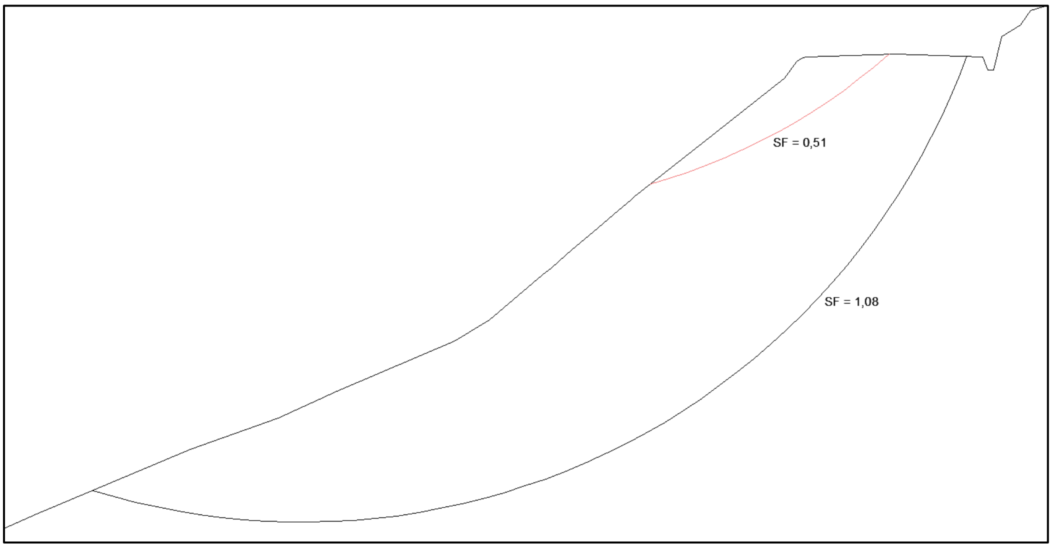


Figure 13. The landslide plane with critical SF and SF=1

Table 6. The parameter of slope

Depth of Landslide Plane	Safety factor		Radius of Failure (R)	Resisting Moment (Mr)	Driving Moment (MD)	ΔMR
m	Existing	Design	m	kN.m	kN.m	kN.m
3,00	0,51	1,50	35,06	4.367,18	8.625,90	8.539,64

Then using the NAVFAC, DM-7, 1971 method, it was calculated to determine the horizontal force that can be received by the pile (Pmax) and the required number of piles to meet the slope stability requirements (n), after that the stability analysis of the slope after reinforcement is performed with the GEO5. The results of the bored pile requirement analysis can be seen in Table 7.

Table 7 Bored pile requirement analysis

Diameter of pile cm	Pmaks kg	Required number of piles	SF	Description
50	27.263,16	0,89	1,65	Slope meet the requirements (SF>1,5)
60	38.485,34	0,63	2,07	Slope meet the requirements (SF>1,5)
80	69.196,69	0,35	3,20	Slope meet the requirements (SF>1,5)

From the analysis that had been performed, it is known that all the dimensions of the bored piles designed meet the requirements of slope stability, which is SF> 1.5 so that the most minimum design is chosen, a diameter of 50 cm with a length of 16 meters thus increasing the safety factor of the slope from SF = 0.51 to SF = 1.65. Illustration of the bored pile installation can be seen in Figure 14.

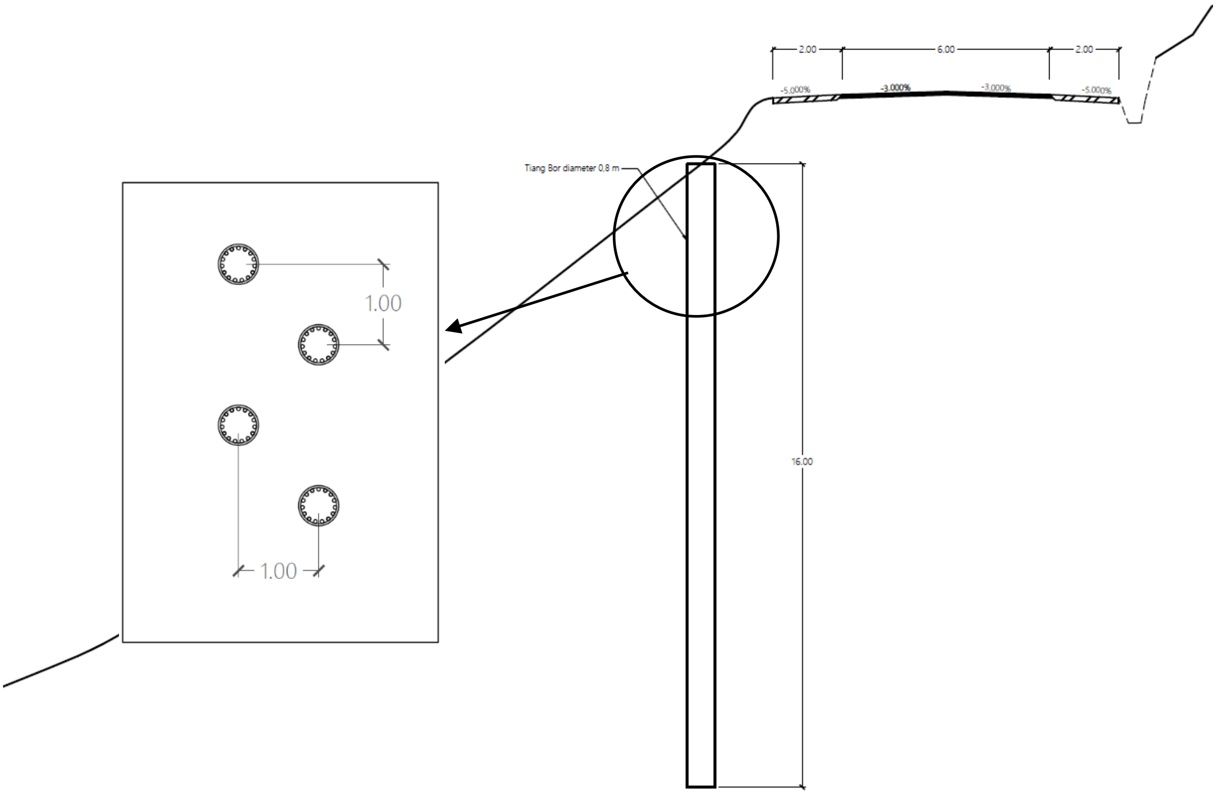


Figure 14. Illustration of the bored pile installation

CONCLUSION

Based on the results of slope stability analysis and slope reinforcement design that has been done, it can be concluded as follows:

1) The stability of the existing slope on the Lainea - Awunio National Road section analyzed using the authentic soil data has a safety factor value, SF = 2,26 and using the cracked soil approach has a safety factor value, SF = 0,51 (failure). The analysis using the cracked soil approach is in line with the conditions in the field.
2) The function of the retaining wall as a reinforcement system is not optimal, because after performing a comparison with the cracked soil approach, it was found that there is a sliding plane under the retaining wall with a safety factor value of SF = 0,66, to overcome this, additional reinforcement is designed with 1,0 meter diameter bored pile with a length of 13 meters so that it can increase the safety factor to SF = 1,60.
3) On unreinforced slopes, alternative reinforcement is designed with 0,50 meter diameter bored piles with length of 16 meters to increase the slope safety factor from SF=0,51 to SF=1,6.

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