ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

Available online at
https://jurnalteknik.unisla.ac.id/index.php/CVL

https://doi.org/10.30736/cvl.v2i2

Study of Groin Structure Planning On a River Bend In Padang Mancang Village

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ARTICLE INFO

Article History :
Article entry : 08-11-2024
Article revised : 10-12-2024
Article received : 14-03-2025

Keywords :
Erosion, Riverbank, Soil, Groin Structure, Stability.

IEEE Style in citing this article :
Muhammad Arrie Rafshanjani amin, M. SAFRIANI, Cut Suciatinas Silvia, Delfian Masrura, and Safrizal, "Study of Groin Structure Planning On a River Bend In Padang Mancang Village", civilla, vol. 10, no. 1, pp. 47–58.

ABSTRACT

The river flows naturally from its source (upstream) to its mouth (downstream). Due to its velocity, riverbank erosion often occurs, especially in curved sections. In meandering rivers, unstable soil can lead to landslides on the outer banks. One affected area is Padang Mancang Village, Kaway XVI Subdistrict, West Aceh Regency. This study aims to design a suitable groin structure to mitigate erosion. The design process considers a 50-year return period flood (Q50), soil properties, and river cross-section data. The proposed groin structure has a length of 30 meters, a foundation width of 10 meters, a top width of 3 meters, and a height of 12 meters. The flood discharge is 2885.307 m³/s. Stability analysis confirms the structure is safe, with safety factors of 3.06 for overturning and 1.89 for sliding, both exceeding the minimum 1.5. The foundation is stable, with a maximum stress of 2.076 kg/cm², below the allowable 7.71675 kg/cm². These results indicate the groin structure effectively prevents riverbank erosion while ensuring structural stability.

1. Introduction

Streambank erosion is the phenomenon of soil erosion on the riverbanks and the scouring of the riverbed by the river's water flow [1]. The impacts of erosion include soil layer loss, damage to conservation structures and other buildings, riverbed sedimentation, and more [2]. Due to erosion occurring on the riverbanks, the soil may experience slumping. A landslide is a form of soil mass movement that occurs under specific conditions and involves a considerable volume [3]. Landslides may happen as a result of soil sliding over an impermeable, water-saturated layer [4].

One of the villages in West Aceh Regency, specifically Padang Mancang Village in Kaway XVI Subdistrict, has been experiencing riverbank erosion. This village is located around the Krueng Meureubo River Basin (DAS). The erosion occurring on the river bend in this village has become increasingly concerning. Plantation land near the riverbank has progressively eroded, and the distance to nearby residential areas is also relatively short. To address streambank erosion, several riverbank protection structures are recommended, such as retaining walls, sheet piles, gabions, and groin structures [5], to reinforce the area.

ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

This study selects the groin structure as an option to address the erosion problem, especially on the river bend. Groin structures are commonly used as protective structures for riverbanks to safeguard them from scouring and can also serve to direct the water flow [6]. This design is expected to produce dimensions that are suitable and stable, allowing the resulting solution to be applicable in efforts to prevent erosion in similar areas in the future

2. Research Method

Data Collection Method. The stages of this research begin with obtaining primary data and collecting secondary data, followed by conducting planning calculations using equations presented in previous subchapters. The data required for the groin structure planning study on the Krueng Meureubo River in Padang Mancang Village, West Aceh Regency, geographically located at 4°13’0" N and 96°10’0" E, consists of primary and secondary.

Primary data is directly obtained from field surveys or the site of the planned structure. Secondary data is obtained from various sources or related institutions and requires further analysis to complete this planning study. The primary data for this study includes soil data, river dimensions, and riverbank slope. Secondary data includes rainfall data, topographic data, and the watershed map.

Data Analysis. The stages involved in data analysis in this study, after collecting primary and secondary data, include calculating the planned rainfall. The planned rainfall calculation is carried out using frequency analysis with Normal, Log Normal, Gumbel, and Log Pearson III distributions. Afterward, a suitable distribution for this study will be determined based on the requirements in Table 1. The next step is to calculate the planned flood discharge using the Snyder method, with equations (1) through (6).

Subsequently, the groin structure dimensions are designed, calculated using equations (7) and (8). Finally, stability calculations for the groin structure against overturning, sliding, and soil bearing capacity are performed. The stability against overturning is calculated using equation (9), followed by an analysis of the hydrostatic force on the groin structure using equations (10) and (11). The stability against sliding is assessed with equation (12), and the stability against soil bearing capacity is calculated using equations (13) to (16). If the stability against overturning, sliding, and soil bearing capacity are found to be insufficient, the groin structure design must be revised.

