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Slope Stability Analysis of Sekayu-Mangun Jaya Road STA 127+350 Reinforced with Retaining Walls

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ABSTRACT

Economic growth that increases the traffic load on national roads requires these roads to have decent, safe and comfortable services. Landslide was occurred on the Sekayu-Mangun Jaya STA 127+350 road section which disrupted traffic activity. This occurrence caused the major road to shift sideways and deteriorate, rendering the route's service capacity insufficient. The road section has been repaired and is planned to use soil retaining wall reinforcement as a countermeasure. This study aims to determine the slope stability of the Sekayu-Mangun Jaya road before and after reinforcement is carried out. Slope stability analysis was performed by empirical methods using infinite slope theory and the finite element method using the Plaxis program. The calculation results show that the safety factor of the slope before the retaining wall is installed at BH-01 is 0.9. This value falls under the category of unstable slope. The safety factor at the BH-02 location was obtained at 1.3 in the moderate stability category. Slope stability after strengthening with the installation of embankments and retaining walls shows an increase in the safety factor at BH-01 to 2.59. After the slope reinforcement was carried out, the slope deformation decreased significantly to 1.5 m. The results implicated that with slope reinforcement, slope stability increases and the possibility of landslides decreases.

***Keywords:** Slope Stability; Factor of Safety; Landslide; Retaining Wall; Finite Element.*

INTRODUCTION

A landslide occurs when the stability of the rocks or soil forming up the slope becomes unstable, causing the land to slide downward [1,2]. The following classifications are used to categorize different types of landslides: compound slips, translational slips, and rotational slips [4].

Landslide disasters are ranked fifth among all natural disasters that occur in Indonesia [2]. Landslides on roads can occur due to high loads due to increased traffic volume, accompanied by river erosion on one side of the road. Landslides caused by erosion result in a decrease in the comfort level of road users and disrupt driving safety [3,4,5].

According to landslide scientific findings, heavy rain, earthquakes, changes in groundwater levels, rapid snow melting, volcanic eruptions, and human activities are the most common triggers for landslides [6,7,8]. To increase slope stability and reduce associated hazards, reducing driving forces and increasing resisting forces are two categories of stabilization used to increase slope stability. According to these two theories, landslide mitigation methods at a location can include dismantling the subgrade, using drainage, strengthening structures, and utilizing the role of vegetation. Due to the complexity, scope and destructive power of landslides, a comprehensive understanding of landslide behavior influenced by each trigger and effective methods for preventing or reducing the risk is required. Landslide prevention using restraint works can be applied using construction from certain structural elements, such as the use of retaining walls, anchors, soil nailing, soldier piles, etc. Construction using this method aims to increase the resistance force in the slip area [9].

Sekayu-Mangun Jaya road section is an Indonesian National Road that connects land transportation to the island of Sumatra. The problem repeatedly happened on this road section is the occurrence of landslides on the road body. One of the landslides took place on the Sekayu-Mangun Jaya STA 127+350 road, the landslide caused the road to slide to the side and erode, resulting in disruption of transportation and mobilization activities. The cause of this landslide was due to increasing traffic loads and continuous sand extraction activities. The growth and development of the economic sector requires the government to be able to create adequate and comfortable road infrastructure and facilities. Therefore, it is necessary to carry out an analysis of the stability of the existing slope and after strengthening it to determine the safe factors for the slope. Slope stability analysis in this research was performed using the empirical method of infinite slope stability and using the finite element method using Plaxis program.

METHODS

This research employs empirical methods and finite elements to calculate slope safety factors. Soil index properties and soil shear strength parameters are obtained from field and laboratory tests. A geoelectric survey was also carried out to determine the nature of the rocks and soil at the research location. The research location is on Sekayu – Mangun Jaya road section KM

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127+350 in Musi Banyuasin Regency, South Sumatra Province (Figure 1).

