

## RECOMMENDATIONS FOR APPROPRIATE DESIGN FOR HANDLING LANDSLIDES ON THE SLOPES OF THE BALAI RIVER (SEI BALAI), BATUBARA REGENCY

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### ABSTRACT

The Sei Balai River, located in the Nibung Hangu/Tanjung Tiram District of Batu Bara Regency, is part of the Bah Bolon River Area and has faced multiple flooding incidents that have led to significant landslides along its banks. A particularly critical area is Lima Beras Village, where the integrity of the riverbanks is jeopardized; if not addressed promptly, this deterioration could disrupt access roads vital for the mobilization of agricultural and plantation products. Geotechnical investigations reveal that the Bearing Capacity Value of the Shallow Foundation Permit from the qc Data showed a capacity of 3.8 Ton/m<sup>2</sup> at a depth of 5 meters (Test No. S-1) and 4.53 Ton/m<sup>2</sup> at the same depth (Test No. S-2). Given the soft soil conditions, gabion construction is proposed for the river slope stabilization. Gabions offer several advantages: they provide erosion resistance, filled with medium to large stones within steel wire mesh, effectively mitigating soil erosion caused by river currents. Additionally, they enhance the stability of river slopes, counteracting both vertical and horizontal soil movements, particularly in areas with high plasticity clay that are prone to landslides. Gabions also absorb live loads and soil movements, alleviating pressure on the slope and reinforcing its base. Moreover, their design allows water to flow through, reducing excessive erosion while maintaining slope integrity. These attributes make gabions an effective solution for managing the Sei Balai River's bank stability.

**Keywords:** *River Slope Design, Gabions, Landslide.*

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### INTRODUCTION

Rivers as a system that is a single ecological system that is vulnerable to environmental changes. The description of the ecological system of a particular river basin can be read from the condition of the river itself. Many parameters as environmental balance can be read from river parameters, such as the comparison of maximum discharge with minimum discharge, the amount of sediment transport, aggradation, degradation, aquatic biota, changes in river morphology (width, depth, slope of the bed, meander shape) one of the consequences of the impact of environmental imbalance in rivers can cause damage to cliffs (landslides) in the form of collapse of river cliffs so that it produces a fairly large volume of sediment and is buried at the bottom of the river even in the downstream part of the river (Das, 2019).

The Sei Balai River, precisely in the Nibung Hangu/Tanjung Tiram District, Batu Bara Regency, is one of the rivers in the Bah Bolon River Area (WS). The Sei Balai River has experienced flooding several times and caused landslides on the riverbanks. One of the most critical locations is in Lima Beras Village, Nibung Hangu/Tanjung Tiram District, Batu Bara Regency, which has damaged the riverbanks, which is feared that if not handled early, it may result in the breaking of access roads for the community in the mobilization and demobilization of agricultural and plantation products in the village (Cascini et al., 2010). For this reason, a handling concept is needed that can control the destructive power of water and minimize the occurrence of cliff erosion.

Geotechnical and soil mechanics investigations are one of the supporting elements in the activity of making a building starting from planning activities to implementation activities. This soil investigation aims to determine technical data or soil parameters that can represent local soil conditions for use in project planning (Fell et al., 2008).

In order to meet the planning calculations, a Soil Investigation is carried out in the field and laboratory to obtain soil parameters in the form of cone tip resistance and skin friction from the results of the Sondir Test, then the type and nature of the soil from the Hand Drill Test, as well as the properties index and engineering properties from the results of the Laboratory Test (Broeckx et al., 2020).

Soil investigations have been conducted in the field consisting of Sondir Testing (Sondering Test), Hand Auger Testing (Hand Auger Test) and Laboratory Testing for the Sei Balai Cliff Reinforcement Planning work, Nibung Hangu/Tanjung Tiram District, Batu Bara Regency (Fitra et al., 2021). The results of the work have been compiled and submitted in this work report book.



**Figure 1. Critical Cliff Location**



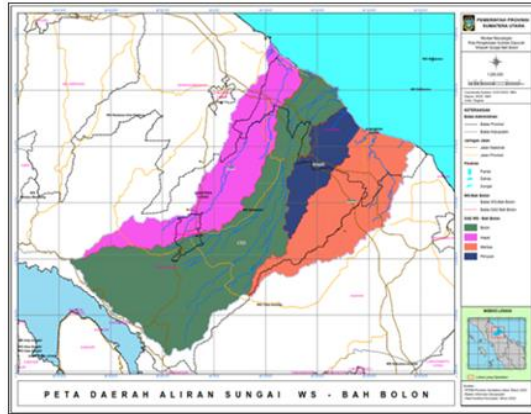
**Figure 2. Inventory of Settlements on Riverbanks**