3. Description and Technical

Planned Flood Discharge. In designing the dimensions for the groin structure, it is first necessary to calculate the planned flood discharge, as this will impact the stability of the construction. The planned flood discharge can be calculated based on the planned rainfall, obtained from statistical analysis of rainfall data using available parameters [7]. The relevant statistical parameters include standard deviation (Sd), skewness coefficient (Cs), coefficient of variation (Cv), and kurtosis coefficient (Ck).

There are several types of distribution analysis in statistics for frequency analysis calculations, namely, normal distribution, log-normal distribution, Gumbel distribution, and Log Pearson III distribution [8]. To determine the appropriate distribution type based on the obtained calculations, matching parameter requirements are applied. The distribution parameter requirements [9] can be found in Table 1.

Table 1. Distribution Requirements

Distribution Type	Requirements
Normal	$Cs \approx 0$ $Ck \approx 3$
Log Normal	$Cs = Cv^3 + 3\ Cv$ $Ck = Cv^8 + Cv^6 + 15\ Cv^4 + 16\ Cv^2 + 3$
Gumbel	$Cs \approx 1{,}14$ $Ck \approx 5{,}4$
Log Pearson Type III	Value other than above

Source: Analysisdata (2024)

ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

Once the planned rainfall value is obtained according to the chosen method, the design flood discharge analysis can be performed. The design flood discharge is the maximum planned discharge in a natural channel, such as a river, which can be conveyed without posing a risk to the surrounding environment or compromising the stability of the river for a certain return period [10]. The synthetic unit hydrograph is one method used to determine the design flood discharge [11]. The synthetic unit hydrograph used in this study is Snyder's synthetic unit hydrograph.

There are four parameters required for calculating the design of flood discharge using this method: lag time, peak flow, base time, and standard duration of effective rainfall [12]. The unit hydrograph can be associated with the physical geometry of the watershed with the following relationships

$$t_p = C_t\,(L \times L_c)^{0,3} \tag{1}$$

$$Q_p = C_p\,(\frac{A}{t_p}) \tag{2}$$

$$t = 3 + (\frac{t_p}{8}) \tag{3}$$

$$t_D = \frac{t_p}{5,5} \tag{4}$$

If the effective rainfall duration tr is not equal to the standard duration tD, then

$$t_{PR} = t_p + 0,25\,\frac{t_R}{t_D} \tag{5}$$

$$Q_{PR} = Q_P\,\frac{t_p}{t_{pr}} \tag{6}$$

Where:

t_D = standard duration of effective rainfall (hours); t_R = effective rainfall duration (hours);
t_P = time from the centroid of the effective rainfall duration tD to the peak of the unit hydrograph (hours);
t_{PR} = time from the centroid of the effective rainfall duration tR to the peak of the unit hydrograph (hours);
t = base time of the unit hydrograph (days);
Q_P = peak discharge for duration tD;
Q_{PR}= peak discharge for duration tR;
L = Length of the main river to the control point considered (km);
L_C = distance from the control point to the point closest to the centroid of the watershed (km);
A = watershed area (km^2);
C_t = coefficient depending on the slope of the watershed, with values ranging from 1.4 to 1.7; C_P = coefficient depending on the characteristics of the watershed, with values ranging from 0.15 to 0.19.

Dimensions of the Groin Structure. A groin is a structure built from the riverbank towards the center to regulate river flow, aimed at addressing erosion at the riverbank location and capable of reducing the flow velocity around the riverbank [13].

In terms of installation relative to the river flow, groins are classified into two types: transversal groins and longitudinal groins. Transversal groins are installed perpendicular to the river flow, while longitudinal groins are formed almost parallel to the direction of the river flow [14].

The length of the groin depends on how far the river flow will be diverted to avoid hitting the riverbank. In sections of the river that experience water impact, the distance between adjacent groins is made closer together because the erosive force of the current will extend towards the riverbank [15]. The calculation for determining the length of the groin can use the following formula

$$F_r = v\,(gD)^{0,5} \tag{7}$$

$$L/B = 0,11(n\ Fr^{0,5})^{1,5} \tag{8}$$

ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

Where:

L = length of the groin (m);
B = width of the river surface at the planned discharge or full discharge (m); Fr = Froude number;
n = empirical coefficient (generally between 2 and 5); D = water depth (m);
v = flow velocity (m/s).

