(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6, Issue. 1, January 2024

Analysis of Existing Slope Reinforcement Design on Clay Shale Soil and Its Alternative Modifications: A Case Study of the Awunio – Lapuko Road Section Sta 4+955 – 5+015 in the Southeast Sulawesi Province

A. Azhari[1,a], Mohamad Khoiri[2,b) & Freddy Siagian[3,c]

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

Correspondent : [a)] azhari.ahmd@gmail.com, [b)] mkhoiri@ce.its.ac.id & [c)] fsiagian70@gmail.com

ABSTRACT

On the Awunio – Lapuko road section, there was a landslide from STA 4+955 to STA 5+015, causing the roadside to collapse. The probable cause is water infiltration into the soil, affecting the clay shale properties. An analysis of the existing slope stability and its planning needs to be carried out. Water management planning and alternative reinforcement are necessary if the stability does not meet the requirements. Slope stability analysis is conducted on the existing slope and existing design using manual calculation methods and the GEO5 program. The stability considered includes shear stability, tilting, and overall stability.The analysis reveals that the existing slope stability is safe from landslides. However, this contradicts the field observations. Therefore, a crack soil approach is used in this study to assess the landslide conditions in the field, resulting in a safety factor (SF) of 0.95 for the road slope. The existing design, a 2.5 m high retaining wall with bored piles of 50 cm diameter and a depth of 8 m, yields slope stability with an SF of 7.91, indicating safety but being excessively costly. The water management system planning indicates that the drainage channel capacity can handle the water discharge from rainfall. Introducing subdrains improves the slope stability from SF 0.95 to 1.38, but additional reinforcement is still needed. An alternative design with a 2.5 m high retaining wall and bored piles of 40 cm diameter and 3 m depth yields a slope stability 3.29. Replacing the retaining wall structure with natural stone using bored piles of 30 cm diameter and 3 m depth results in an SF of 2.18. If an alternative subdrain with additional gabion reinforcement is implemented, the slope stability becomes 2.23. Additionally, an alternative design using geotextiles results in slope stability with an SF of 1.77. All alternative reinforcements are deemed safe and meet stability requirements

Keyword : clay shale, slope stability, retaining wall with bored pile, gabion, subdrain

INTRODUCTION

Roads are one of the crucial infrastructures in the implementation of transportation systems that facilitate the movement of people or goods, thereby impacting other aspects such as the economy, social sphere, and tourism. The construction of roads can create connectivity and accessibility for remote and isolated areas that are far from modern developments. The existence of these roads can support the discourse of balanced development throughout Indonesia.. The infrastructure must be managed to be able to function sustainably well, economically, efficiently, effectively, and must respect the sustainability (green) principle (Soemitro & Suprayitno, 2019). Infrastructure needs to be well managed. Thus, it needs to be well operated, well maintained, well constructed, well designed, well planned, well registered, well disposed of. Operation and maintenance must be based on infrastructure conditions or infrastructure performance (Suprayitno et al., 2020)

Landslide occurred on the Awunio – Lapuko road section at STA 4+955 to STA 5+015, located in Moramo District, South Konawe Regency, Southeast Sulawesi Province, as shown in **Figure 1**. The landslide occurred on the lower slope area along a 65-meter stretch, causing the road shoulder to collapse following the path, posing a potential danger to road users traversing that section. The landslide is suspected to occur due to the contact between clay shale soil and water entering the road body through cracks on the surface, transforming the soil condition beneath the road body as if it were sandy. The Mechanism of water infiltration could decrease the strength of soil rapidly (Satrya et al., 2019).

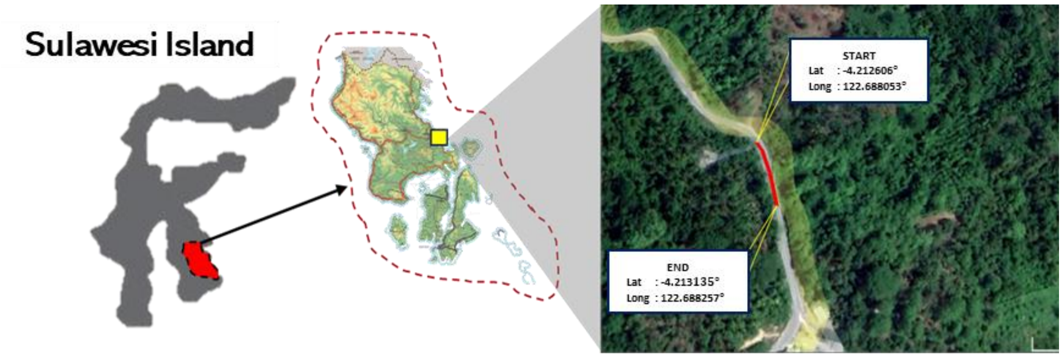


Figure 1. The location point of the landslide is at STA 4+955 – 5+015
(Layout Drawing P2JN, 2022)

Clay shale soil is highly sensitive to weather changes or exposure to air and water. Generally, clay shale soil is very susceptible to climate and weather changes, resulting in fissures and soil weathering in areas directly exposed to the air (Alhadar et al., 2014). Based on information obtained from the Head of the Regional Work Unit II of Southeast Sulawesi Province, there is a layer of clay shale soil on the Awunio – Lapuko road section where, when the soil is wet, it behaves like mud, but in dry conditions, the soil becomes very hard and strong like rock. This is also supported by the results of N-SPT drilling, which found hard-consistency soil (N>60) at 2 – 4 meters deep.

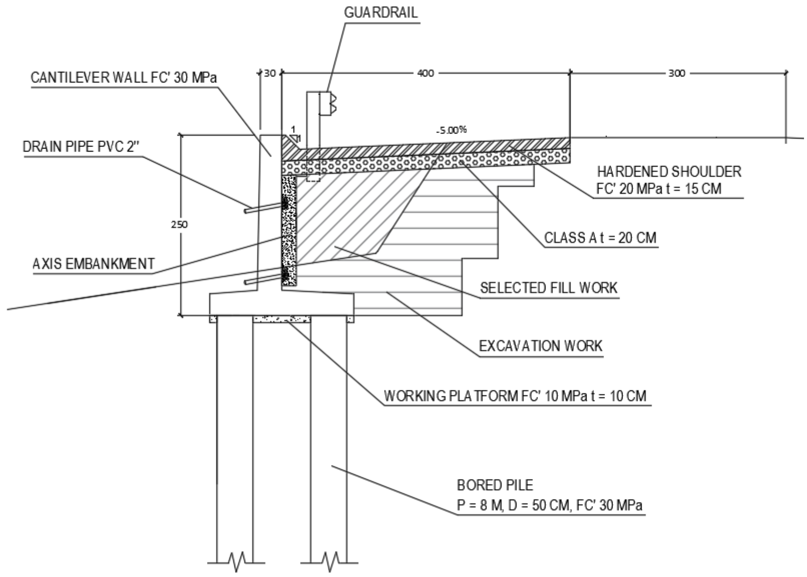


Figure 2. Existing Reinforcement Design
(Layout Drawing P2JN, 2022)