### **Study Area**

Batu Bara Regency is located between 02o46'00" - 03o25'00" North Latitude and 99o05'00" - 99o39'00" East Longitude. The area of Batu Bara Regency is 3545.8 km<sup>2</sup> with the capital of the regency being Lima Puluh. Administratively, Batu Bara Regency has the following boundaries:

- a. North : Malacca Strait;
- b. East : Asahan Regency and Malacca Strait;
- c. South : Asahan Regency and Simalungun Regency;
- d. West : Serdang Bedagai Regency;

The administrative location of the work is in Lima Laras Village, Nibung Hangu/Tanjung Tiram District in Batu Bara Regency in the North Sumatra Province, which can be reached by land with a distance of ± 110 km with a journey of ± 2 (two) hours from Medan, which can be seen in Figure 2-1 below.

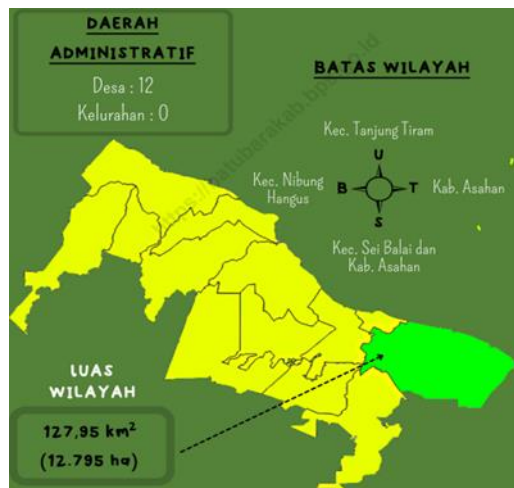


**Figure 1. Peta Lokasi Kegiatan**

Source: Coal in numbers 2023

The location of the Sei Balai River is precisely in the Nibung H Angus/Tanjung Tiram District. The geographical location of the Nibung H Angus/Tanjung Tiram District is at 30 North Latitude and 990 East Longitude. The Nibung H Angus District has an area of 127.95 km<sup>2</sup>, the capital of the district is Ujung Kubu. Administratively, the Sei Balai Hilir District has the following boundaries:

- a. North : Tanjung Tiram District
- b. East : Asahan Regency
- c. South : Sei Balai District and Asahan Regency
- d. West : Nibung H Angus District



**Figure 2. Lokasi Sungai Sei Balai di Kecamatan Nibung/Hangus**

Source: Nibung H Angus District in figures, 2023

### Climate and Rainfall

Like most other areas in North Sumatra, Batu Bara Regency is a tropical climate area. So this area has 2 seasons, namely the dry season and the rainy season. The dry season and the rainy season are usually marked by the number of rainy days and the volume of rainfall in the month of the season. The dry season usually occurs from January to July and the rainy season usually occurs from August to December, between the two seasons there is a transitional season.

Rainfall is the height of rainwater collected in a flat place, does not evaporate, does not absorb and does not flow. Rainfall of 1 (one) mm means that in an area of 1 square meter in a

flat place, 1 mm or 1 liter of water is collected. Rain intensity is the amount of rainfall per unit of time. If it is said that the intensity is large, it means heavy rain and this condition is very dangerous because it can cause flooding, landslides and negative effects on plants.

The highest rainfall in 2022 in Batu Bara Regency occurred in August, which was 292 mm, the lowest occurred in April, which was 41 mm, while the highest number of rainy days occurred in October, which was 25 days, and the lowest number of rainy days occurred in January, March, and April, which were 7 days. The details can be seen in Table 2-1 below.

**Table 1. Rainfall in Batu Bara Regency**

Month	Rainfall (mm)	Rain Day (Day)
January	33	7
February	123	12
March	72	7
April	41	7
May	236	17
June	95	17
July	54	8
August	292	14
September	150	15
October	210	25
November	255	22
December	264	18

Source: Batu Bara Regency in Figures, 2023

### Topography

In general, the topography of this area is a lowland area with an altitude ranging from 1-32.9 m above sea level. The height of the area and the distance to the capital in each sub-district in Batu Bara Regency can be seen in Table 2-2 below.

**Table 2. Height of Region and Distance to Capital City by District in Batu Bara Regency**

Subdistrict	Altitude (m.a.s.l)	Distance to the Capital of Regency
(1)	(2)	(3)
Sei Balai	14	31
Tanjung Tiram	1	18
Nibung H Angus	1	31
Talawi	3	15
Datuk Tanah Datar	14	16
Lima Puluh	28	0
Lima Puluh Pesisir	5	23
Datuk Lima Puluh	4	11
Air Putih	10	15
Sei Suka	13	20
Laut Tador	32,9	33
Medang Deras	2	46

Source: Batu Bara Regency in Figures, 2023

### Erosion and Sediment Problems

Erosion is the loss or erosion of soil or parts of the soil from one place that is transported by water or wind to another place. According to (Tamrin, 2022), soil erosion occurs through three stages, namely the first stage of breaking up lumps or soil aggregates into small grains or soil

particles (detachment), the second stage of moving or transporting small to very fine grains (transportation) and the third stage is the deposition of these particles in a lower place or at the bottom of a river or reservoir (deposition) which is also called sediment.