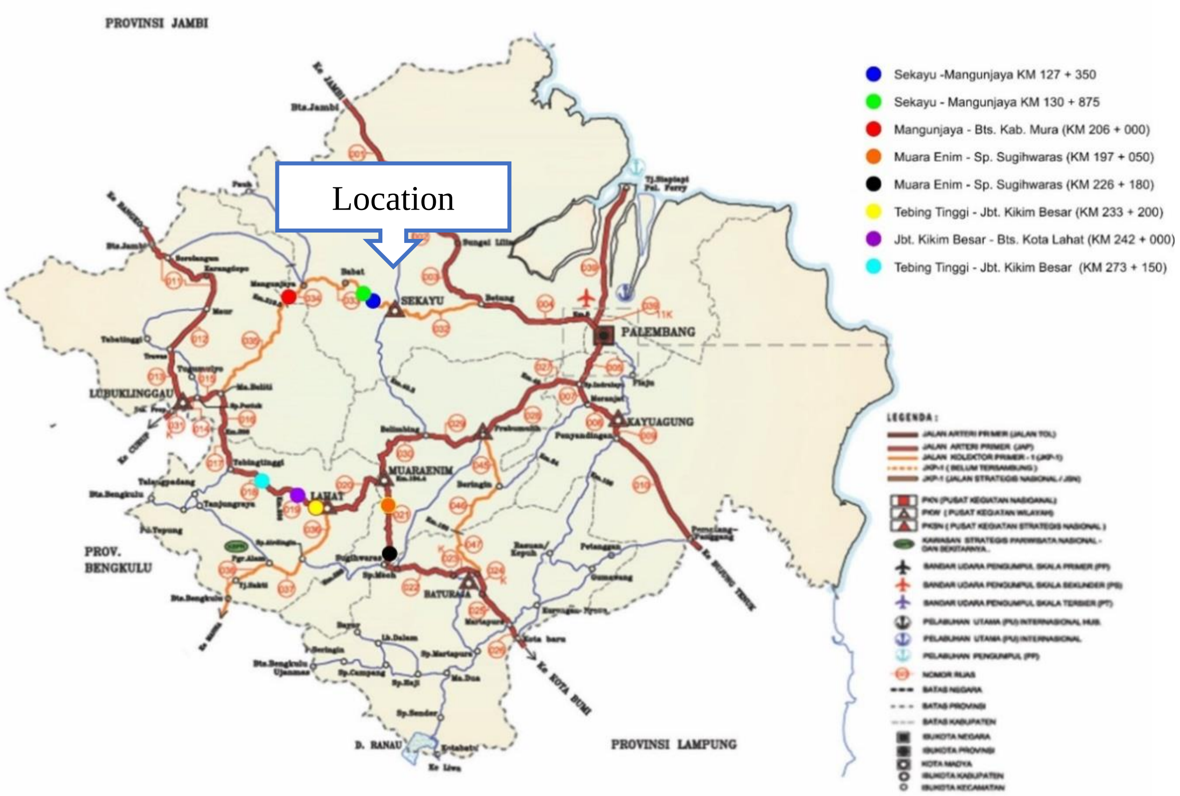

Figure 1: Research Location

Slope Stability Analysis

Slope stability analysis is calculated using the infinite slope method. Soil parameters in the form of physical properties and mechanical properties from preliminary tests are used in calculating the safety factor. The calculation of the safety factor using the infinite slope method is described in the following equation [10]:

1. Unsaturated Soil Conditions

$$FS = \frac{c}{\gamma \cos^2\alpha \tan\alpha} + \frac{\tan\varphi}{\tan\alpha} \quad (1)$$

Where:

FS = Safety factor
c = Cohesion (kN/m^2)
φ = Internal Friction Angle (°)
α = Slope Angle (°)
γ = Unit Weight of Soil (kN/m^3)

2. Saturated Soil Conditions

$$FS = \frac{c}{\gamma_{sat}\, H \cos^2\alpha \tan\alpha} + \frac{\gamma' \tan\varphi}{\gamma_{sat} \tan\alpha} \quad (2)$$