A groin that is too long has a detrimental effect on river stability. Generally, the ratio of groin length (L) to river width (B) should be below 10% [16]. For the intervals of the constructed groins, careful observations were conducted on the Tone River, yielding a relationship between the interval and the groin length [17], as shown in Table 2.

Table 2. Relationship between Groin Length and Interval

Location of Groin Construction in the River	Relationship between Interval (D) and Length (L)
Straight Section	D = (1,7-2,3) L
Outer Bend	D = (1,4 – 1,8)L
Inner Bend	D = (2,8 – 3,6) L

Source: Analysisdata (2024)

Stability Analysis of the Groin Structure. Stability analysis will be determined by horizontal and vertical forces originating from the soil and water. With this calculation, information regarding the planned structure's compliance with the required stability can be obtained.

A stability review of river structures is necessary, particularly regarding overturning. The impact of hydrostatic pressure forces from the flow can cause instability in the structure. The hydrostatic force impacting the groin tends to overturn it, with the rotation center at the groin's toe. This overturning moment can be countered by the moment due to the groin's weight. The calculation of the safety factor against overturning (SF) is defined by the following equation [18]:

$$SF = \sum Mt \ / \sum Mg > 1{,}5 \quad (9)$$

where:

$\sum Mt$ = moment resisting overturning (kNm);
$\sum Mg$ = actual total moment causing overturning (kNm); SF = Safety Factor.

The hydrostatic force is the horizontal force resulting from the movement of water flow from upstream that impacts the construction wall of the river [19]. Hydrostatic pressure is a function of the depth below the water surface, acting perpendicular to the face of the structure profile. The magnitude of the moment due to hydrostatic pressure is as follows [20]:

$$P_{air} = 0{,}5 \ . \ H^2 \ . \ \gamma_w \quad (10)$$

$$M_{air} = P_{air} \times H/3 \quad (11)$$

where:

H = water depth (m);
γ_w = unit weight of water (kN/m³);
P_{air} = water pressure/hydrostatic pressure (ton);
M_{air} = water pressure moment (kN.m).

Friction between the soil and the foundation serves to resist the forces that would otherwise shift the structure in another direction. This soil pressure can cause sliding at the base and can be calculated for its stability using the following equation [21]:

$$SF = \sum Rv \ / \sum Rh > 1{,}5 \quad (12)$$

Where:

$\sum R_V$ = magnitude of the vertical forces acting around the structure (kN);
$\sum R_H$ = magnitude of the horizontal forces acting around the structure (kN); SF = Safety Factor.

The soil supporting the structure will receive forces due to weathering, which poses a risk of settlement and can lead to structural instability [22]. In this case, these forces will become pressure on the upper part and may cause the groin structure to become unstable on one side.

$$e = B/2 - [(Mt - Mg) / \sum Rv] < B/6 \quad (13)$$

$$qu = (c \times N_c \times F_{cd} \times F_{ci}) + (q \times N_q \times F_{Nq} \times F_{qi}) + (0{,}5 \times \gamma \times B' \times B_\gamma \times F_{\gamma d} \times F_{\gamma i}) \quad (14)$$

$$t_{izin} = q_u / 3 \quad (15)$$

$$q_{max} = t_{izin} \geq \sum Rv/B\,[1 \pm (6e/B)] \quad (16)$$

where:

e = eccentricity;
q_u = ultimate bearing capacity (kg/m²); N_c, N_q, N_γ = Terzaghi bearing capacity factors; γ = unit weight of soil (kg/m³);
t_{izin} = allowable stress (kg/m²); q_{max} = maximum pressure (kg/m²).

4. Results and Discussions

Location of Planning. The groin structure is planned based on the river layout map. The construction will be built on the riverbank that is experiencing erosion along 200 meters of the right bank of the river, specifically in Padang Mancang Village. An overview of the planning study location can be seen in Figure 1, which depicts the existing condition of the riverbank. The groin structure will be constructed at several sections of the river that experience overflow, and its position has been mapped in advance.