Based on this information, it can be concluded that the likelihood of landslides is very low because the soil has a high N-SPT value with hard consistency. Based on the results of sieve analysis testing at a depth of 4.5 – 5.0 meters, it was found that the percentage of silt/clay is 20.574%, while at a depth of 9.5 – 10.0 meters, the percentage of silt/clay is 58.784%. Geological aspects also support the fact that the Awunio – Lapuko road section has clay rock and falls into the Tmpb category. Tmpb (Tertiary Mio Pliocene Boepinang) is an area of the Boepinang formation where there is clay sand, marl sand, and sandy rock, estimated to have existed since the Tertiary Miocene era.

The mitigation to be undertaken involves the construction of a retaining wall reinforced with bored piles, each with a length of 8 meters, as shown in **Figure 2**. The retaining wall, along with bored piles, will be installed over 24 meters, following the alignment of the road body, as illustrated in **Figure 3**.

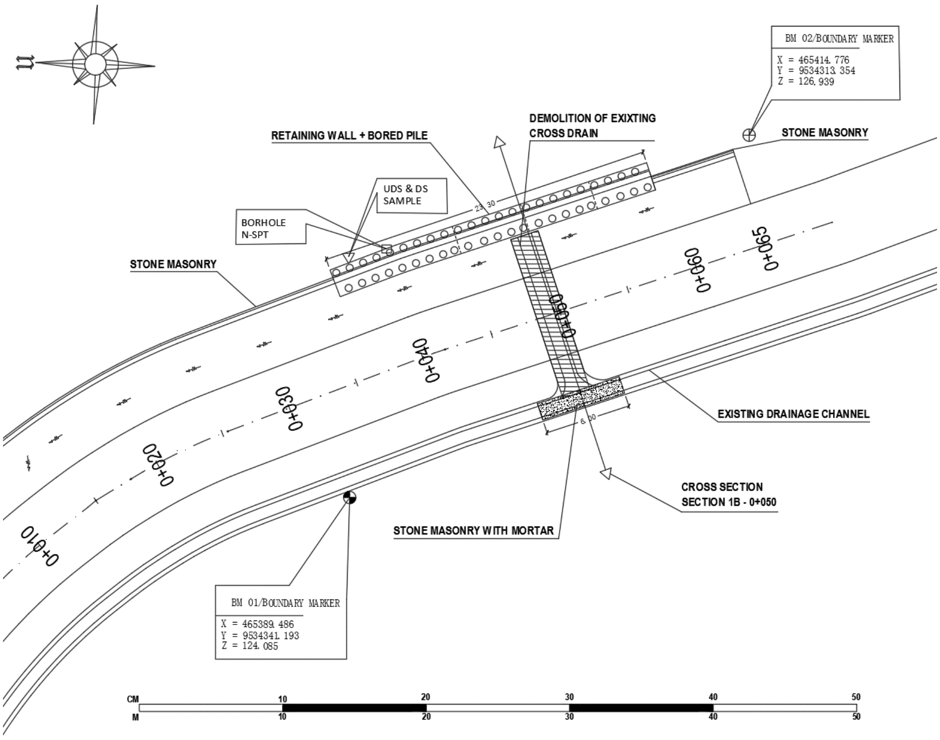


Figure 3. Map of the landslide location situation
(Layout Drawing P2JN, 2022)

The stability analysis of the existing slope and its reinforcement planning has not been conducted, necessitating stability analysis before and after reinforcement. If the stability of the existing reinforcement does not meet the requirements, additional reinforcement planning is required. Therefore, this study will analyze the stability of the existing slope and the existing design to determine their safety levels. Additionally, it will explore additional reinforcement through modifications to the existing design to enhance structural safety against vertical and horizontal forces, if necessary. The study will also include a water management system on the slope of the Awunio – Lapuko Road section STA 4+955 – 5+015. This method can serve as an alternative for consideration in the field.

LITERATURE REVIEW

Stability of Retaining Wall

According to SNI 8460:2017 regarding the Geotechnical Design Requirements, retaining walls must be designed based on overturning, horizontal displacement, and bearing capacity. However, these requirements have been replaced with new ones, where stability against overturning needs to be recalculated if stability against sliding/tilting is already secure. 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.

1. Sliding stability

   Due to lateral forces such as the active earth pressure (Pa) at work, the retaining wall can experience sliding. The lateral forces Pa will face resistance from the passive earth pressure Pp and the frictional force between the base of the wall and the soil. The formula used to calculate the factor of safety:

$$SF = \frac{Fr}{\sum Ph} \quad \ldots(1)$$

where,

$$Fr = R \times \tan\phi + c' \times B + Pp \quad \text{…(2)}$$

$$\Sigma Ph = Pa \quad \text{…(3)}$$

where:

SF = safety factor
Fr = resisting the retaining wall against sliding (kN)
ΣPh = total horizontal force pressure (kN)
R = total weight of the retaining wall itself (kN)
c = cohesion (kPa)
B = width of the foundation base (m)
Pp = passive pressure (kN)

2. Tilting stability

Tilting is the term used to control retaining walls with the center of moment occurring in the middle width of the foundation, taking into account both vertical and horizontal forces and soil-bearing capacity. The retaining wall structure is not tilting if the value of s_{max} is less than s_{safe}. There are two conditions for calculating s_{max}:

a. If $\frac{\sum V}{A} > \frac{\sum M}{W}$ then there is no tilting if $s_{max} \leq s_{safe}$

$$s_{max,\,min} = \frac{\sum V}{A} \pm \frac{\sum M}{W} \quad \text{…(4)}$$

$$W = \frac{I}{\frac{1}{2}B} \quad \text{…(5)}$$

where:

ΣV = total of vertical forces (kN)
A = B x 1’ (m^2)
ΣM = total moment occurring at point O
s_{maks} = maximum stress occurring beneath the retaining wall
s_{safe} = allowed stress occurring beneath the retaining wall
I = inersia moment (m^4)
B = width of the foundation base (m)

b. If $\frac{\sum V}{A} < \frac{\sum M}{W}$ then there is no tilting if $s_{max} \leq s_{safe}$ and e < 1/6B

$$s_{max} = \frac{2\sum V}{3\,(1/2B - e)} \quad \text{…(6)}$$

$$e = \frac{\sum M}{\sum V} \quad \text{…(7)}$$

where:

ΣV = total of vertical forces (kN)
A = B x 1’ (m^2)
ΣM = total moment occurring at point O
s_{maks} = maximum stress occurring beneath the retaining wall
s_{safe} = allowed stress occurring beneath the retaining wall
I = inersia moment (m^4)
B = width of the foundation base (m)

To calculate s_{safe}, you can use the following formula:

$$S_{safe} = q_{safe} = \frac{q_{ult}}{SF} + \gamma\, Df \quad \text{…(8)}$$

$$qu = c \times Nc + Df \times \gamma \times Nq + 0{,}5 \times B \times \gamma \times N\gamma - \gamma \times Df \quad \ldots(9)$$

where:

qu	= ultimate bearing capacity (kN/m^2)
c	= cohesion (kN/m^2)
q	= traffic load (kN/m^2)
γ	= soil density (kN/m^3)
B	= width of the foundation (m)
Df	= depth of the foundation (m)
Nc, Nq, Nγ	= soil bearing capacity factor (function ϕ)

Bearing Capacity of Pile

The bearing capacity of a pile is assessed based on the vertical and horizontal forces acting on it.

1. Bearing capacity of pile on vertical forces

   In terms of pile reinforcement based on load-bearing capacity, piles can be divided into two types: end-bearing piles and friction piles (Seftian et al., 2015). Generally, the axial load capacity can be formulated as follows:

$$Q_{ult} = Q_s + Q_p - W_p \quad \ldots(10)$$

where:

Qult	= ultimate bearing capacity
Qs	= friction piles
Qp	= end bearing piles
Wp	= weight of the pile

Then, to obtain the allowable single pile capacity, it is determined using the following formula:

$$Qa = Qult/SF \quad \ldots(11)$$

where:

Qa	= bearing capacity of single pile
SF	= 2,5 – 3 safety factor

The frictional resistance or the skin friction resistance of a pile can be calculated using the formula:

$$Q_s = a \times c_u \times L_i \times p \quad \ldots(12)$$

where:

a	= coefficient of adhesion between soil and pile
cu	= undrained cohession
Li	= thickness of the soil layer
p	= circumference of the pile

The end bearing capacity of a pile is generally expressed as an equation:

$$Q_p = Ap \times (c_u \times N_c + \sigma_v \times N_q) \quad \ldots(13)$$

where:

Ap	= cross-sectional area of the pile
cu	= undrained cohesion
σv	= overburden pressure
Nc Nq	= bearing capacity factor

The ultimate capacity of a pile group, taking into account the pile efficiency factor, is expressed by the following formula:

$$Q_g = Eg \times n \times Q_a \qquad \ldots(14)$$

where:

Qg	= maximum load of a pile group
Eg	= efficiency of pile group
n	= number of piles in the group
Qa	= maximum load of a single pile

2. Bearing capacity of pile on horizontal forces

The use of piles increases the soil's shear resistance, consequently enhancing the soil's bearing capacity. One of the forces acting on the pile is the horizontal force. To calculate the maximum horizontal force acting on the pile it can be determined using the following formula:

$$P_{max} = \frac{M_{crack}}{F_m \cdot T} \qquad \ldots(15)$$

where:

Mcrack	= cracking moment acting on the pile due to Pmax (kg-cm)
Fm	= coefficient of moment due to lateral force
Pmax	= maximum horizontal force endured by the pile (kg)
T	= stiffness factor (cm)

The effective stiffness factor (T) can be calculated using the following formula:

$$T = [\frac{EI}{f}]^{1/5} \qquad \ldots(16)$$

where:

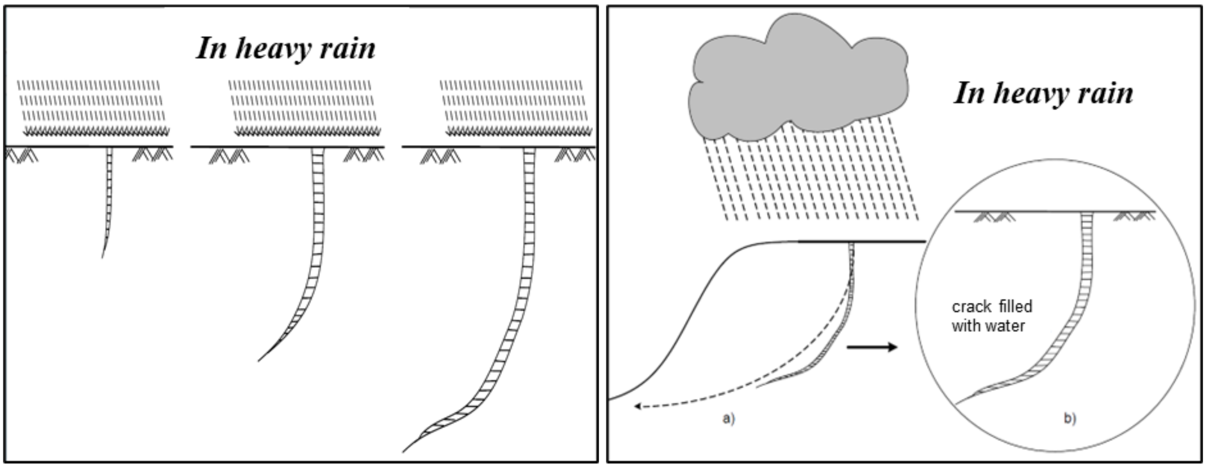
E	= elastic modulus of pile (kg/cm^2)
I	= inertia moment of pile (cm^4)
f	= coefficient of variation of soil modulus (kg/cm^3)
T	= stiffness factor (cm)

Subdrain

Subdrain is a drainage channel or pipe placed in the ground on or along slopes. Its function is to channel water trapped within the slope to drainage channels below the slope. In this way, pore water pressure can be significantly reduced, reducing the load on the slope, and improving overall stability. Subdrains are useful as drainage systems that help maintain the groundwater level as low as possible, thus increasing the Factor of Safety (SF) and extending the lifespan of slope reinforcement. Subdrains are installed from the top of the slope to the toe of the slope, ensuring that the slope remains in a dry condition. The planning of subdrains should be behind the slip surface with an SF = 1 (critical) (Tarigan et al., 2020).