Where:

H = Depth of Slope (m)

γ_{sat} = Unit Weight of Saturated Soil (kN/m^3)
γ' = Effective Unit Weight of Soil (kN/m^3)

3. Partially Saturated Soil Conditions

$$FS = \frac{c + \{[(\gamma_d h_1 + \gamma' h_2)\cos^2\alpha] \tan\varphi\}}{(\gamma_d h_1 + \gamma_{sat} h_2)\cos\alpha \sin\alpha} \quad (3)$$

Where:
h_1 = Depth of Slope above Groundwater Level (m)
h_2 = Depth of Slope below Groundwater Level (m)
γ_d = Unit Weight of Dry Soil (kN/m^3)

Stability of Retaining Wall

Retaining walls are slope reinforcement structures that function to resist collapse or lateral pressure on land that has a sloping shape [11, 12, 13, 14]. According to [15], the design for the dimensions of a cantilever type retaining wall is shown in Figure 2.

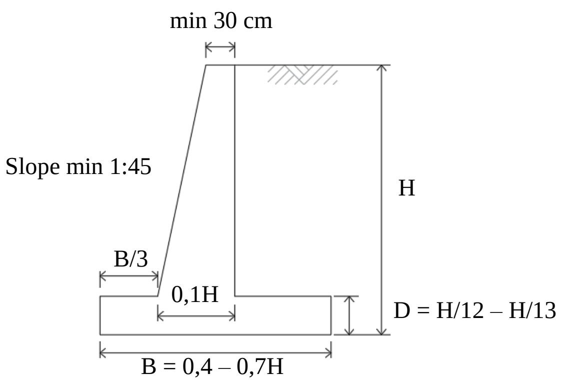

Figure 2: Dimensional Design of Cantilever Type Retaining Walls

The stability of retaining walls includes stability against overturning, shearing and the bearing capacity of retaining walls. The stability equation for retaining walls is described as follows [16]:

1. Overturning Stability

$$F_{gl} = \frac{\sum MW}{\sum Mgl} \quad (4)$$

Where:
ΣMgl = Overturning Moment (kN.m)
ΣMw = Overturning Resistance Moment (kN.m)
F_{gl} = Safety Factor of Overturning

2. Shearing Stability

$$F_{gs} = \frac{\sum RH}{\sum PaH} \quad (5)$$

Where:
ΣRH = Total Horizontal Resisting Force
ΣpaH = Total Driving Force
F_{gs} = Safety Factor of Shearing

3. Bearing Capacity

$$qu = cN_c + \gamma dN_q + \frac{1}{2}\gamma BN_\gamma \quad (6)$$

Where:
q_u = Ultimate Bearing Capacity (kN/m^2)
c = cohesion (kN/m^2)
γ = Unit Weight of Soil (kN/m^3)
Nc,Nq,Nγ = Bearing Capacity Factor

RESULTS AND DISCUSSIONS

Preliminary Test Results

From the results of geoelectric measurements at KM 127+350, it was found that there was a distribution of variations in resistivity values both laterally and vertically in the medium through which the electric current passed. The landslide zone is visible at a distance of ± 88-104 m, with the constituent rocks having a weak level of compactness (low rock bearing capacity) with sandy clay lithology to a depth of ± 25 m and almost even thickness, then below it is a water saturated zone (rock /water saturated soil) this is indicated by the low resistivity value of 1.6 – 13.0 Ωm (Figure 3)

