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Protection of Bah Bolon River Cliffs with Geosynthetic Reinforcement on Segmental Concrete Blocks – A Comprehensive Analysis

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Abstract:- Riverbed erosion causes landslides and erosion of riverbanks. Landslides that occur on riverbanks are one type of landslide caused by the rapid flow of the river. Retaining wall construction can be built to protect riverbanks from erosion and maintain soil stability. Therefore, the purpose of this study is to plan a riverbank retaining wall that maintains internal and external stability. The method used designing a retaining wall from segmental concrete blocks with geosynthetic reinforcement based on soil data, cliff height, and cliff slope at the riverbank location. This study was conducted in the Bah Bolon River, Simalungun Regency, North Sumatra Province from March 2021 to July 2021. The safety factor of the retaining wall was analyzed, both for internal and external stability. The results of the analysis revealed that the value of the soil friction angle is an important soil parameter in determining the design of retaining walls. The wall safety factor value increases along with the rise of the soil friction angle value. It was determined that Geosynthetic reinforcement is more economical while retaining walls are more stable on soils with higher friction angle values.

Keywords: Geosynthetic Reinforcement1, Retaining Wall2, River Bank3, Segmental Concrete4, Stability5.

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1. Introduction

Rivers are natural channels that can be used to channel water (Mukhriansyah, 2018). Water flowing through rivers can cause erosion of the bottom soil and riverbanks. Continuous erosion will form holes in the riverbed and riverbanks.

Riverbanks are prone to landslides due to water erosion on river walls. River flow can cause erosion, which occurs as a result of erosion of riverbanks by strong river currents, especially at river bends. If the rocks that make up the riverbank are not strong, then soil erosion can very easily occur and cause landslides in the long term. Riverbank landslides themselves are one type of landslide caused by river flow.

The process of cliff landslides occurs due to the erosion process at the base of the cliff which causes erosion of the river wall. This landslide can cause land subsidence and increase sediment at the bottom of the river (Earlie et al., 2018). The higher the sediment, the lower the river flow discharge. Therefore, efforts are needed to increase public awareness and participation in river conservation (Sianturi et al., 2019).

Landslides are a type of land movement that disrupts slope stability and causes other natural disasters (Sianturi, 2014). Landslides occur due to driving factors and triggering factors. Driving factors are factors that affect the condition of the material itself while triggering factors are factors that cause the movement of the soil. Generally, factors that trigger and cause landslides on river cliffs are river water level, riverbed slope, river flow discharge, type of riverbed grains, and river wet cross-section.

Disrupted river flow impacted the distribution of clean water for community needs (Raihan et al., 2023). Riverbank landslides can be prevented with ripraps, gabions, concrete retaining walls, and another retaining wall blockage. Better river management is needed to increase the need for clean water and the welfare of the community (Sianturi et al., 2022).

Wall construction is a slope reinforcement built to protect river banks from erosion and maintain soil stability against rolling and sliding. However, increasing rainfall in river basins potentially collapses the river banks (Sukatja et al., 2021). Conventional retaining walls in the form of gravity walls or cantilever walls made of concrete masonry are considered to retain the river banks. Retaining walls was a paramount construction in civil works that affected other works. Retaining walls were structures designed to withstand lateral pressure (Ishak, 2018). The reinforced soil with steel strip reinforcement or geosynthetic sheets was generally used. These grids can be bamboo grids that have been proven to have a good impact on soil reinforcement (Waruwu et al., 2018, Waruwu, et al., 2019; Waruwu, 2020). Vertical reinforcement can use a concrete glued plate system and bamboo poles (Waruwu et al., 2016; Waruwu et al., 2020; Maulana et al., 2019).

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The construction of retaining walls consists of layers of compacted embankment with a facing made of high-accuracy precast concrete reinforced with belts or friction ties. This construction is called Geoforce Segmental Retaining Wall (GSRW). Well-designed and maintained retaining walls can prevent erosion on cliffs and riverbeds during rain. Thus, the impact of natural disasters such as floods and landslides in residential areas can be prevented (Rosihun & Endaryanta, 2011).

Types of retaining wall construction can be gravity walls, semi-gravity, cantilever, counterfort walls, and reinforced soil walls or reinforced soil walls. River bank retainers can be in the form of gabions to regulate the direction of river currents, reduce flow speed, and secure river banks (Benyamin et al., 2017). However, for retaining walls, reinforced soil walls use geosynthetic materials or metal materials. Segmental concrete block walls are reinforced with geosynthetic reinforcements consisting of segmental soil retaining wall concrete blocks and geosynthetic reinforcements (Sholeh, 2016).

The safety factor without reinforcement is between 1.2 and 1.4, while the safety factor against overturning force with reinforcement is around 3.5 (Mina et al., 2019). The safety factor of the soil retaining stability is influenced by the soil retaining. Thus, the safety factor value depends on certain conditions.

Gravity-type retaining walls provide a high safety factor against overturning and bearing capacity because they have significant weight and an adequate base width. The safety condition for cliff design is satisfactory for cuts and embankments if the safety factor is 1.3 to 1.4, while a safety factor of 1.5 to 1.7 produces a steady cliff from the slope of the dam body (Yuliana et al., 2018).

The research location is the Simalungun area because Pema tang Sinatra and several locations in Simalungun often experience landslides due to the high rainfall intensity in this area (Sianturi et al., 2018). The purpose of this study is to conduct soil testing on river banks, plan soil retaining structures, and analyses safety factors for internal stability, both tensile and shear resistance, and external stability on river banks, especially against sliding and overturning.

2. Methods

The research material was taken from the location of the Bah Bolon River cliff in Simalungun Regency, North Sumatra Province. The Bah Bolon River watershed (DAS) passes through cities and plantation areas in the Simalungun area. Rapid development has triggered increased erosion and sediment, reducing infiltration. This can affect the morphology of the Bah Bolon River as seen in Figure 1. a and the embankment plan as seen in Figure 1b.

The analysed river cliff is shown in Figure 2a. The reinforced soil segmental retaining wall with segmental elements reinforced with geosynthetics is shown in Figure 2b.