The Erosion Hazard Level (EBH) is the level of threat of damage caused by erosion on a land. Soil erosion can turn into a disaster if the rate of erosion is faster than the rate of soil formation. The BHE classification refers to Table 3 below.

**Table 3. EBH Classification**

Classification of Erosion Hazard Level (EBH)	Erosion (ton/ha/year)	Description
I	< 15	Very Light
II	15 –60	Light
III	60 –180	Medium
IV	180 –480	Heavy
V	> 480	Very Heavy

Sedimentation is soil and parts of the soil that are transported by water from a place that experiences erosion in a river basin and enters a body of water. Sediment generally settles at the bottom of the foothills, in floodplain areas, in water channels, rivers and reservoirs. Sediment that enters the body of water is only part of the soil that is eroded from its place. Some of the soil carried by erosion will settle somewhere on the land at the bottom of the erosion site in the watershed.

Sediment in water bodies is based on the type of sediment and the size of the soil particles and the mineral composition of the parent material that makes it up, various types of sediment are known such as sand and clay. Based on the size of the particles, sediment is found dissolved in rivers/sediment load (suspended sediment) and creeping on the riverbed/creeping sediment (bed load).

**METHOD**

This study investigates the suitability of gabion construction for stabilizing the Sei Balai Riverbanks in the Nibung H Angus/Tanjung Tiram District of Batu Bara Regency. The methodology involves several key steps. First, a thorough field assessment of the Sei Balai River area, particularly Lima Beras Village, was conducted to identify the extent of flooding and landslide damage. This involved visual inspections, measuring bank erosion, and documenting existing conditions affecting riverbank integrity (Debataraja et al., 2022). Next, geotechnical testing was performed to evaluate the soil characteristics and bearing capacity of the riverbanks. Soil samples were collected from various depths, specifically focusing on Test No. S-1 and S-2, both taken at a depth of 5 meters, where the Bearing Capacity Values were determined to be 3.8 Ton/m<sup>2</sup> and 4.53 Ton/m<sup>2</sup>, respectively (IUGS, 1997). Based on the geotechnical data, a design for gabion structures was developed, with gabions filled with medium to large stones and encased in steel wire mesh to ensure adequate resistance to erosion and structural stability (Hardiyatmo, 1992). The performance of gabions was then evaluated in terms of their ability to mitigate soil erosion and enhance the stability of river slopes, particularly regarding their resistance to vertical and horizontal soil movements in areas with high plasticity clay conditions. Additionally, the permeable design of the gabions was analyzed to ensure that water could flow through without causing excessive erosion, thus maintaining

the integrity of the slopes. Through these steps, the methodology aims to determine the effectiveness of gabion structures in stabilizing the Sei Balai Riverbanks and preventing further damage to the surrounding infrastructure.

## **RESULTS AND DISCUSSION**

### **Soil Methods and Investigations**

#### ***Sondir (Sondering Test) Implementation Method***

The purpose of the Sondir Penetration Test (Sondering Test) is to determine the cone/end resistance/cone resistance of the underlying soil layer expressed in kg/cm<sup>2</sup> and the skin friction, namely the cone or biconus resistance force expressed in kg/cm. This test is usually carried out before building pile foundations, or other deep foundations. The results of this sondir test are used to:

- a. Determine what type or kind of foundation to use
- b. Calculate the bearing capacity of the original soil
- c. Determine how deep the foundation should be placed later

Equipment preparation, including installation/adjustment of the tool at the point to be probed. Measurements begin at a depth of 20 cm by pressing the cone, cone readings (CR) are taken by turning the pressure bar without stopping. The friction sleeve will be connected and produce cone resistance and adhesive resistance readings. Adhesive resistance is obtained by subtracting the cone resistance reading from the adhesive resistance. This reading is done every 20 cm interval until it reaches hard ground. Undisturbed soil samples and disturbed soil samples taken from the field are then taken to the laboratory to be tested in order to determine the soil properties, namely index properties and engineering properties.