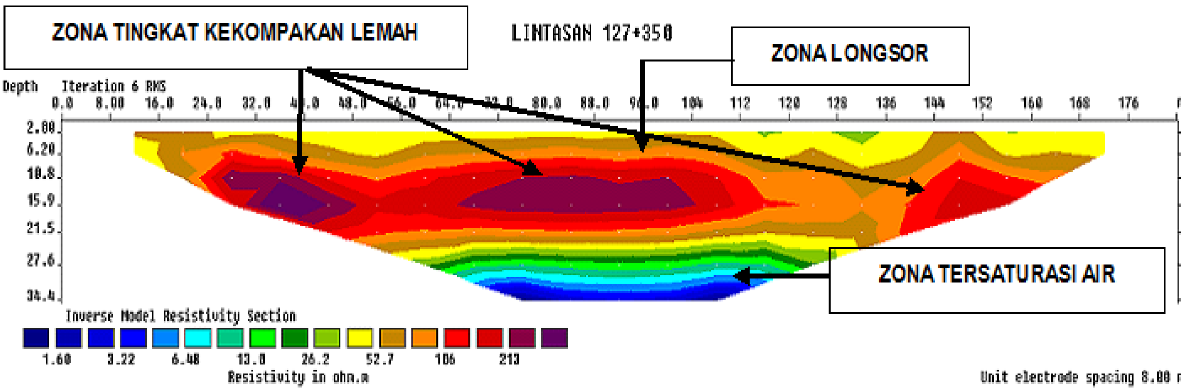

Figure 3: Geoelectric Test Results on STA 127+350

Slope Stability Analysis Before Reinforcement

After calculating slope stability before reinforcing the slope empirically using equations (1), (2), and (3), slope stability analysis was carried out using the Plaxis program. Figure 4 shows infinite slope conditions and the results of the slope safety factor values. A recapitulation of safety factor values can be seen in Table 1.

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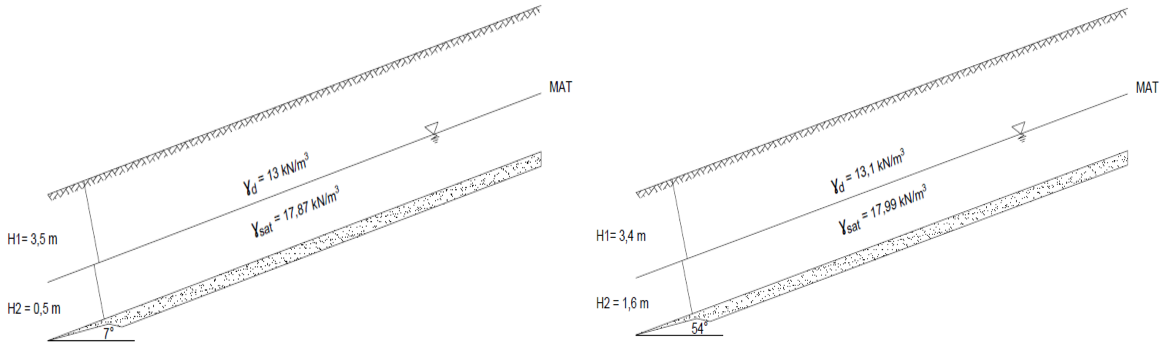

Figure 4: Slope Geometry with Soil Parameters in BH-01 and BH-02

Table 1: Results of empirical slope stability analysis

Bore Hole	**Safety Factor (FS)**
BH-01	0,93
BH-02	1,30

Figure 4 and Table 1 show the results of slope stability analysis before slope strengthening. The safety factor value obtained for BH-01 was 0.93 and BH-02 was 1.30. According to [17], the slope stability classification of $F < 1$ includes the unstable slope category, while $1.25 < F < 1.5$ includes moderate stability. So BH-01 is classified as unstable and BH-02 is classified as moderate stability.

Soil parameters used to analyze slope stability using the Plaxis program can be seen in Table. 2.

Table 2: Soil parameters for slope stability analysis in the Plaxis program

Soil Parameter	**Unit**		
Borehole Number		BH-01	BH-02
Material Model		Mohr-Coulomb	Mohr-Coulomb
Drainage Type		*Undrained*	*Undrained*
γ_{sat}	kN/m^3	17,87	17,99
γ_{unsat}	kN/m^3	12,78	12,85
E	kN/m^2	50.000	50.000
ν		0,33	0,33
c	kN/m^2	21	16
φ (phi)	°	9,57	9,47
ψ (psi)	°	0	0

The results of the slope stability analysis using the Plaxis program application obtained output as in Figure 5.