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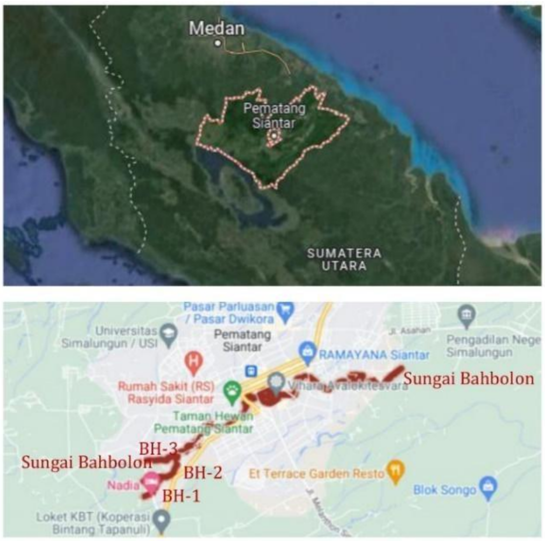
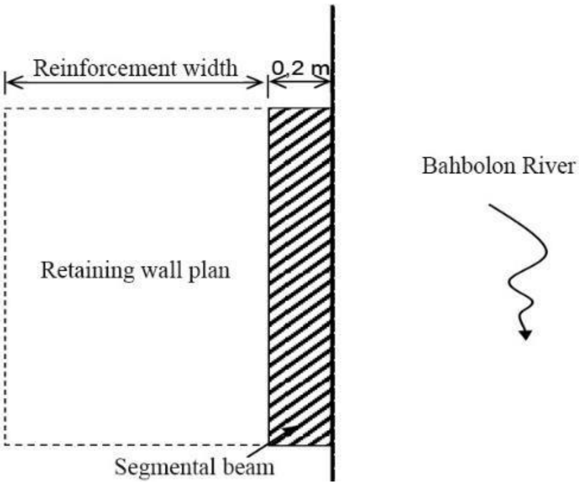
Soil samples were taken at 3 points representing the condition of the cliff in terms of height and slope, consisting of points BH-1, BH-2, and BH-3 as shown in Figure 1a. Disturbed and undisturbed samples were taken from each borehole at a depth interval of 22.5 m. Soil samples were taken from each point to be tested in the Soil Mechanics Laboratory of Simalungun University. Physical properties are known through density, water content, Atterberg limit, sieve analysis, and hydrometer tests, while technical properties are known through shear strength tests. The soil shear strength test was determined using a CD-type direct shear tester. Soil data was obtained from the direct shear test results including cohesion (c') and soil friction angle (ϕ'). This test is relevant to the soil parameters used in the analysis of retaining walls.





(a) (b)

Figure 1: (a) Bahbolon river watershed (b) Retaining wall plan

Figure 2:(a) River Cliff Shape at Research Location (b) Segmental retaining wall reinforced with segmental elements with geosynthetic reinforcement.

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Soil sample testing for each test point is one tube. The number of test objects consists of 3 soil samples tested with a series of tests in the laboratory.

Bor hole test points (BH-1, BH-2, and BH-3) as shown in Figure 1.a. Each drill hole takes undisturbed samples in 1 sample tube. Based on this test, an analysis of the results is carried out to obtain the soil parameters required for the stability analysis of the planned retaining wall.

The research stages start with site observation, cliff measurement, taking disturbed and undisturbed soil samples, soil sample testing, then continued with soil retaining design, and stability analysis. The complete research procedure can be seen in the research flow diagram as shown in Figure 3.

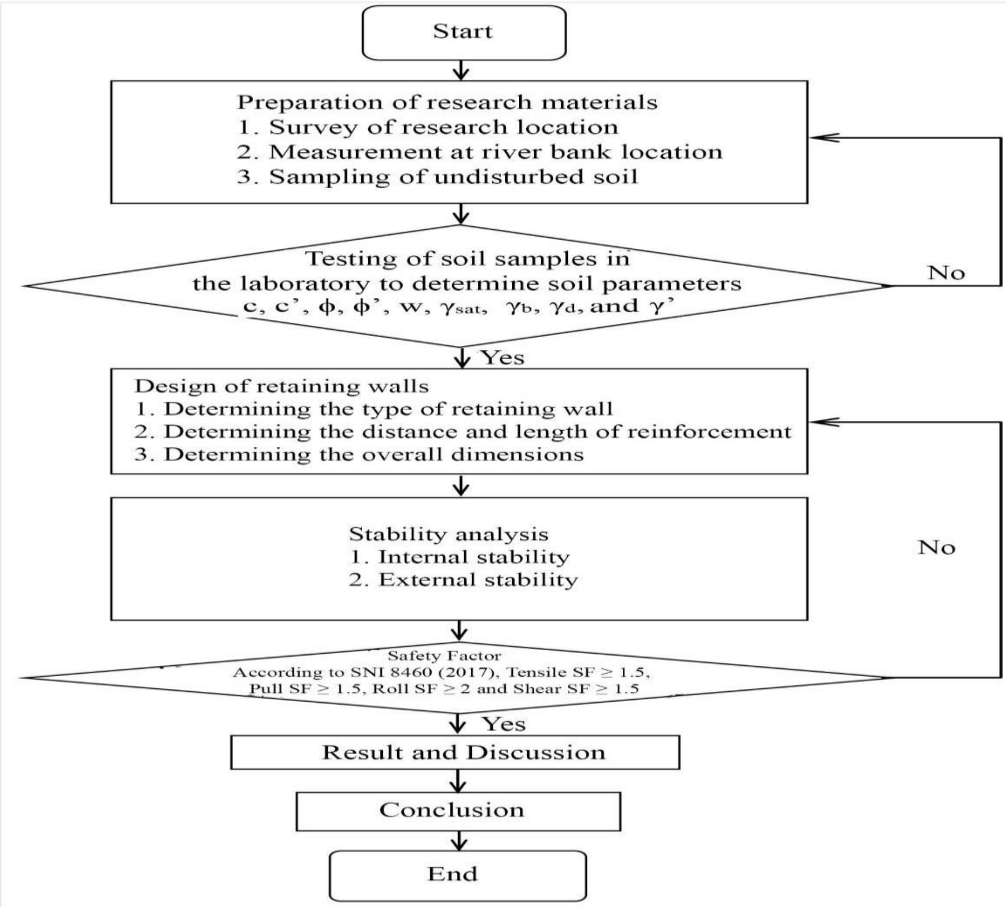

Figure 3: Preparation of research materials

2.1.Lateral Earth Pressure

Lateral pressure is distinguished based on the condition of the soil around the construction, namely active lateral earth pressure, passive lateral earth pressure, and still earth pressure. The lateral pressure value is the multiplication of vertical pressure by the earth pressure coefficient.