#### **Bearing Capacity of Pile Foundation from CR Value**

From the results of the sondir test, the bearing capacity of the pile foundation is calculated using the following formula:

$$Q_u = Q_p + Q_s;$$

$$Q_p = A_p \cdot (CR - r)$$

$$Q_s = TF \cdot A_k$$

$$Q_i = \frac{Q_p}{FK1} + \frac{Q_s}{FK2}$$

where:

- a.  $Q_u$  = Ultimate bearing capacity of the pile (kg or tons)
- b.  $Q_i$  = Permissible bearing capacity of the pile (kg or tons)
- c.  $Q_p$  = Bearing capacity of the end of the pile (kg or tons)
- d.  $Q_s$  = Friction capacity kg or tons
- e. TF = Total skin friction kg/cm
- f. CR-r = Cone Resistance on average 4 D up and 4 D down (D = pile diameter )
- g.  $A_p$  = Cross-sectional area of the pile (cm<sup>2</sup>)
- h.  $A_k$  = Perimeter of the pile (cm)
- i. FK1 = Safety factor of bearing capacity at the end of the pile (3 is used)
- j. FK2 = Safety factor of pile resistance (5 is used)

Shallow Foundation Bearing Capacity From CR Value

To calculate the bearing capacity of the soil from the results of the penetration test, the following formula is used:

$$Q_u = \frac{CR}{10} \longrightarrow \frac{Q_u}{FK}$$

where :

$Q_u$  = Ultimate soil bearing capacity (ton/m<sup>2</sup>)

$Q_i$  = Permitted soil bearing capacity (ton/m<sup>2</sup>)

CR = Cone Resistant

10 = Reduction Factor

FK = Safety Factor (taken 5)

Determination of Urban Areas according to PUPR Ministerial Regulation No. 28 of 2015, it was found that Sei Balai Hilir District is not an Urban Area, so the category of the Sei Balai River that crosses the district is:

1. The Sei Balai River is a river with embankments
2. The Sei Balai River is a river outside the Urban Area

Based on PUPR Ministerial Regulation No. 28 of 2015, the width of the Sei Balai River boundary is included in Article 6 of PUPR Ministerial Regulation No. 28 of 2015, rivers without embankments outside urban areas:

- a. For large rivers with a watershed area of more than 500 km<sup>2</sup>, it is determined to be at least 100 meters from the left and right edges of the riverbed along the river channel.
- b. For small rivers with a watershed area of less than or equal to 500 km<sup>2</sup>, it is determined to be at least 50 meters from the left and right edges of the riverbed along the river channel.

In this case, the Sei Balai River has a watershed area of 231 km<sup>2</sup> so that the width of the river boundary is at least 50 meters from the left and right edges of the riverbed along the river channel.

### Boundary Condition Modeling

Discharge data can be in the form of a planned discharge in the form of a flood hydrograph as input into the boundary condition for modeling conditions. The planned discharge data has been obtained in the analysis above with several predetermined recurrence periods. The downstream boundary conditions in this modeling use river slope value data.

The following are the results of the flood water level of the Sei Balai River at several points on the cross section of the Sei Balai River as shown in the following figure:

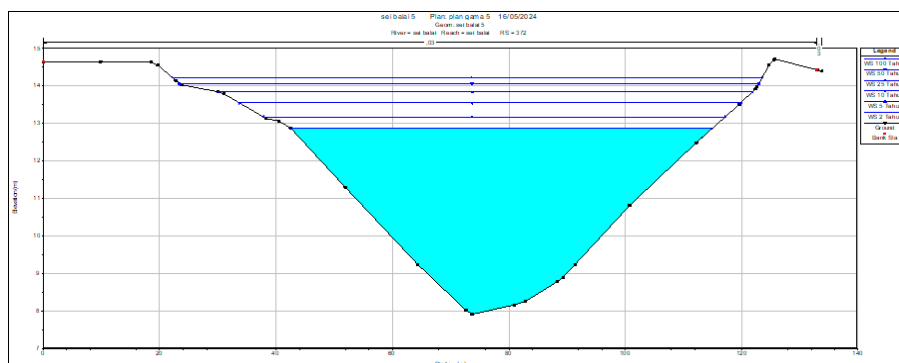
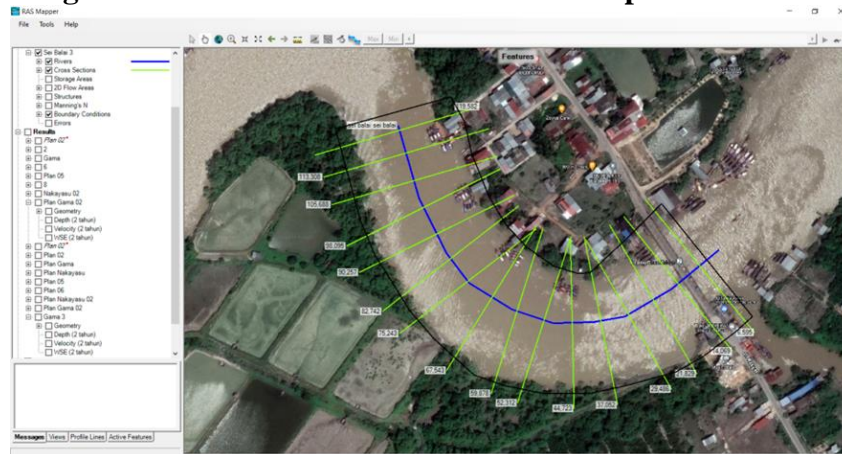