Crack Soil

In the soil, there are cracks or fissures where, during rainfall, rainwater can enter these crack surfaces. If the rainfall is not heavy, the rainwater does not fill all the gaps or cracks. Some water that enters immediately flows through cracks on the other side. However, during heavy rainfall, the flow of rainwater into the cracks increases. The water pressure becomes significant, making it seem like the pressure in the cracked area is filled with water. The high water pressure on the cracked surface gradually allows the fissures to propagate, making the slope more critical than before, as shown in **Figure 4**. The initially short crack surfaces will gradually lengthen. This occurs because the material around the crack dissolves, causing the soil to lose its cohesion (c) value. Since the soil no longer has cohesion, its behavior will resemble loose sand. If the cracks propagate down the slope, a landslide may occur due to the lack of cohesion in the cracked area, making the soil unable to withstand its weight and the load above it.



(Mochtar, 2021)

Figure 4. Cracked soil mechanism

RESEARCH METHOD

Slope stability analysis can be carried out using several methods, such as the Limit Equilibrium Method (LEM), Finite Element Method (FEM), Finite Difference Method (FDM), and others. The most popular and frequently used method is the LEM (Shoffiana et al., 2022). The slope stability analysis is divided into two conditions: against the existing slope and the existing design, using manual calculation methods and the GEO5 software. The stability considerations include resistance against, sliding, tilting, and overall stability.

In the analysis of the existing slope, calculations are performed using soil data obtained from laboratory tests using UDS (Undisturb Sample) and DS (Disturb Sample) from the landslide location. Suppose the results of the landslide area and safety factors do not align with field conditions. In that case, the crack soil approach will be applied by modifying groundwater levels and soil cohesion to 0.

A similar analysis is conducted for the slope with the installed reinforcement design consisting of a retaining wall with bored piles. A water management system and alternative reinforcement will be planned if the existing design does not meet requirements. The water management system is designed considering the water flow at the landslide site to determine the drainage channel capacity and the appropriate subdrain design to reduce the risk of landslides. Planned reinforcement alternatives include retaining wall with bored piles using diameters (30, 40, and 50 cm) variations and lengths (3, 4, 5, 6, 7, and 8 m), gravity wall with bored pile, subdrain with gabion reinforcement, and geotextile reinforcement.

ANALYSIS

Stability of Existing Slope

The slope stability analysis is conducted using the limit equilibrium method with the GEO5 software. Soil parameters input into the analysis are based on laboratory test results as shown in **Table 1**.

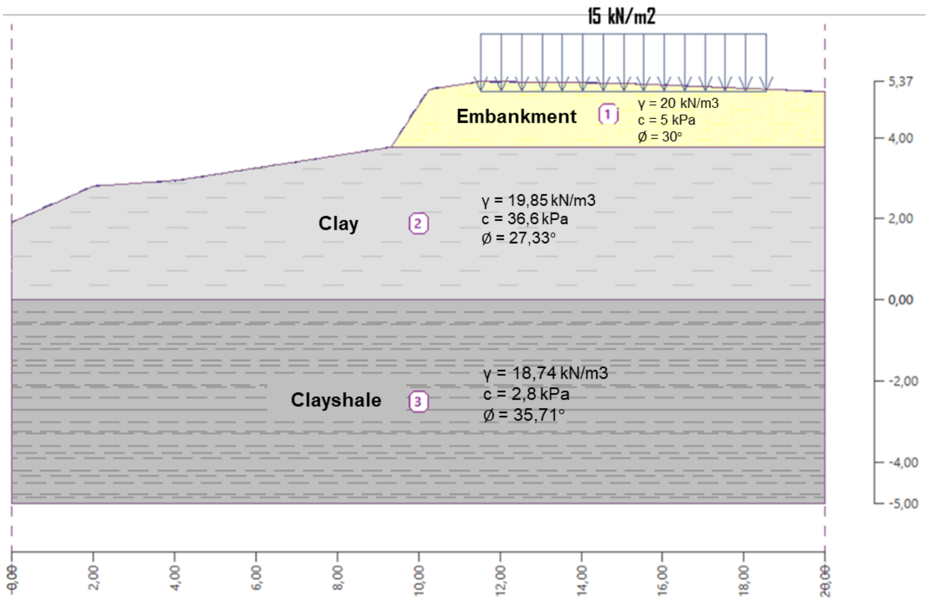


Figure 5. The modeling of the existing slope geometry

Table 1. Input of soil parameters into the GEO5 software

Parameters	**Unit**	**Embankment**	**Clay**	**Claystone**
Unit weight (γ)	kN/m^3	20,00	19,85	18,74
Stress-state			Effective	
Angle of internal friction (Ø)	derajat	30,00	27,33	35,71
Cohesion of soil (c)	kPa	5,00	36,80	2,8
Saturated unit weight (γsat)	kN/m^3	20,00	20,41	23,87

Based on the analysis results, the slope has a Safety Factor (SF) of 1.85 using the optimization analysis to find the minimum sliding surface. This indicates that the slope is considered stable or safe against landslide hazards, as SF > 1.50. However, this contradicts the field incident where a landslide occurred, resulting in road shoulder erosion. Therefore, an analysis approach using the crack soil theory is conducted. In this approach, water is modeled at the ground surface level, as the modeling is created under the worst slope conditions, where the soil appears to be submerged in water and behaves like sand (c = 0).

It is found that the stability of the existing slope, using the crack soil theory approach with the load from a Class I road vehicle, does not meet stability requirements, with a Safety Factor (SF) < 1.5. The slope's SF is 0.95, as shown in **Figure 6**. Therefore, the existing slope's SF using the crack soil approach, which is less than 1.5, leads to landslides in the field. Consequently, interventions are needed to improve the slope's SF.