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2.2.Active Lateral Earth Pressure

The active earth pressure coefficient according to Rankine and Coulomb is described in Equation (1) and Equation (3), while the active earth pressure according to Rankine and Coulomb is shown in Equation (2) and Equation (4). Equation (2) occurs in special conditions, where the angle □□ = 0º and α = 90º, using the active lateral pressure coefficient (K_a) from Equation (1). Conversely, if the angles □ and α are taken into account, then Equation (4) uses the K_a value from Equation (3). The Rankine and Coulomb theories can be used to analyze safety factors in the stability analysis of retaining walls for cliff reinforcement.

$= {}^2 45 - {}_2 \ldots\left(\ldots\ldots -\right)\ldots\ldots\ldots\ldots$ (1) $= {}^1{}_2 \ldots \Upsilon . {}^2 + \ldots\ldots\ldots\ldots$ (2)

$c^2(□-□)$

$$= \frac{}{c \quad {}^2 .c \quad (□+□)\left[1+\sqrt{\frac{\sin(\ +\ ).\sin(\ -\ )^2}{\cos(□+□).\cos(□-\ )}}\right]} \ldots\ldots\ldots \quad (3)$$

$= \quad {}^1{}_2 \ldots \Upsilon . {}^2 \ldots\ldots\ldots\ldots\ldots\ldots$ (4)

Where:

Ka = Active lateral pressure coefficient

Pa = Active lateral earth pressure

□ = Angle of friction in the soil

□ = Bulk weight of the soil

2.3.Passive Lateral Earth Pressure

The passive lateral earth pressure coefficient according to Rankine and Coulomb is described in Equation (6) and Equation (7), while the passive lateral earth pressure according to Rankine and Coulomb is shown in Equation (6) and Equation (8). Equation (6) occurs in special conditions, where the angle □□ = 0º and α = 90º, using the sand lateral pressure coefficient (Kp) from Equation (5). If taking into account the angles □ and α, then Equation (8) uses the Ka value from Equation (7).

$= {}^2 \quad \left(45 - \frac{}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots$ (5)

$= \quad {}^1{}_2 \ldots \Upsilon . {}^2 + \ldots\ldots\ldots\ldots\ldots$ (6)

$c^2(□+□)$

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$$= \frac{c \quad ^{2}.c \quad (\square + \square)}{\left[1 + \sqrt{\frac{\sin(\ -\ ).\sin(\ +\ )^{2}}{\cos(\square - \square).\cos(\square -\ )}}\right]} \ldots\ldots\ldots (7)$$

$$= \ \frac{1}{2} . . \Upsilon . ^{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where:

Kp = Passive lateral pressure coefficient

Pp = Passive lateral earth pressure

□ = Angle of friction in the soil

□ = Bulk weight of the soil

2.3.1. Internal Stability

Internal stability is related to the reinforcement dimensions of the planned soil retaining wall. The internal stability review consists of a review of the tensile force and the pullout force of the reinforcement or reinforcement.

2.3.2. Review of Tensile Force

Tensile force requires active earth pressure coefficient parameters according to Rankine and Coulomb that can be calculated from Equation (1) and Equation (3). Tensile force (T) can be calculated using Equation (9) and the safety factor for tensile force as in Equation (10), where the thickness of the segmental beam (z) and the width of the horizontal beam (b), as shown in Figure 4.

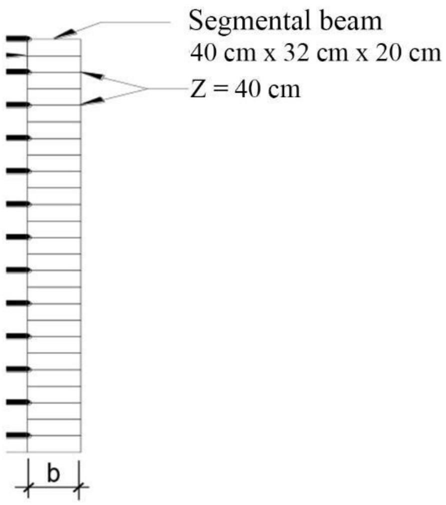

Figure 4: Segmental Beam

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= 12_ . . ϒ. 2. ………………………………… (8)

Where:

T = Tensile force

Ka = Active lateral pressure coefficient

□ = Soil unit weight H = Pressure head b = Horizontal beam width

S= ______ ………………………………….. (10)

...d

Where:

SF = Safety factor

Ka = Active lateral pressure coefficient

T = Tensile force

□ = Internal friction angle of soil

□ = Soil unit weight

2.4.Review of Reinforcement Pullout Force

The active lateral earth pressure coefficient used in the calculation of pullout force according to Rankine and Coulomb is described in Equation (1) and Equation (3). The mechanism of reinforcement pullout force can be seen in Figure 5. The resistance force (DFR) can be found using Equation (11). Where Lo = overlap thickness (m), □$□_f$= material shear coefficient with material = tan ϕ, $□_s$ = material shear coefficient with soil = tan □, and the maximum force (DF_{max}) as in Equation (12). The value of ϕ is approximated from the soil shear angle from the shear strength test results, while the value of □ is determined from the shear angle between the wall and the soil (in practice it is usually taken = 1/3 ϕ). The safety factor against reinforcement pullout force is found using Equation (13).