Source: current condition location of planning (2024)

Figure 1. Groin Structure Planning Location

Hydrological Analysis. This calculation is conducted to understand the hydrological characteristics of the river drainage area where the research object is located. The data used in the hydrological analysis consists of rainfall data that has been processed into monthly maximum rainfall data, which is one of the key datasets for estimating the planned flood discharge.

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ISSN (*Print*) 2503-2399

The analysis of planned rainfall is calculated for return periods of 2 years, 5 years, 10 years, 25 years, and 50 years. The planned rainfall calculations are based on rainfall data collected over the past 14 years, from 2006 to 2019. This data is obtained from the Cut Nyak Dhien Nagan Raya Meteorological and Climatological Station. The data used is the maximum monthly rainfall data, as shown in Table 3

Tabel 3. Maximum Monthly Rainfall Data

Year	Month												Max [mm]
	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Agt	Sep	Okt	Nov	Des	
2006	50,0	70,0	52,0	42,0	19,0	54,0	66,0	65,0	88,0	107	60,0	31,0	107,0
2007	39,0	41,0	31,0	37,0	50,0	37,0	60,0	101	35,0	135	42,0	94,0	135,0
2008	94,0	100	31,0	95,0	94,0	40,0	96,0	90,0	96,0	75,0	77,0	69,0	100,0
2009	25,0	63,0	96,0	88,0	100	66,0	45,0	59,0	95,0	45,0	75,0	26,0	100,0
2010	91,0	56,0	69,0	154	72,0	50,0	30,0	40,5	101	58,0	65,0	80,0	154,0
2011	71,5	50,0	90,5	105	55,0	40,0	90,0	90,0	50,5	90,5	90,0	90,0	105,0
2012	90,0	100	100	74,5	45,5	75,0	93,0	48,0	51,0	107	76,0	90,0	106,5
2013	78,5	80,5	60,5	72,5	70,5	45,5	15,5	65,5	25,0	15,0	85,5	80,5	85,5
2014	102	112	178	65,0	51,0	82,0	58,0	177	71,0	98,0	163	59,0	178,0
2015	1,58	1,69	1,32	4,00	1,72	3,86	1,72	1,93	2,56	3,30	5,76	2,93	5,76
2016	6,06	3,09	3,22	3,53	6,25	2,05	1,75	6,05	1,27	3,72	3,12	1,92	6,25
2017	4,12	2,25	2,49	3,67	1,44	0,98	1,34	1,88	1,68	6,58	2,51	6,03	6,58
2018	3,21	5,05	12,5	13,9	3,20	1,59	12,4	11,7	11,7	23,59	17,8	10,8	23,59
2019	6,73	3,77	4,97	12,4	2,35	7,65	5,71	8,55	6,77	23,58	11,3	11,1	23,58

Source: Calculation Result (2024)

After obtaining the maximum monthly rainfall values, the next step is to calculate the frequency analysis using several distribution methods. The frequency analysis values are calculated to determine which distribution is suitable for this study. The results of these calculations are presented in Table 4.

Table 4. Statistical Parameters for Frequency Analysis of Several Methods

No	Symbol	Result			
		Distribusi Normal	Log Normal	Gumbel	Log Pearson III
1	s	57,964	1,2724	57,964	0,5526
2	Cv	0,714	0,326	0,714	0,3265
3	a	-12492,8	-1,868	-12492,8	-0,153
4	Cs	-0,064	-0,907	-0,064	-0,907
5	Ck	2,455	2,768	2,455	2,768

Source: Calculation Result (2024)

To select the distribution based on the results of the calculations for the four distributions, the distribution requirements according to Table 2 must be reviewed. The values of Cs and Ck from the calculations are compared with the requirements, and the results are presented in Table 5. Based on the data presented in this table, it can be concluded that the distribution that meets the requirements is the Log Pearson Type III distribution, with results of $Cs = -0.907$. After obtaining a distribution that meets the requirements, the planned rainfall is calculated for each return period.

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ISSN (*Print*) 2503-2399

Distribution Type	Requirement	Calculation		Conclusion
Normal	Cs ≈ 0	-0,064	0	
	Ck ≈ 3	2,455	3	Does not meet the requirements
Log Normal	$Cs = Cv^3 + 3Cv$	-0,907	1,000	Does not meet the requirements
	$Ck = Cv^8 + 6Cv^6 + 15Cv^4 + 16Cv^2 + 3$	2,768	4,831	Does not meet the requirements
Gumbel	Cs = 1,431	-0,064	1,1396	Does not meet the requirements
	Ck =4,704	2,455	5,4002	Does not meet the requirements
Log Pearson III	Other than above	-0,907	-	meet requirements
		2,768	-	meet requirements

Source: Calculation Result (2024)

Based on the calculations performed, the highest rainfall discharge for the return period (T) occurs at the 50-year return period, reaching 352.054 mm/hour. The value of KT is obtained from the interpolation of Cs, after which the planned rainfall is calculated as shown in Table 6.