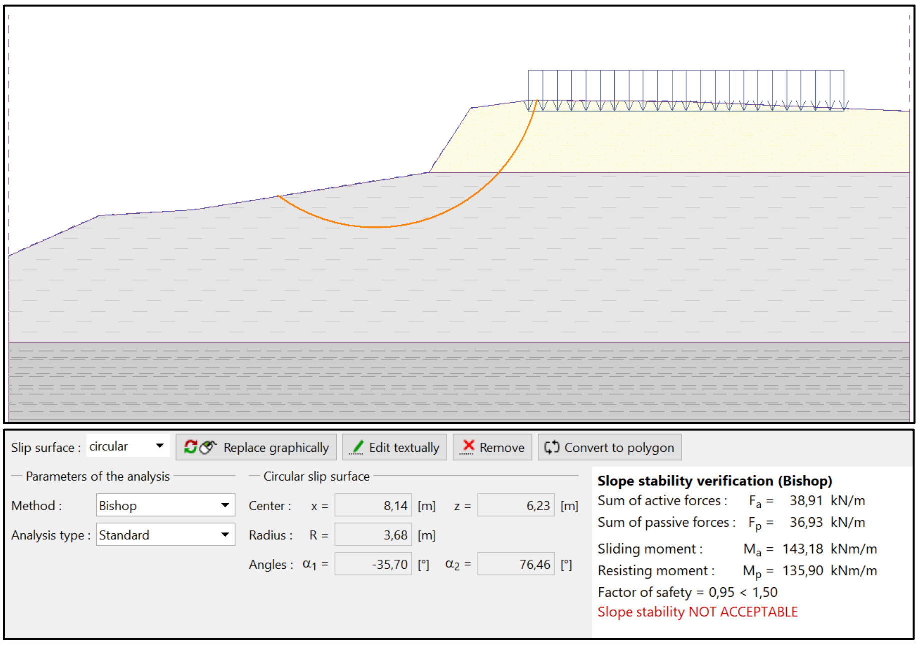


Figure 6. The slope modeling using the crack soil approach

Stability of Existing Design

Based on SNI 8460:2017, the existing retaining wall dimensions do not meet the requirements, necessitating a redesign of the retaining wall dimensions. According to the GEO5 program analysis results, the front and rear parts of the wall have a satisfactory value of 61.1%, the upper part of the foot has 43.2%, and the lower part of the foot has 30.5%. This indicates that the reinforcement needs for the wall are adequately met with a satisfactory value > 50%. However, the satisfactory values in both the upper and lower parts of the foot are < 50%, suggesting that the reinforcement in these areas is considered excessive. Therefore, a reduction in the number of reinforcements or a decrease in the reinforcement diameter is needed to create an effective and efficient reinforcement design for the lower part of the wall.

The stability analysis of the existing design is divided into conditions with and without bored piles. The analysis involves manual calculations considering the forces acting on the structure and using the GEO5 program. In the case of the retaining wall structure without bored piles, stability is compromised against sliding, while stability against overturning and bearing capacity meets the permissible requirements. Therefore, adding bored piles is appropriate to enhance the structural resistance against sliding forces. In the analysis of the retaining wall structure with bored piles, stability against overturning, sliding, and bearing capacity is fulfilled, as indicated in **Table 2**.

Table 2. The results of the stability analysis for the existing design

No.	Conditions	Sliding		Tilting			Overall Stability
		Manual	GEO5	Manual	GEO5	Desc.	GEO5
1	Retaining wall without bored pile	0,80	0,83	4,81	7,10	$s_{max} \leq s_{safe}$ e < 1/6B NOT OK	1,23
2	Retaining wall with bored pile	29,78	4,88	8,48	8,36	SF > 3.00 OK	7,91

The installed bored pile consists of 2 piles with a diameter of 50 cm and a length of 8 m. Each pile has an ultimate vertical load capacity of 425.38 tons and an allowable load capacity of 141.79 tons. When considering them as a group, the pile group has a capacity of 248.2 tons with an efficiency of 0.875.

From a slope stability perspective, the existing design of a retaining wall with bored piles yields a Safety Factor (SF) of 7.91, indicating that the structure is very safe and meets stability requirements. Additionally, the exact slope modeling using the reinforced retaining wall with bored piles is analyzed under minimum conditions, resulting in an SF of 2.96. This indicates that the structure remains very safe and complies with stability requirements.

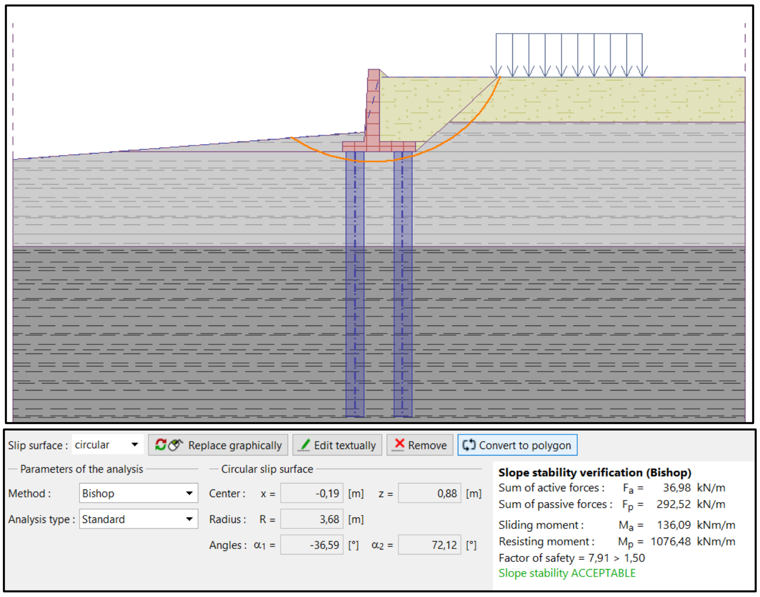


Figure 7. The stability results of retaining wall with bored piles on overall stability

Water Management System

There are three (3) conditions to consider when implementing water management measures on a slope: before water enters cracks or fissures, after water enters cracks or fissures, and after water passes through the sliding surface. When water enters cracks or fissures, appropriate measures involve directing water flow using drainage channels to the nearest outlet to prevent water from pooling or flowing over the road surface. In the second condition, when the water has entered cracks or fissures, efforts can be made in order to prevent the water from reaching and penetrating a sliding surface. In this case, the effort involves the construction of subdrains. If water has passed through the sliding surface, landslides are highly likely. Therefore, appropriate measures in this condition involve reinforcement, including retaining walls, piles, geotextiles, and other slope stabilization methods.

In the analysis of the flow in the existing drainage channel, it was found that the capacity of the drainage channel can still accommodate the water flow resulting from the maximum rainfall in the last ten years. The rainfall flow is 1.26 m^3/second, while the capacity of the existing drainage channel is 2.52 m^3/second. Thus, the flow into the installed drainage channel on the field can still be contained without overflowing onto the road.

To design subdrain, data on the sliding surface's Safety Factor (SF) is needed, approximately ≈ 1, as this is a critical condition for the slope. Analysis using the GEO5 software aims to achieve SF ≈ 1. The planned subdrain design is positioned behind the critical sliding surface (SF = 1.02) with three layers of subdrains consisting of stone wrapped in non-woven geotextile with a width of 15 cm and height of 50 cm along a length of 65 m. The result shows increased slope stability to 1.38, making the slope safe against landslides but still not meeting the stability requirement of SF < 1.5. Therefore, reinforcement measures for the subdrain design are necessary to improve SF and meet the requirements.