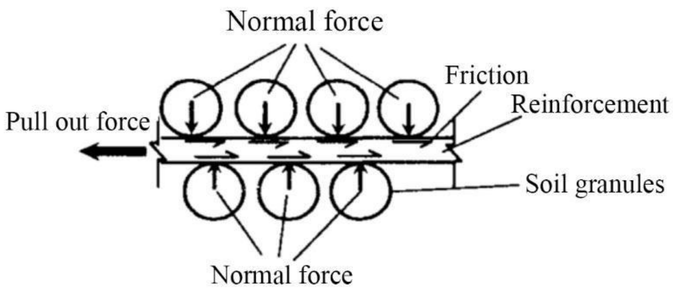

Figure 5: Reinforcement Pullout Mechanism

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$S = {}_0 . . (- d). (+)$ .... (11)

$S = . . . d$ .... (12)

$S =$ —— .... (13)

S

Where:

SF = Safety factor

DF_R = Resistance force

DF_{max} = Maximum force

Lo = Overlap thickness

H = Pressure head

□ = Soil unit weight

$□_F$ = Material shear coefficient with material

$□_S$ = Material shear coefficient with soil

2.4.1. External Stability

The external stability reviewed in this study is limited to the effects of external forces that cause overturning and sliding. According to Hulagabali et al. (2024), the minimum safety factor for each retaining wall is a minimum of 2 for the safety factor against overturning and a minimum of 1.5 for the safety factor against lateral sliding. Active lateral earth pressure (Pa) is calculated using Equation (2) for the Rankine method and Equation (4) for the Coulomb method. The safety factor against overturning hazards is greater than 2. Overturning stability is determined based on the comparison of the passive moment (MR) with an active moment at 1/3 of the retaining height (MD). Gravity and passive moment can be determined using Figure 6.

$1. 1 + 2. 2 + ss + .si.$

$S = \frac{\qquad}{\quad . \quad / \quad ci. \; 3}$

Where:

SF = Safety factor W = Gravity x = Horizontal distance Pa = Active lateral earth pressure H = Pressure head.

The active lateral earth pressure (Pa) used in the analysis of the safety factor against shear force is the same as that used in the analysis of the safety factor against overturning force. The safety

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factor against shear hazard is greater than 1.5. Shear stability is determined based on the comparison of passive force (FR) with active force (FD).

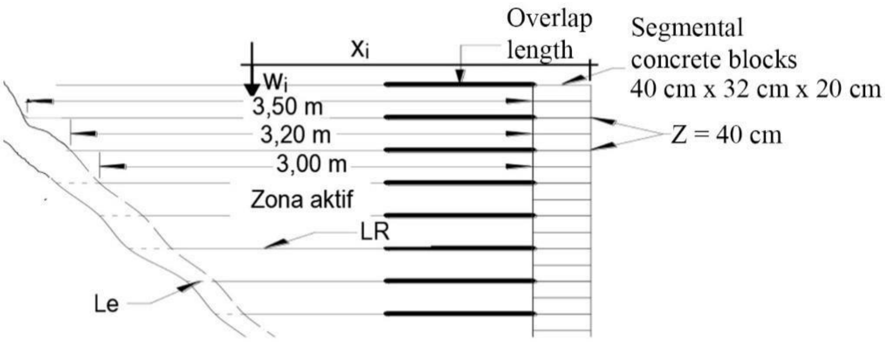

Figure 6: Sketch of retaining wall

+12+ss[+.si . tan]

S= .ci ………… (15)

Where:

SF = Safety factor W = Gravity x = Horizontal distance Pa = Active lateral earth pressure H = Pressure head.

3. Results and Discussion

The discussion in this study is limited to the results of the analysis carried out based on Equations 1 to Equation 15. The discussion was also unrelated to the analysis using certain software. The analysis results of soil retaining on river banks were carried out in 3 (three) stages, including analysis of lateral earth pressure, internal stability, and external stability for each retaining wall design point at locations BH-1, BH-2, and BH-3. The analysis of lateral earth pressure is intended to obtain the coefficient value in a stationary state (Ko), the active lateral earth pressure coefficient (Ka), and the passive lateral earth pressure coefficient (Kp) as seen in Equation (1), Equation (3), Equation (5), and Equation (7).

Details can be figured out in related reference books.

These coefficients are obtained using the Rankine method and the Coulomb method. Based on this coefficient, the lateral earth pressure is obtained in active and passive states. Internal stability analysis assumes the use of Rankine and Coulomb failure planes. The safety factor for internal stability reviewed is the safety factor against tensile force and reinforcement pullout

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force. External stability analysis or also called global stability analysis. This analysis is carried out to check for overturning and sliding hazards.

These coefficients are obtained using the Rankine method and the Coulomb method. Based on this coefficient, the lateral earth pressure is obtained in active and passive states. Internal stability analysis assumes the use of Rankine and Coulomb failure planes. The safety factor for internal stability reviewed is the safety factor against tensile force and reinforcement pullout force. External stability analysis or also called global stability analysis. This analysis is carried out to check for overturning and sliding hazards.

The soil data from the laboratory test results and the soil retaining design data to be analysed are shown in Table 2. Point 1 is planned at location BH-1, point 2 is planned at location BH-2, and point 3 is planned at location BH-3 (Figure 1). The soil retaining from segmental concrete blocks with geosynthetic reinforcement is planned at three points at the research location. This is distinguished based on the height of the river bank and soil data.

3.1.Safety Factor Against Tensile Force

The safety factor against tensile force is analysed using Equation (10). The results of the analysis can be seen in Table 1. The safety factor against the tensile force from the Rankine and Coulomb methods does not provide significant differences. The safety factor appears to be influenced by the value of the internal friction angle of the soil. A higher internal friction angle value indicates a better safety factor.

Table 1: Safety Factors against Tensile Forces

Height (m)	Share angle (□)	Safety factor	
		Rankine	Coulomb
5	9.72	2.00	2.00
5.7	14.00	2.28	2.28
6	26.50	2.399	2.40

Source: Prepared by the author (2024)

Example of calculating the safety factor against tensile force at slope height H = 6 m, horizontal beam width b = 0.32 m, Rankine method Ka = 0.383, and soil volume weight (γ) = 19.16 kN/m^3.

T Rankine = ¹2_ . ².