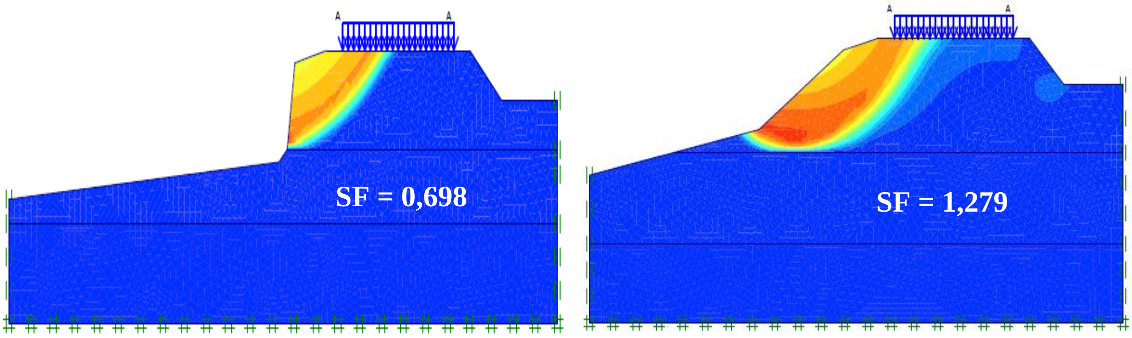

Figure 5: Results of Slope Stability Analysis Using the Plaxis Program

Figure 5 is the output of the Plaxis program which shows the displacement or movement of soil mass on the slope, with a slope safety factor value of BH-01 of 0.698 and BH-02 of 1.279. Based on the value of the safety factor, the slope stability of BH-01 is classified as unstable and BH-02 is classified as moderate stability.

Slope Stability Analysis After Reinforcement

Based on the slope stability analysis before slope reinforcement, it was found that the slope stability on the Sekayu-Mangun Jaya STA 127+350 road section was classified as an unstable slope at locations BH-01 and BH-02 with moderate stability. Therefore, it is planned to reinforce the slopes using cantilever type retaining walls on BH-01 as a requirement to increase the safety factor of the slopes on the Sekayu – Mangun Jaya STA 127+350 road section. The slope reinforcement model can be seen in Figure 6.

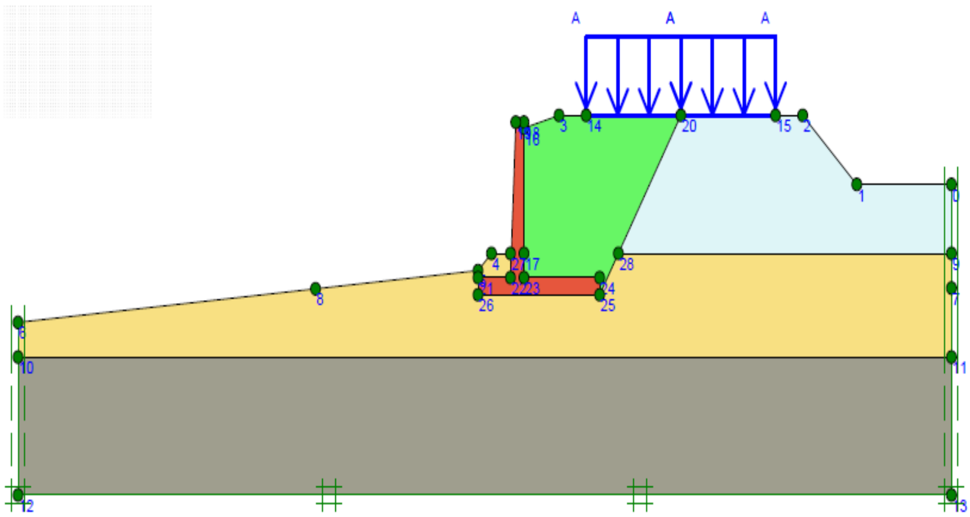

Figure 6: BH-01 Slope Geometry with Cantilever Type Retaining Wall Installation

Figure 6 is a modeling of slope reinforcement using a cantilever type retaining wall and selected embankments with soil parameters for the Plaxis program input as in Table 3.