Table 3. The comparison of analysis results with the previous research on subdrain

No.	Road Section	Overall Stability	
		Before Reinforcement	After Reinforcement
1.	Access Road PLTA MUSI KM. 5 (Tarigan, 2020)	0,451	1,365
2.	Access Road PLTA MUSI KM. 8 (Tarigan, 2020)	0,338	1.017
3.	Awunio - Lapuko	0,95	1,38

Alternative Reinforcement

Alternative reinforcements are necessary to create a suitable design for the landslides occurring on the Awunio – Lapuko road section STA 4+955 – 5+015. The planned alternative reinforcement will consist of retaining wall with bored piles, gabion with bored pile, a reinforced subdrain design with gabion, and geotextile designed based on applicable regulations and field-specific requirements to meet stability requirements.

Alternative Retaining Wall With Bored Pile

The retaining wall dimensions are planned based on the criteria set in SNI 8460:2017, and the reinforcement design is calculated according to SNI 2847:2013 with variations in reinforcement diameter, as shown in **Table 3**. The alternative retaining wall reinforcement design with the maximum satisfactory value and meeting the requirements is chosen based on the results. In the wall section, flexural reinforcement of 4D19 – 300 mm and shear reinforcement of Ø14 – 250 mm are used, while in the foot section, flexural reinforcement of 5D13 – 250 mm and shear reinforcement of Ø10 – 250 mm are employed.

Table 4. The results of the calculation of alternative retaining wall reinforcement

No.	Diameters (mm)	Type	Wall			Foot		
			Flexural		Shear (mm)	Flexural		Shear (mm)
			Quantity (unit)	Spacing (mm)		Quantity (unit)	Spacing (mm)	
1	13	Deformed	9	125	Ø10 – 250	5	250	Ø10 – 250
2	16	Deformed	6	200	Ø12 – 250	3	500	Ø12 – 250
3	19	Deformed	4	300	Ø14 – 250	2	1000	Ø14 – 250

For the determination of the dimensions of the bored pile, variations in the diameter and length of the bored pile were carried out and then analyzed using GEO5 to obtain the minimum safety factor, as shown in **Table 4**. The selected alternative bored pile dimensions are a diameter of 30 cm and a length of 5 m, resulting in a safety factor (SF) of 1.84. Therefore, the structure is considered safe against landslides and meets stability requirements.

Next, the bored pile is analyzed for the horizontal force acting on it. The analysis results show that the maximum lateral force that the pile can withstand (Pmax) is 3.70 tons, requiring one pile. The deflection produced by the pile is 1,23 cm, smaller than the requirement of 2.5 cm. The maximum moment generated by the pile is 224,400 kg.cm, still below the crack moment of the pile, which is 448,800 kg.cm.Stability analysis was conducted on the alternative retaining wall structure under conditions without bored piles and with bored piles. For the retaining wall without bored piles, stability against sliding did not meet the requirements, resulting in a landslide. Therefore, the additional installation of bored piles can enhance the soil forces resisting the sliding force, ensuring the stability of the structure against landslides and meeting the requirements, as indicated in **Table 5**. The slope stability also increased to 2.11, indicating that the alternative retaining wall with bored piles can be used to address the landslide issue effectively.

Table 5. The analysis of the dimensions and length of the bored pile on SF

No.	Length of Pile	Diameter of Pile (cm)	SF *Overall Stability*	Description
1	8 m	50,00	2,81	slope meets the requirements and does not experience landslides
		40,00	2,60	slope meets the requirements and does not experience landslides
		30,00	1,90	slope meets the requirements and does not experience landslides
2	7 m	50,00	2,73	slope meets the requirements and does not experience landslides
		40,00	2,55	slope meets the requirements and does not experience landslides
		30,00	1,89	slope meets the requirements and does not experience landslides
3	6 m	50,00	2,65	slope meets the requirements and does not experience landslides
		40,00	2,48	slope meets the requirements and does not experience landslides
		30,00	1,88	slope meets the requirements and does not experience landslides
4	5 m	50,00	2,54	slope meets the requirements and does not experience landslides
		40,00	2,39	slope meets the requirements and does not experience landslides
		30,00	1,84	slope meets the requirements and does not experience landslides
5	4 m	50,00	2,41	slope meets the requirements and does not experience landslides
		40,00	2,29	slope meets the requirements and does not experience landslides
		30,00	1,84	slope meets the requirements and does not experience landslides
6	3 m	50,00	2,18	slope meets the requirements and does not experience landslides
		40,00	2,13	slope meets the requirements and does not experience landslides
		30,00	1,80	slope meets the requirements and does not experience landslides

Table 6. The result of the stability analysis of the alternative retaining wall with bored piles

No.	Conditions	Sliding		Tilting			Overall Stabilty
		Manual	GEO5	Manual	GEO5	Desc.	GEO5
1	Alternative retaining wall without bored pile	0,82	0,99	3,50	5,88	$s_{max} \leq s_{safe}$ e < 1/6B NOT OK	1,20
2	Alternative retaining wall with bored pile	2,16	2,76	4,18	3,73	SF > 3.00 OK	3,29

Alternative Gravity Wall with Bored Pile

Reinforcement using gravity wall to replace a retaining wall with a larger weight due to reinforced concrete reduces the load borne by bored piles. The height of the gravity wall is designed similarly to the retaining wall with a height of 2.5 meters. The dimensions of the bored pile used are with a diameter of 30 cm and a length of 3 meters. Based on the analysis results using GEO5, a safety factor (SF) of 2.18 was obtained, indicating that this reinforcement is safe against sliding and meets stability requirements.