$= \frac{1}{2} . 0.383 \;\; 19.16 \;\; 6^2 \;\; 0.32$

= 42.25 kN

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SF Rankine = ________

...d

=

0.383 $\frac{42.25}{x\ 19.16\ x\ 6\ x\ 0.40}$

$= \frac{42.25}{17{,}61}$

= 2.399 > 1.5

Table 2: Soil Data and Soil Retaining Parameters

Parameter	Units	Location of Retaining Walls		
		Location 1	Location 2	Location 3
Soil density, □	t/m^3	2.163	1.947	1.983
Cohesion, c	Kg/cm^2	0.320	0.267	0.267
Shear angle, □	o	9.72	14.00	26.50
River cliff height, H	m	5	5.7	6
The friction angle between the ground and the wall, □	o	6.18	9.33	17.67
The slope of the fill surface, □	o	0	0	0
Landslide angle to horizontal, α	o	26.56	26.56	26.56
The slope of the wall face to the horizontal, □	o	1.80	1.80	1.80
Segmental wall stack inclination angle, □	o	90	90	90

Source: Prepared by the author (2024)

The relationship between the height of the river bank and the safety factor against the tensile force is shown in Figure 7. The safety factors calculated from the two methods appear to be almost the same as each other. It showed that the parameters required to determine the tensile force between the two methods are not much different from each other. The safety factor that increases with the cliff height shows a linear relationship. The cliff height is the same as the height of the retaining wall.

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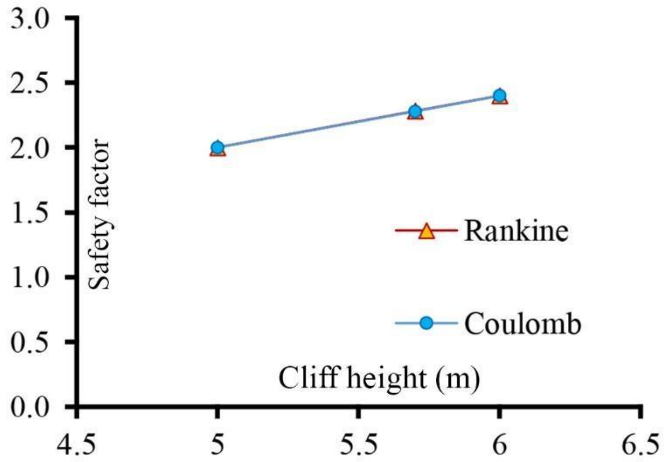

Figure 7: Safety factor against tensile force based on cliff height

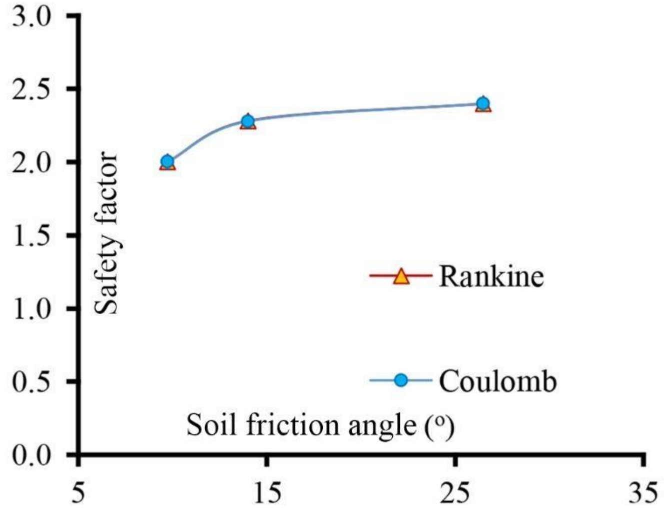

Figure 8: Safety Factor against Tensile Force Based on Soil Friction Angle

3.2.Safety Factor Against Reinforcement Pullout Force

The safety factor against reinforcement pullout force was calculated using Equation (13). The results of the analysis at each point are shown in Table 3. The safety factor shows a higher value at high soil friction angles. The safety factor using the active lateral soil coefficient from the Rankine method is slightly higher than the Coulomb method.

Table 3: Safety Factors against Reinforcement Pullout Forces

Height (m)	Share angle (□)	Safety factor	
		Rankine	Coulomb

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5	9.72	2.26	1.91
5.7	14.00	3.90	3.47
6	26.50	4.99	4.19

Source: Prepared by the author (2024)

The relationship between the height of the cliff and the safety factor against the pullout force of the reinforcement is shown in Figure 9. The height of the retaining wall follows the height of the river cliff. In general, the total height of the retaining wall from the base to the top is higher than the height of the river cliff because some of the retaining wall construction is embedded in the river bank to a depth lower than the elevation of the eroded river bed. This condition needs to be considered. The safety factor increases with the height of the retaining wall. The higher the cliffs, the higher soil shear angle value is also obtained.

When viewed from the value of the shear angle factor, other factors that can affect the safety factor can still be reviewed from the groundwater level, cohesion value, and permeability value of the material that affects the stability of the retaining wall. This is seen in the relationship between the soil shear angle and the safety factor against the pullout force of the reinforcement in Figure 10. An increase in the shear angle value from 9.72^o to 14^o shows a significant increase in the safety factor and a slight increase at a shear angle of 26.50^o. The shear strength parameters used in this analysis consist of the soil shear angle value and the cohesion value.

One example of calculating the safety factor for reinforcement pullout forces at slope height H = 6 m, horizontal beam width b = 0.32 m, Ka Rankine method = 0.383, Ka Coulomb method = 0.870, and soil volume weight (γ) = 19.16 kN/m^3.

3.2.1. DFR resistance style

$$= L_o . \gamma . (H - dz) . (\mu_F + \mu_S)$$
$$= 1 \times 19{,}16 \times (6 - 0{,}40) \times (0{,}50 + 0{,}32)$$
$$= 87{,}98 \text{ kN/m}$$

Maximum force on the bottom at depth Z = H

DFmax Rankine

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$$= K_a.\gamma.H.dz$$
$$= 0{,}383 \times 19{,}16 \times 6 \times 0{,}40$$
$$= 17{,}61\ \text{kN/m}$$

$$\text{SF Rankine} = \frac{DF_R}{DF_{max}} = \frac{87{,}98}{17{,}61} = 4{,}99 > 1{,}5$$