Figure 3. Cross-section of one point of the river cross-section

Source: Consultant Analysis Results 2024



**Figure 4. River Cross-Section Situation Map and Site Plan**



**Figure 5. Flow Direction Arrow Display on HEC-RAS**

### **River Wall Stability (Embankment)**

In general, the causes of damage to the embankment body are as follows:

- Formation of a continuous slip plane due to the slope of the embankment being too steep.
- Collapse of the embankment slope due to water saturation in the embankment body caused by water seepage during floods or during continuous rain.
- Leaks in the embankment foundation.
- Erosion of the front slope of the embankment by river currents.
- Overflow on the embankment crest.
- Shifting of the foundation due to earthquakes.
- The stability of the embankment slope is carried out using the slip plane method with the formula:

$$F_s = \frac{\sum sl}{\sum W \sin \theta}$$

$$F_s = \frac{\sum \{cl + (W \cos\theta - ul) \tan\phi\}}{\sum W \sin \theta}$$

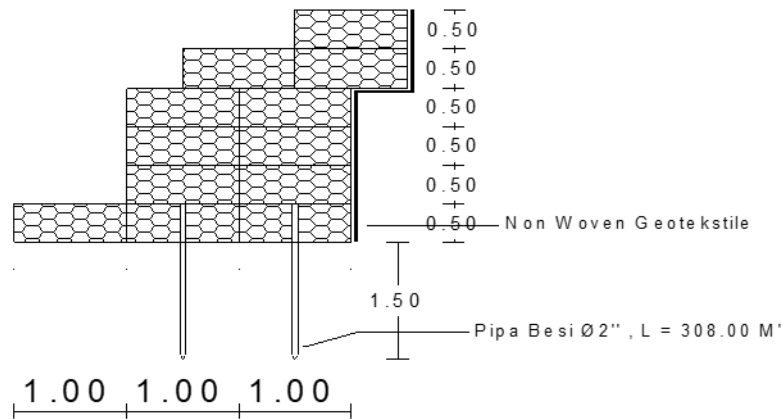
Where:

- $F_s$  = Safety factor
- $W$  = Stress due to vertical section gravity per unit width (t/m)
- $L$  = Length of vertical section slip circle arc (m)

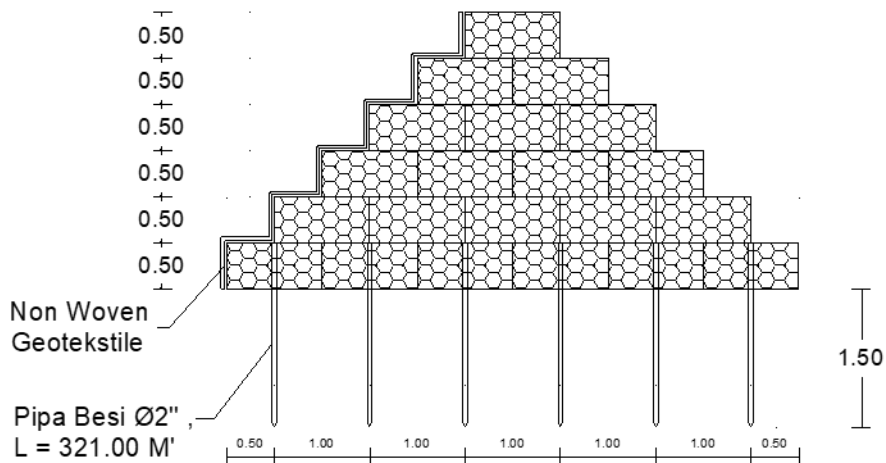
- d.  $\alpha$  = Angle between each section center line and the slip plane (degrees)
- e.  $u$  = Pore water pressure per unit area of the slip plane (t/m<sup>2</sup>)
- f.  $s$  = Shear strength per unit area (t/m<sup>2</sup>)
- g.  $\tau = c + \sigma \tan \phi$
- h.  $\sigma' =$  Effective strength perpendicular to the slip plane (t/m<sup>2</sup>)
- i.  $c$  = Cohesion (t/m<sup>2</sup>)
- j.  $\phi$  = Internal friction angle (degrees)

**Gabions**

Based on the initial survey, several locations along the Sei Balai River experienced erosion. Therefore, planning of gabion-type riverbank protection structures is needed to overcome erosion. The analysis carried out includes analysis of planned rainfall, planned flood discharge, flood water level, and gabion size design. There are several types of gabions that are designed as seen in the following Figure 3-4.