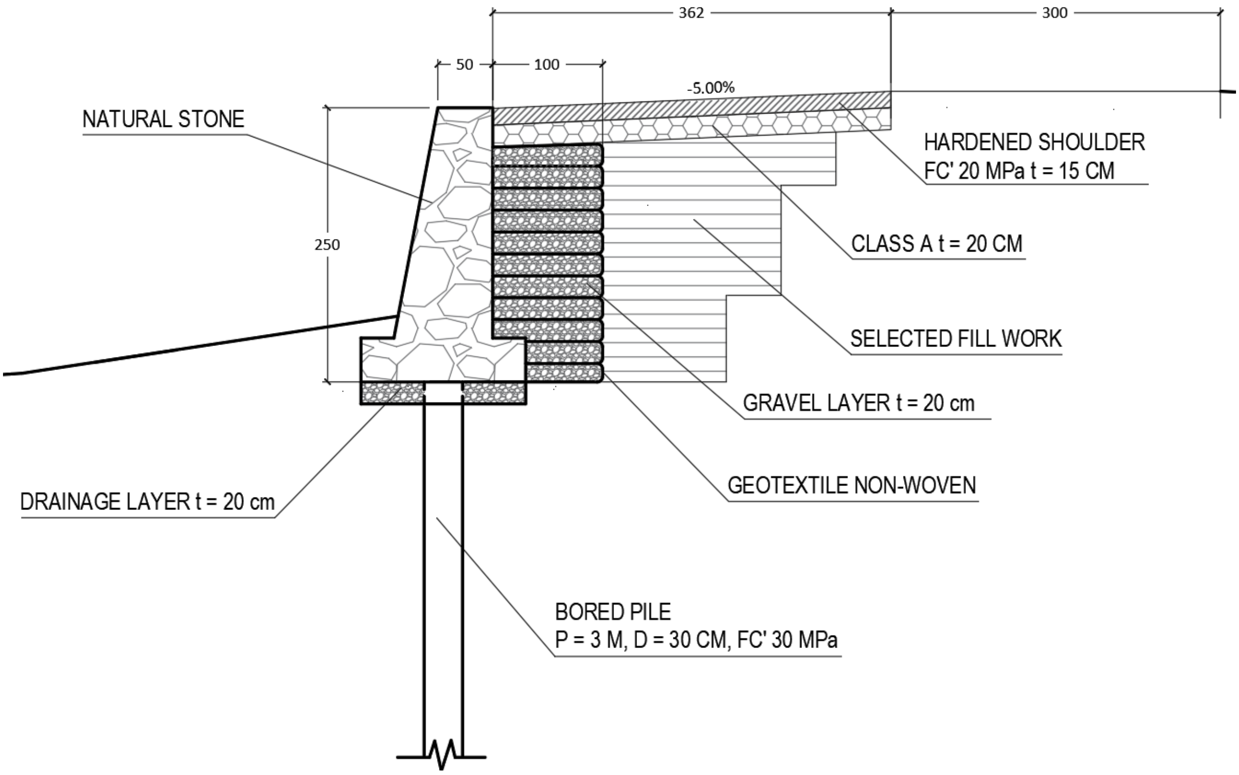


Figure 8. Alternative design of gabion with bored pile

Alternative Subdrain with Gabion Reinforcement

Additional reinforcement in the form of gabions filled with stone pairs wrapped in geogrid with a tensile strength of 27.55 kN/m, as used in a previous study (Kesuma, 2023) consists of 3 layers of gabions. This reinforcement will be installed along a length of 65 m. Behind the gabion, there is an extension of the geogrid installed along a depth of 1.50 m into the soil. Stability analysis results yielded a safety factor (SF) of 2.23, indicating that this reinforcement alternative can be used in the field as it is safe and meets the stability requirements (SF > 1.50)

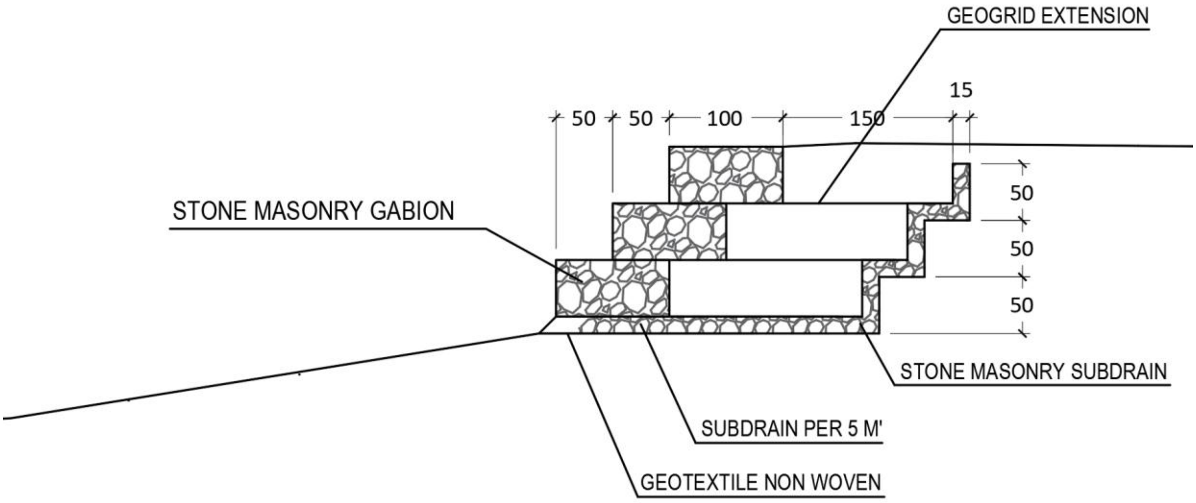


Figure 9. Alternative design of subdrain with gabion reinforcement

Table 7. The comparison of analysis results with the previous research on gabion reinforcement

No.	Road Section	Overall Stability	
		Before Reinforcement	After Reinforcement
1.	Pejagan – Prupuk (Kesuma, 2023)	0,84	1,59
2.	Awunio – Lapuko	0,95	3,18

Alternative Geotextile Reinforcement

In this alternative reinforcement, non-woven geotextile with tensile strength (Tult) = 50 kN/m and a safety factor (SF) = 3 is used, resulting in Tall = 16.67 kN/m. Based on stability analysis using the GEO5 software, it is found that after adding four layers of geotextile with a length of 5.95 m, the slope safety factor (SF) increases to 1.77. Therefore, the installation of subdrains with geotextile reinforcement meets stability requirements as SF > 1.50.

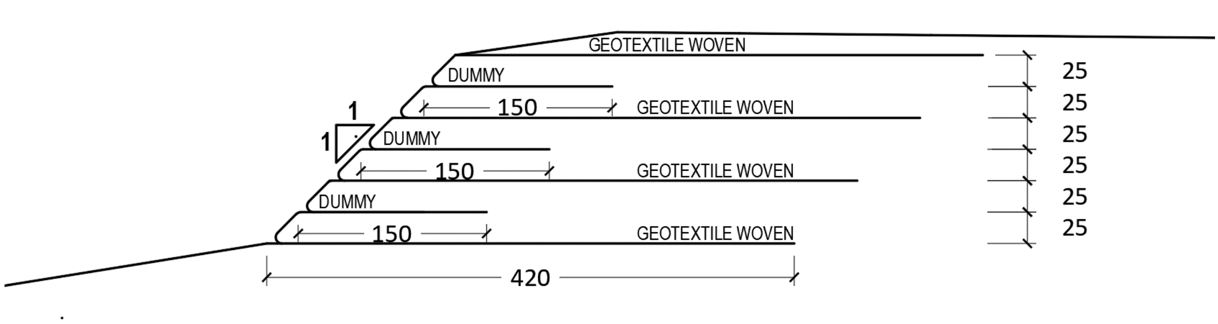


Figure 10. Alternative geotextile reinforcement design

Table 8. The comparison of analysis results with the previous research on geotextile reinforcement