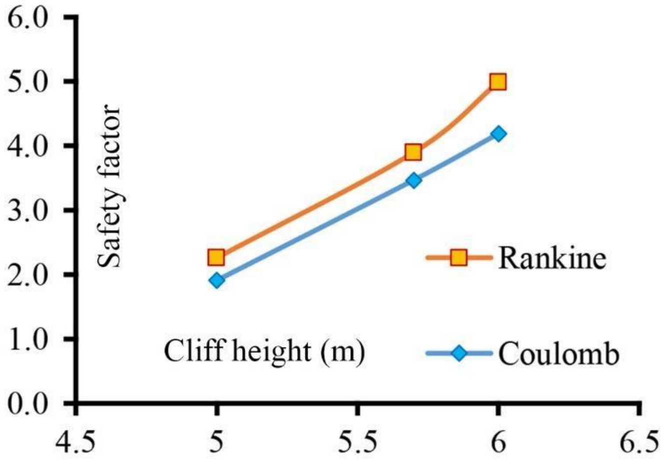

Figure 9: Safety Factor against Reinforcement Pullout Force Based on Cliff Height

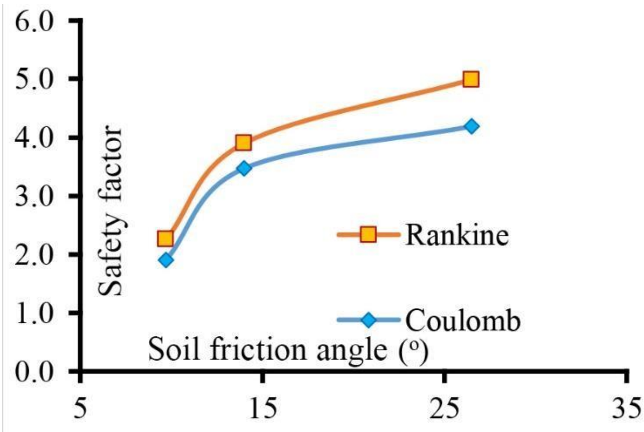

Figure 10: Safety Factor Against Reinforcement Pullout Force Based on Soil Friction Angle

3.3.Safety Factor Against Overturning

Analysis of safety factor against overturning using Equation (14). The complete analysis results are described in Table 4. The safety factors of the two methods do not seem much different from each other. The height of the safety factor is influenced by the value of the soil friction angle.

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3.3.1. Rankine

One example of calculating the safety factor against overturning force at a slope height of H = 6 m, horizontal beam width b = 0.32 m, Ka Rankine method = 0.383, Ka Coulomb method = 0.870, and soil volume weight (γ) = 19.16 kN/m³. Example of safety factor for Rankine method.

$S = \frac{}{} > 2$

Viewed 1/3 of the total length of 3.8 m

$$S = \frac{1 \cdot 1 + 2 \cdot 2 + ss + .s}{.\cos . /3}$$

$$= \frac{(1.95 \quad 6 \quad 2.5 \quad 1.25) + (1.95 \quad 4 \quad 1.3 \quad 3.15) + 4.6 + 15.76 \quad 0.30 \quad 3.8)}{15.76 \quad 0.95 \quad 6/3}$$

$$= \frac{36.56 + 31.94 + 4.6 + 17.96}{29.94}$$

= 3.00 > 2

Table 4: Safety Factors against Overturning Forces

Height (m)	Share angle (□)	Safety factor	
		Rankine	Coulomb
5	9.72	3.00	2.80
5.7	14.00	3.70	3.90
6	26.50	4.00	3.85

Source: Prepared by the author (2024)

The relationship between the height of the river bank and the safety factor against overturning is shown in Figure 11. Similar to the safety factor against tensile force and reinforcement pullout force, the safety factor against overturning shows a linear relationship when viewed against the height of the bank. The safety factor determined based on the active lateral soil coefficient of the Rankine method is not much different from the Coulomb method. When viewed from the difference shear angle, it was seen that the safety factor is higher at a shear angle value of 14o, while at a shear angle value of 26.50o, there is no significant change in the safety factor (Figure 12). It shows that the safety factor against overturning increases significantly at shear angle values up to 14o. The increase in shear angle above 14o is not significant because of the influence of the height of the retaining wall that causes the overturning force to increase and the safety factor to decrease.

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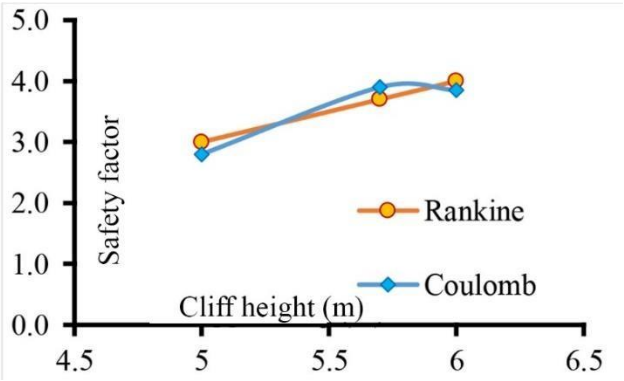

Figure 11: Safety Factor against Overturning Based on Cliff Height

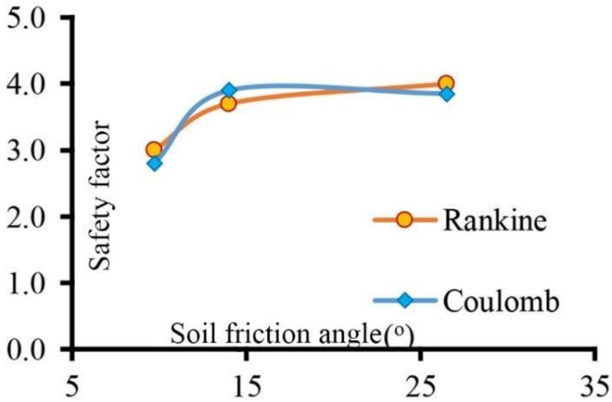

Figure 12: Safety Factor against Overturning Based on Soil Friction Angle

3.4.Safety Factor Against Shear

The value of the safety factor against shear is calculated using Equation (15). The results of the analysis shown in Table 5 are the results of the analysis under safety conditions. The reinforcement length of 8.3 m for a retaining wall with a height of 5 m has safety factors against shear forces of 1.49 for Rankine and 1.50 for Coulomb, respectively. A retaining wall with a height of 5.7 m requires a reinforcement length of 7.7 m to achieve a safety factor above 1.5, while a retaining wall with a height of 6 m requires a reinforcement length of 6 m. It shows that the friction angle value affects the design of the soil retainer.