**Figure 6. Common Type Gabions**



**Figure 7. Pyramid Type Gabion**

**Gabion Design Notes Detailed Design Point**

From the soil test results from the research location below to the laboratory, the following data was obtained.

- a. Data Collection Results

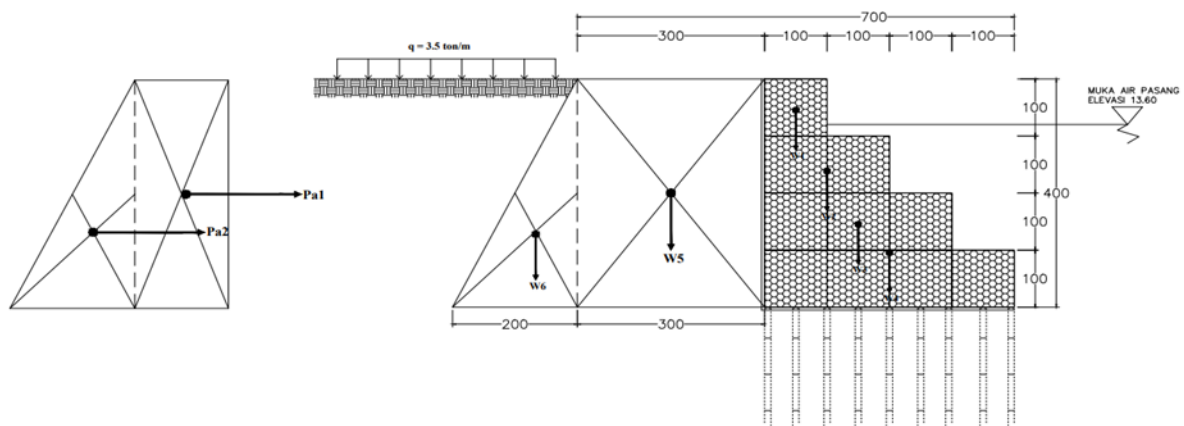
**Recommendations for Appropriate Design for Handling Landslides on the Slopes of the Balai River (Sei Balai), Batubara Regency**

1. Data Struktur			
Berat Jenis Pasangan Batu ( $\gamma_b$ ) :		2.2	$t/m^3$
Berat Jenis Beton ( $\gamma_c$ ) :		2.4	$t/m^3$
q		3.5	$t/m^2$
2. Data Tanah :			
Berat volume tanah ( $\gamma_1$ ) :		1.675	$t/m^3$
Berat volume tanah ( $\gamma_2$ ) :		1.65	$t/m^3$
Sudut geser dalam ( $\phi_1$ )		23	derajat
Sudut geser dalam ( $\phi_2$ )		23	derajat
Kohesi tanah C1		1.43	$t/m^2$
Kohesi tanah C2		1.57	$t/m^2$
3. Data Air :			
Berat volume air ( $\gamma_w$ ) :	1		$t/m^3$
4. Dimensi Dinding Penahan Tanah			
H =	4	m	B = 3 m
H1 =	3.2	m	b1 = m
h2 =	0.8	m	b2 = m
h3 =	3.2	m	b3 = m
h4 =	0.8	m	b4 = m

**b. Analysis of Retaining Walls**

**Calculation of Active Earth Pressure**

Active earth pressure is a force that tends to reduce the balance of the retaining wall.



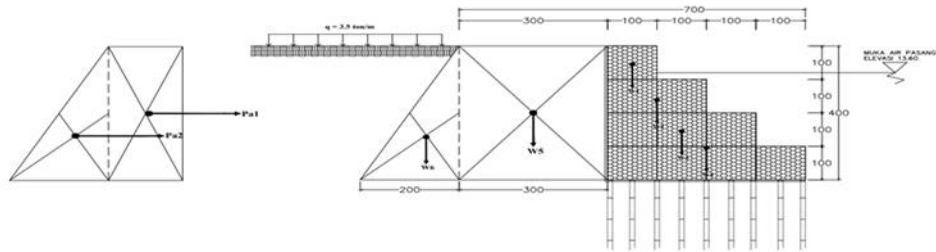
**Figure 8. Forces acting on Gabions**

The active pressure coefficient can be calculated using the formula:

$K_a = tg^2(45 - \frac{\phi}{2})$		$K_p = tg^2(45 + \frac{\phi}{2})$
$K_a = tg^2 \times (45 - (23 / 2))$		$K_p = tg^2 \times (45 + (23 / 2))$
$K_a = 0.4380925$		$K_p = 2.2826$