Table 3: Slope reinforcement parameters on Plaxis

Soil Parameter	Unit	Value
Embankment		

Material Model		Mohr-Coulomb
Drainage Type		Drained
γ_{sat}	kN/m^3	20
γ_{unsat}	kN/m^3	16
E	kN/m^2	8.000
ν		0,3
c	kN/m^2	21
φ (phi)	°	30
ψ (psi)	°	-
Retaining Wall		
Material Model		*Linear Elastic*
Drainage Type		*Non-porous*
γ_{beton}	kN/m^3	24
E	kN/m^2	24.150
ν		0,15

The results of stability calculations for retaining walls can be seen in Table 4.

Table 4: Retaining Wall Stability

No	Stability Factor	Safety Factor
1	Overturning	2,374
2	Shearing	2,399
3	Bearing Capacity	3,626

From the results of calculating the stability of the retaining wall, it was obtained that the safety factor value for overturning control and shear control was > 2, and the bearing capacity was > 3, so the retaining wall was categorized as safe [14].

Slope Deformation

The value of the slope safety factor after reinforcement with retaining walls can be seen in Figure 7 which is the output of the Plaxis program.

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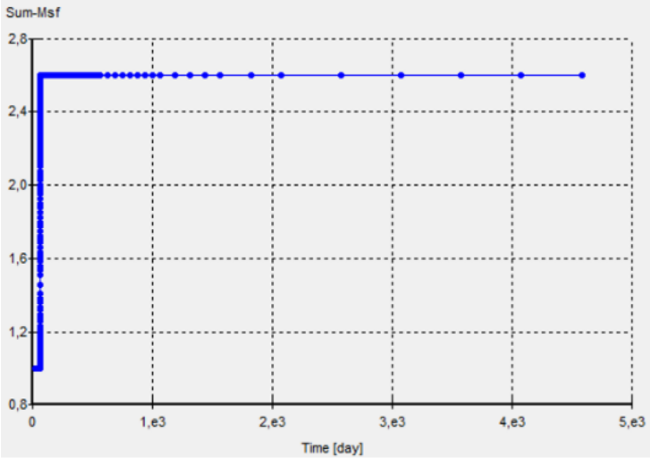
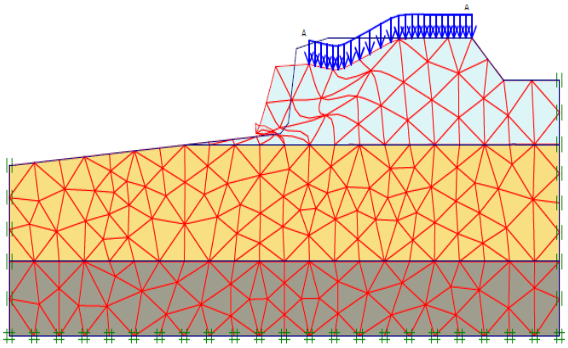


Figure 7: Plaxis Output for Safety Factor Values After Reinforcement

Figure 7 depicts the relationship curve between Time and Sum-Msf on the Plaxis curve, the safety factor value obtained after slope reinforcement is 2.59. Thus, the stability of the slope after reinforcement is classified as safe because the safety factor value is > 1.5.

The following are the results of the deformation output after being analyzed using the Plaxis program application.