Table 5: Safety Factors against Shear Forces

Height (m)	Share angle (□)	Safety factor	
		Rankine	Coulomb
5	9.72	1.49	1.50
5.7	14.00	1.60	1.70

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6	26.50	2.90	3.00

Source: Prepared by the author (2024)

The relationship between the cliff height and the safety factor against shear force appears different from other reviews (Figure 13). The safety factor against shear force shows a non-linear relationship with the cliff height.

The height of the planned retaining wall is the same as the height of the cliff. The higher the retaining wall, the higher the gravity, so the resistance force against shear is higher. It resulted in a higher safety factor on high retaining walls. The safety factor against shear is closely related to the value of the friction angle in the soil. The increase in the safety factor against shear has a linear relationship with the value of the friction angle in the soil (Figure 14).

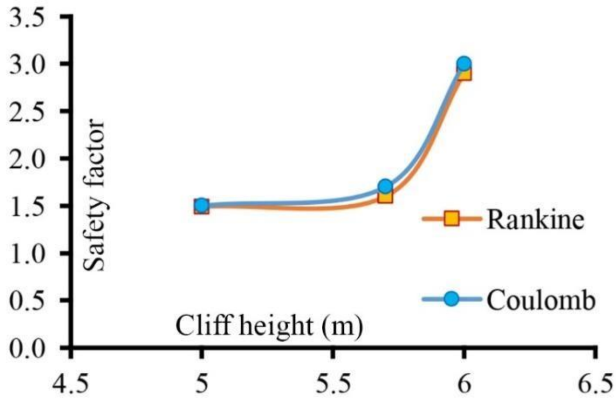

Figure 13: Safety Factor against Shear Based on Cliff Height

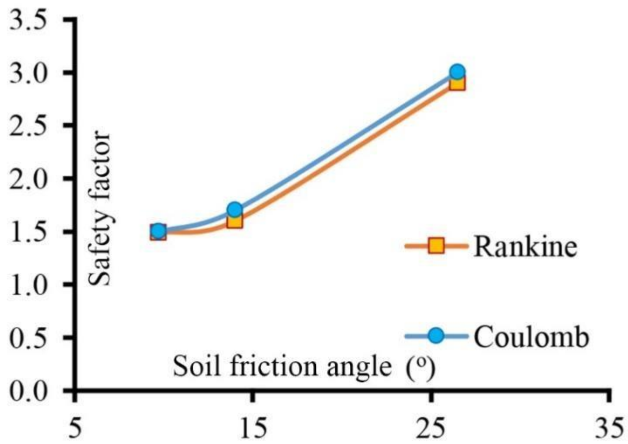

Figure 14: Safety Factor against Shear Based on Soil Shear Angle

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3.5.Retaining Wall Design Results

The results of the retaining wall design that meets the safety requirements can maintain the stability of the river bank. A retaining wall is said to be safe if the safety factor is above 1.5 for shear force and above 2 for overturning force. The retaining wall height must be proportional and easy to apply to the foot of the cliff (Hamidi & Sadisun, 2021). The design of retaining walls on river cliffs is carried out at 3 points that are distinguished based on the height of the cliff and the slope of the slope.

The results of the retaining wall design that meets the safety requirements at point one with a retaining height of 5 m are shown in Figure 15. The safe reinforcement length is 8.3 m with a distance between layers of 0.4 m. Figure 16 shows the results of the retaining wall design at point two with a retaining height of 5.7 m, the length of reinforcement that meets the safety requirements is 7.7 m, and the distance between layers is 0.4 m.

The cross-section of the retaining wall at point three is shown in Figure 17. A safe and qualified retaining design is obtained at a retaining wall height of 6 m, a reinforcement length of 6 m, and a distance between reinforcement layers of 0.4 m.

The retaining wall was designed from a segmental concrete block and reinforced with geosynthetic reinforcements. The segmental concrete blocks measure 40 cm × 32 cm × 20 cm. Reinforcement or reinforcement from geosynthetic materials is designed with a

spacing of 40 cm. The length of the reinforcement is adjusted to the planning results influenced by the height of the cliff, the slope, and the value of the soil friction angle. Geosynthetic reinforcement is obtained longer at lower soil friction angle values.