Pa 1	=	$K_a \times q \times H1$	Pp 1	=	$K_p \times q \times H1$
	=	6.133 ton		=	6.391 ton
Pa 2	=	$1/2 \times K_a \times \gamma' \times H1^2$	Pp 2	=	$1/2 \times K_p \times \gamma' \times H1^2$
	=	3.757 ton		=	19.576 ton

Calculating the weight of the retaining wall as follows:



Bidang W1			
W1	=	$b \times h \times yb$	
	=		2.2 ton
W2	=	$b \times h \times yb$	
	=		4.4 ton
W3	=	$b \times h \times yb$	
	=		6.6 ton
W4	=	$b \times h \times yb$	
	=		8.8 ton
W5	=	$b \times h \times y1$	
	=		20.1 ton
W6	=	$b \times h \times y1$	
	=		6.7 ton

Menghitung momen karena gaya-gaya terhadap titik 0			
Momen = Gaya x jarak			
Bidang	W (berat) kN	Jarak dari titik Guling O (m)	Momen (ton.m)
1	2.200	3.500	7.700
2	4.400	3.000	13.200
3	6.600	2.500	16.500
4	8.800	2.000	17.600
5	20.100	5.500	110.550
6	6.700	7.670	51.389
<b>Jumlah</b>	<b>48.800</b>		<b>216.939</b>
$\Sigma W =$	48.8 ton		
$\Sigma Mw =$	216.939 ton.m		

Tekanan tanah aktif			
Bangun	Pa (ton)	Jarak dari titik guling O (m)	Momen (ton.m)
1	6.133	1.6	9.813
2	3.757	1.07	4.008
<b>Jumlah</b>	<b>9.890</b>		<b>13.821</b>
Tekanan tanah pasif			
Bangun	Pp (ton)	Jarak dari titik guling O (m)	Momen (ton.m)
1	6.391	1.28	8.181
2	19.576	0.997	19.511
<b>Jumlah</b>	<b>25.967</b>		<b>27.691</b>
$\Sigma Ptotal =$		9.890	-
			25.967
			-16.077 ton
$\Sigma Mgtotal =$		13.821	-
			27.691
			-13.871 ton

c. Overturning Stability

Lateral earth pressure caused by the soil behind the retaining wall tends to overturn the wall, with the center of rotation located at the toe of the retaining wall.

$Fgl \frac{\Sigma Mw}{Mgtotal} =$	$\frac{216.939}{13.871}$		
		$= 15.640 > 1,5$	OK

d. Sliding Stability

Sliding stability is the comparison between the forces that resist and the forces that push the soil retaining wall. The resisting forces include the adhesion forces between the soil and the retaining wall, while the pushing forces include the lateral pressure from the backfill behind the retaining wall.

Ph =	Cd x B + ΣW x tan φ				
=	1.57 x	3	+	48.8	x 0.4245
=	25.424	ton			
Fgl =	$\frac{\sum Ph}{\sum Pa}$				
=	$\frac{25.424}{9.890}$				
=	2.571	> 1,5		OK	

e. Stability Against Collapse of Soil Bearing Capacity

In this case, the Hansen equation will be used in the calculation, assuming the foundation is located on the surface.

$X_e = \frac{\sum Mw - \sum Ma}{\sum w} =$		
=	216.939	- 13.871
=	8.750	m

<b>Eksentrisitas (e)</b>		
$e = \frac{B}{2} - X_e$		
=	$\frac{3}{2} - 8.750$	
=	-7.250	m

<b>Lebar Efektif (B') = B - 2e</b>		
B' = B - 2e		
=	17.500	m
A' = B' x l		
=	17.500	m

<b>Gaya - gaya yang ada pada dinding</b>	
a. Gaya Horizontal =	-16.077 ton
a. Gaya Vertikal =	48.8
Faktor kemiringan beban :	
$i_q = \left[ 1 - \frac{0.5 \times \sum H}{\sum V \times A' \times c \times \phi} \right]$	
=	1.016

Berdasarkan tabel : (untuk φ = 25°)	
Nc =	25.1
Nq =	12.7
Ny =	9.2
$i_c = i_q \cdot \left[ \frac{1 - i_q}{N_q - 1} \right]$	
=	1.016832256
$i_y = \left[ 1 - \frac{0.75 \times \sum H}{\sum V \times A' \times c \times \phi} \right]$	

<b>Kapasitas Dukung Ultimit untuk Pondasi di permukaan menurut hansen</b>	
Df =	0
dc = dq = dy	
Sc = Sq = Sy	
Didapat :	
$q_u = i_q \times c \times N_c + 0.5 \times i_y \times B' \times \gamma^3 \times N_y$	
=	77.224 ton/m <sup>2</sup>
Bila dihitung berdasarkan lebar pondasi efektif, yaitu tekanan pondasi ke tanah dasar terbagi rata secara sama, maka :	
$q' = \frac{\sum V}{B'}$	
=	2.789 ton/m <sup>2</sup>
faktor aman terhadap keruntuhan kapasitas daya dukung tanah :	
$F = \frac{q_u}{q'}$	
=	27.693 > 3 OK