(a) Deformation Before Reinforcement

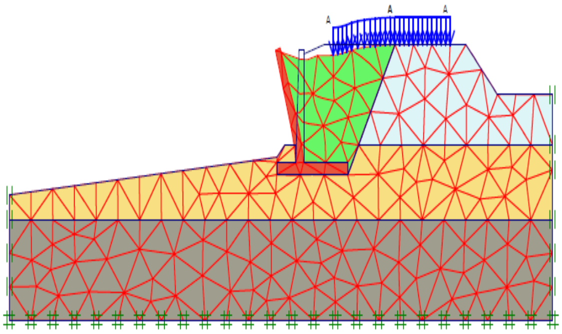
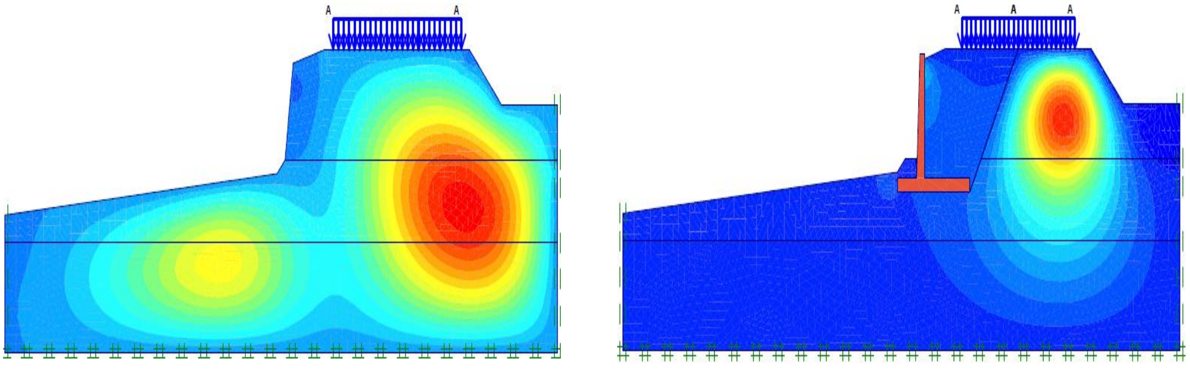

(b) Deformation After Reinforcement

Figure 8: Slope Deformation

The deformation values in Figure 8(a) and (b) indicate the deformation before and after slope strengthening, respectively, with 117 × 10^3 m and 1.5 m, respectively. This indicates that the deformation prior to slope strengthening is larger than the deformation following slope reinforcement. Landslides are more likely to occur when the deformation value is high.

Consolidation

Consolidation can be seen in Figure 9 which is the output of pore water pressure on the slope. Figure 9 (a) shows the pore water pressure before slope reinforcement which has a value of -731.91 × 10^{-3} kN/m^2 with consolidation lasting 1907 days or more than 5 years. In (b) the pore water pressure after slope reinforcement has a value of 992.91 × 10^{-3} kN/m^2 with consolidation lasting 4518 days or more than 13 years.



(a) Pore Water Pressure Before Reinforcement (b) Pore Water Pressure After Reinforcement

Gambar 9. Pore Water Pressure Conditions on Slopes

CONCLUSIONS

Analysis of the stability of the original slope and after reinforcement was carried out on the Sekayu – Mangun Jaya road section STA 127+350 using empirical methods and finite elements. Based on the results of the slope stability analysis, it is known that the value of the slope safety factor before strengthening falls into 2 classifications, which are unstable on the slope at point BH-01 and moderate stability on the slope at point BH-02. Reinforcement method with embankment and cantilever type retaining walls was applied to the slope and its stability was calculated using Plaxis software. The results of the slope stability analysis after reinforcement showed a significant increase in the safety factor value. The deformation that occurred on the slope before strengthening was known to have a value of 117×10^3 m, after strengthening the slope the deformation became 1.5 m. Landslides are more likely to occur if there is significant deformation. It has been determined that consolidation after slope reinforcing lasts for 4518 days, or more than 13 years, whereas consolidation prior to slope reinforcing lasts for 1907 days, or more than 5 years. Retaining walls and embankments strengthen slopes, increasing slope stability while minimizing the likelihood of landslides.

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