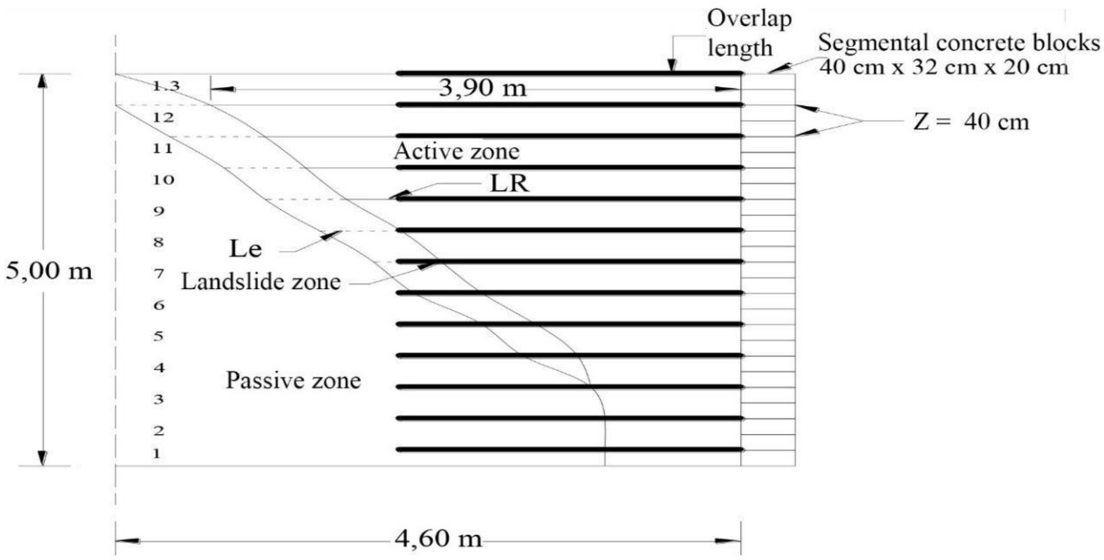

Figure 15: Results of Soil Retaining Design at Point 1

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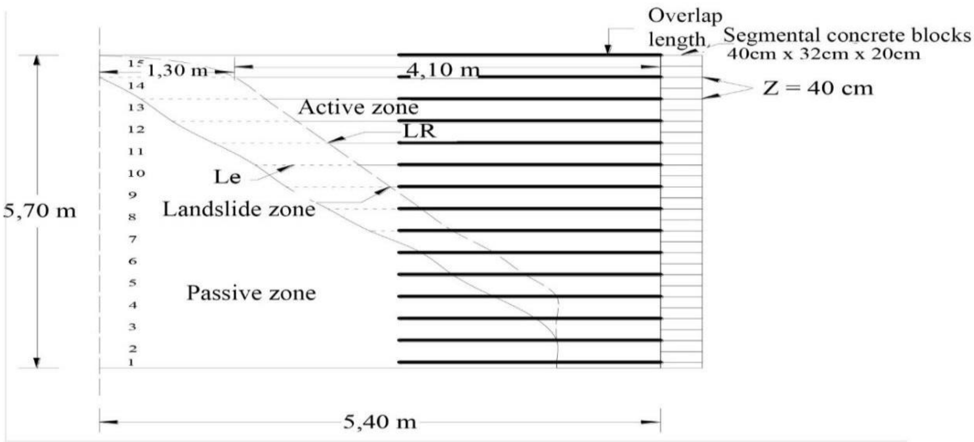

Figure 16: Results of Soil Retaining Design at Point 2

In addition to the retaining wall model used in this study, several other types of retaining walls impact the stability of river banks. Gravity retaining walls showed a good performance depending on the wall itself (Sari et al., 2020). Retaining wall modeling can use retained flexible barriers that adjust to field conditions and rise according to the cliff height.

Retaining walls can be designed with cantilever walls and sheet piles as a method of river bank strength. It has been applied to rivers in Balangan Regency, South Kalimantan Province (Widhiasari & Prasetia, 2018).

The results of the retaining wall design obtained are retaining walls that are stable against the dangers of overturning and sliding. Amran and Kurniawan (2017) argue that retaining walls are safe against overturning and sliding if the safety factor obtained is > 1.5 (Saad et al., 2023).

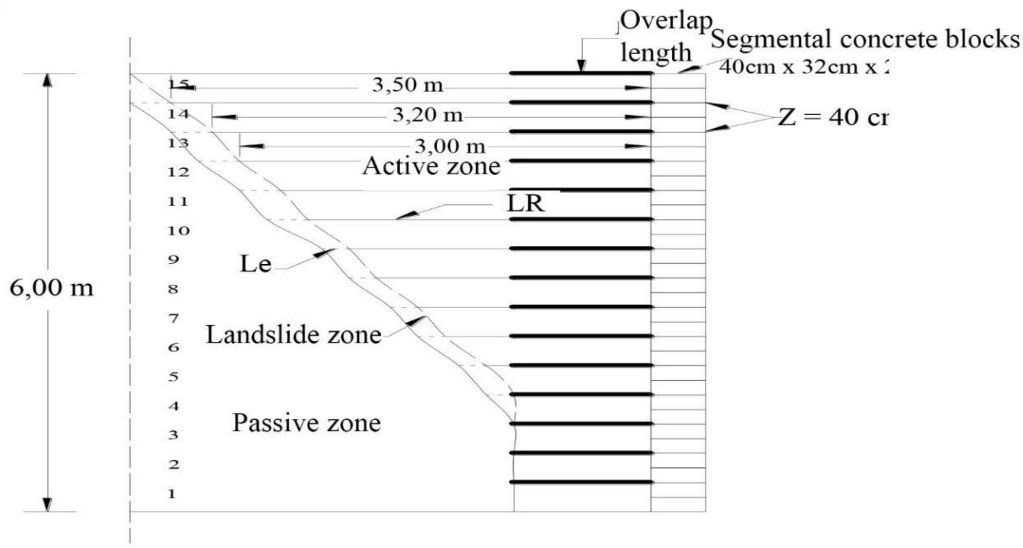

Figure 17: Results of Soil Retaining Design at Point 3

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Stable riverbank retaining walls can anticipate soil erosion along riverbanks. Retaining walls alone are not good enough to anticipate erosion of the riverbed and banks (Sianturi et al., 2021). Therefore, it is better to use the combination of a retaining wall (if the cliff is relatively low <8 meters and sheet piles if the cliff is> 8m), then combine with current directors or groins. It aimed to prevent debris flow and control sediment on the riverbed. Thus, it was useful for disaster management. Retaining walls that are safe from shifting, overturning, and collapse of soil-bearing capacity can contribute to flood control (Sianturi et al., 2022).

4. Conclusion

The soil test required to determine soil parameters can use a direct shear test or triaxial test. The soil fills behind the retaining wall is assumed to be in a drained condition. Thus, it is more relevant to use the results of a direct shear test.

Based on this test, the friction angle values are different from each other. The friction angle value in this study is high on the lower river bank. The soil friction angle value is crucial in designing retaining walls. Other parameters that are no less important are the cohesion value and the effect of the magnitude of pore water pressure due to the presence of water level, either due to M.A.T, the influence of rain, or fluctuations in river water level.

The design of the retaining wall adjusts to the height of the river bank and the slope of the slope. The retaining wall used in this study is a soil retainer made of segmental concrete blocks reinforced with geosynthetic reinforcement. The length of the geosynthetic reinforcement is influenced by the height of the bank, the slope, and the soil friction angle value. The value of the soil friction angle more dominantly affects the length of the geosynthetic reinforcement. A lower soil friction angle shows longer geosynthetic reinforcement. The type of geosynthetic used is a polymeric sheet material with high tensile strength. The front ends of these geosynthetic reinforcements are overlapped between the segmental elements.

The overall safety factor is higher on river banks with higher soil friction angle values. Especially in the safety factor against the reinforcement pullout force and shear force, while the safety factor against tensile force and overturning force shows an increase in the value of the friction angle up to 14o.

The safety factor is closely related to the active lateral soil coefficient that can be determined using the Rankine and Coulomb methods. The safety factor using the soil coefficient from the Rankine method is generally higher than the Coulomb method. The Ka value of the Coulomb method is higher than the Ka value of the Rankine method. It affects the higher active lateral force that lowers the safety factor.

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