Sondir Test Depth Results as Reference for River Slope Design Selection

Sondir Test (Sondering Test), it can be concluded that the level of soil density is as follows:

**Table 3.1. Sondir test results for the Sei Balai River slope**

No. Test	Coordinate	Total Depth	GWL	CR	TSF
		m	m	kg/cm <sup>2</sup>	kg/cm
S - 1	N : 3.211228° E : 99.593272°	25.00	3.00	175	941.33
S - 2	N : 3.210962° E : 99.592608°	23.80	2.20	218	601.33

**Drilling Test Results and from the results**

The results of the drill test and the results of visual observations in the field are as follows:

Visual observations in the field as follows:

No. Test	Coordinate	GWL (m)	Depth (m)	Description
HB - 1	N : 3.211228° E : 99.593272°	3.00	0.00 - 1.80	Lempung berlanau, abu-abu cerah, sangat lunak, plastis sedang kadar air sedang, kekakuan sedang.
			1.80 - 2.40	Lempung berlanau, abu abu cerah, sangat lunak, plastis sedang, kadar air sedang, kekakuan sedang.
			2.40 - 3.00	Lempung berlanau, abu abu gelap, rendah, plastis sedang, kadar air sedang, kekakuan sedang.
			3.00 - 4.00	Pasir kuarsa berlanau sisipan serpihan kerang, abu-abu gelap, plastis rendah, kadar air rendah, kekakuan rendah.
HB - 2	N : 02° 30' 2.04" E : 99° 52' 26.01"	2.20	0.00 - 1.80	Lempung berlanau, abu-abu cerah, lunak, plastis sedang kadar air sedang, kekakuan sedang.
			1.80 - 2.40	Lempung berlanau berpasir sisipan kayu lapok dan serpihan kerang, abu abu gelap kehitaman, sangat lunak, plastis sedang, kadar air sedang, kekakuan sedang.
			2.40 - 3.00	Pasir berlanau sisipan serpihan kerang, coklat gelap, rendah, plastis rendah, kadar air rendah, kekakuan rendah.
			3.00 - 4.00	Pasir kuarsa berlanau sisipan serpihan kerang, abu-abu gelap.

**CONCLUSION**

Dengan demikian, pemilihan desain yang tepat untuk mengatasi longsor pada tebing sungai memerlukan strategi pencegahan yang komprehensif, termasuk menghindari pembangunan di tebing, memilih lokasi bangunan yang aman, menjaga keberadaan pohon di sekitar tebing, dan memasang bronjong yang efektif. Berdasarkan hasil investigasi geoteknik, beberapa kesimpulan diperoleh sebagai berikut:

Pertama, dari hasil uji sondir (Sondering Test), tingkat kepadatan tanah dapat disimpulkan dengan hasil sebagai berikut: Pada uji S-1 dengan kedalaman 5 meter, daya dukung izin (Qi) adalah 3,8 ton/m<sup>2</sup> dengan lebar pondasi (B) sebesar 1 meter. Pada uji S-2 dengan kedalaman yang sama, daya dukung izin (Qi) adalah 4,53 ton/m<sup>2</sup> dengan lebar pondasi (B) sebesar 1 meter.

Kedua, desain yang sesuai pada tebing sungai Sei Balai adalah konstruksi bronjong karena berdasarkan data sondir hingga kedalaman 25 meter, tanah masih lunak. Pemilihan desain bronjong pada tebing sungai dengan kondisi tanah lunak didasarkan pada beberapa alasan penting: (a) Bronjong dapat menahan erosi tanah yang disebabkan oleh arus sungai dengan mengisi batu-batu berukuran sedang hingga besar dalam anyaman kawat baja, yang membantu mencegah erosi oleh air sungai. (b) Bronjong meningkatkan stabilitas tebing sungai dengan menahan beban hidup dan pergerakan tanah. Keberadaan air pada tebing dengan

kondisi tanah lempung yang plastisitasnya tinggi dapat menyebabkan longsor, namun bronjong dapat menahan gerakan vertikal dan horizontal. (c) Pemasangan bronjong di kaki tebing sungai dapat mengurangi risiko longsor, karena bronjong menahan beban hidup dan pergerakan tanah, sehingga mengurangi tekanan pada tebing dan memperkuat kaki tebing. (d) Bronjong memiliki sifat permeabel, yang memungkinkan air tetap mengalir melalui batu-batu yang mengisi bronjong, sehingga air dapat mengalir melalui tebing tanpa menyebabkan erosi yang berlebihan.

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