No.	Road Section	Overall Stability	
		Before Reinforcement	**After Reinforcement**
1.	Ponorogo – Trenggalek (Fitriadi, 2019)	1,17	1,75
2.	Awunio – Lapuko	0,95	1,77

CONCLUSION

Based on the data from soil investigation and laboratory testing, it was found that the slope was considered safe against landslide incidents. However, contradicting the field observations where landslides occurred, a crack soil approach was applied to understand the slope conditions resembling the landslide events in the field, with a Safety Factor (SF) of 0.96. The mitigation using retaining wall with bored piles resulted in excessively high stability, which could have been more optimal for handling landslides. Designing water management system with drainage channels and subdrains proved insufficient to address landslides. Therefore, alternative reinforcement plans were developed, including retaining wall with bored piles, gabion with bored pile, subdrains with gabion reinforcement, and geotextile reinforcement.

The alternative retaining wall with bored piles was planned using new retaining wall dimensions, with bored piles having a diameter of 40 cm and a length of 3 m, totaling 1 unit. This structure can withstand vertical and horizontal forces, producing slope stability with SF = 3.29. The alternative of using gravity wall with bored pile yields a safety factor (SF) of 2.18, ensuring safety against sliding and meeting stability requirements. Meanwhile, the alternative subdrain with gabion reinforcement, consisting of 3 layers with a tensile strength of geogrid is 50 kN/m, resulted in slope stability of 2.23, ensuring safety against landslides and meeting stability requirements. The alternative geotextile reinforcement requires four layers with a tensile strength of 50 kN/m to achieve slope stability of 1.77, making it applicable in the field and safe against landslides.

ACKNOWLEDGEMENT. This research is funded by BPSDM Kementerian PUPR and the author expresses gratitude to BPJN Southeast Sulawesi for providing the data to support this research.

[1] Abramson, Lee. W., Lee, Thomas. S., Sharma, S., & Boyce, G. M. (2002). *Slope Stability and Stabilization Method* (2nd ed.). John & Wiley Sons, Inc.
[2] Alhadar, S., Asrida, L., Prabandiyani, S., & Hardiyati, S. (2014). "Analisis Stabilitas Lereng Pada Tanah Clay Shale Proyek Jalan Tol Semarang-Solo Paket VI STA 22+700 sampai STA 22+775". *Jurnal Karya Teknik Sipil*, Vol. 3, Hal.: 336–344. Semarang.
[3] Departemen Permukiman & Prasarana Wilayah. (2002). *Panduan Geoteknik 4: Desain dan Konstruksi*. WSP International. Bandung.
[4] Hardiyatmo, H. C. (2003). *Mekanika Tanah II* (3rd ed.). Gadjah Mada University Press.
[5] Hardiyatmo, H. C. (2006). *Penanggulangan Tanah Longsor dan Erosi*. Gajah Mada University Press.
[6] Hardiyatmo, H. C. (2010). *Analisis & Perancangan Fondasi II*. Gadjah Mada University Press.
[7] Hardiyatmo, H. C. (2014). *Analisis & Perancangan Fondasi* (2nd ed., Vol. 1). Gadjah Mada University Press.

[8] Manudianto, Dedy., Endah, Noor., & Siahaan, Hardy P. (2023). "Alternative of Soil Improvement Methods on Organic Soil Using Preloading and Vertical Piles for Embankment with Varied Heights. Case Study: Construction of Batanjung Port Access Road in Pulang Pisau Regency, Central Kalimantan". *Journal of Infrastructure and Facility Asset Management.* Vol. 5, No. 1, Hal.: 11-26. Surabaya.
[9] Mochtar, I. B. (2021). *The Phenomena of Cracked Soil*. Institut Teknologi Sepuluh Nopember.
[10] NAVFAC DM-7. (1971). *Design Manual - Soil Mechanics, Foundations, and Earth Structures*. U.S Naval Publications and Forms Center.
[11] Satrya, T. R., Soemitro, R. A. A., Maulana, M. A., & Soetanto, R. (2019). "Assessment of Infrastructure Assets InducedbyWaterLevel Fluctuation along the Bengawan Solo River". *Journal of Infrastructure and Facility Asset Management.* Vol. 1, No. 2, Hal.: 105. Surabaya.
[12] Seftian, E., Sumampouw, R. J. E. R., & Balamba, S. (2015). "Analisis Daya Dukung Tiang Pancang Dengan Menggunakan Metode Statik dan Calendring Studi Kasus : Proyek Pembangunan Manado Town Square 3". *Jurnal Sipil Statik*, 3(9), 631–643. Manado.
[13] Shoffiana, Nur A., Lastiasih, Yudhi., & Satrya, Trihanyndio R. (2022). "Comparison of Embankment Reinforcement Requirements with Geotextile on Soft Soil with 2D and 3D Slope Stability Analysis Methods". *Journal of Infrastructure and Facility Asset Management.* Vol. 4, No. 2, Hal.: 65-78. Surabaya.
[14] SNI 2847. (2013). *Persyaratan Beton Struktural Untuk Bangunan Gedung*. www.bsn.go.id
[15] SNI 8460. (2017). *Persyaratan Perancangan Geoteknik*. www.bsn.go.id
[16] Soemitro, R. A. A., & Suprayitno, H. (2019). "Preliminary Reflection on Basic Problematics of National Public Infrastructure Financing in Indonesia". *Journal of Infrastructure and Facility Asset Management.* Vol. 2, No. 1, Hal.: 51. Surabaya.
[17] Suprayitno, H., Soemitro, R. A. A., Maulana, M. A., & Hesna, Yervi. (2020). "Preliminary Reflection on Performance Indicator and Performance Factor for Infrastructure Asset Management". *Journal of Infrastructure and Facility Asset Management.* Vol. 2, No. 1, Hal.: 35. Surabaya.
[18] Tarigan, B. A. C., Mochtar, I. B., & Arif, M. (2020). "Rekomendasi Solusi untuk Mengatasi Kelongsoran pada Lereng Jalan Akses PLTA Musi (KM 5 dan KM 8) dengan Pendekatan Cracked Soil". *Jurnal Teknik ITS*, 9(2), 265–271. Surabaya.