Table 6. Planned Rainfall Analysis

T [Years]	P_T [%]	K_T	K_T x s	Log X_T	X_T [mm]
2	25	0,149	0,082	1,775	59,577
5	10	0,854	0,472	2,165	146,072
10	5	1,146	0,633	2,326	211,766
25	2	1,404	0,776	2,469	294,257
50	1	1,545	0,854	2,547	352,054

Source: Calculation Result (2024)

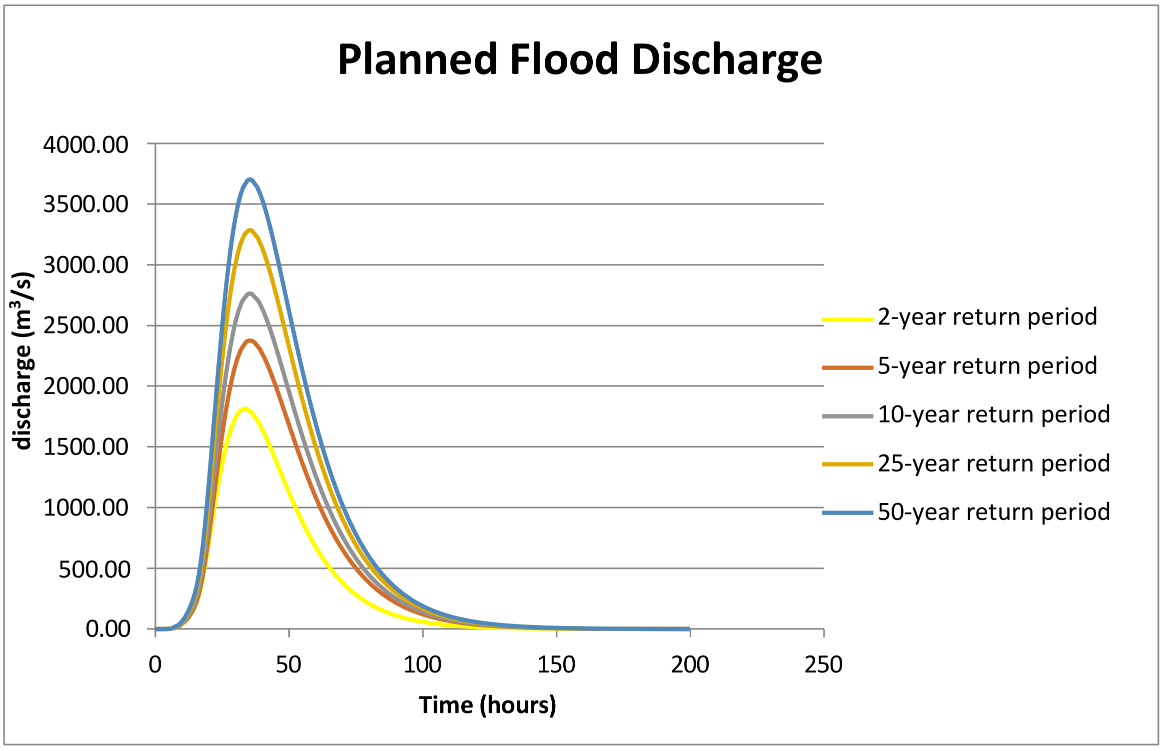
Next, the planned flood discharge is calculated using the Snyder HSS method for return periods of Q2, Q5, Q10, Q25, and Q50. The results of these calculations are shown in Table 7. The maximum value occurs at the 50-year return period, amounting to 2885.307 m³/s. The graph depicting the base time hydrograph using the Snyder HSS method is presented in Figure 2.

Table 7. Planned Flood Discharge

Return Period [Years]	2	5	10	25	50
Planned Flood Discharge [m^3/s]	446,584	1197,152	1735,561	2411,626	2885,307

Source: Calculation Result (2024)

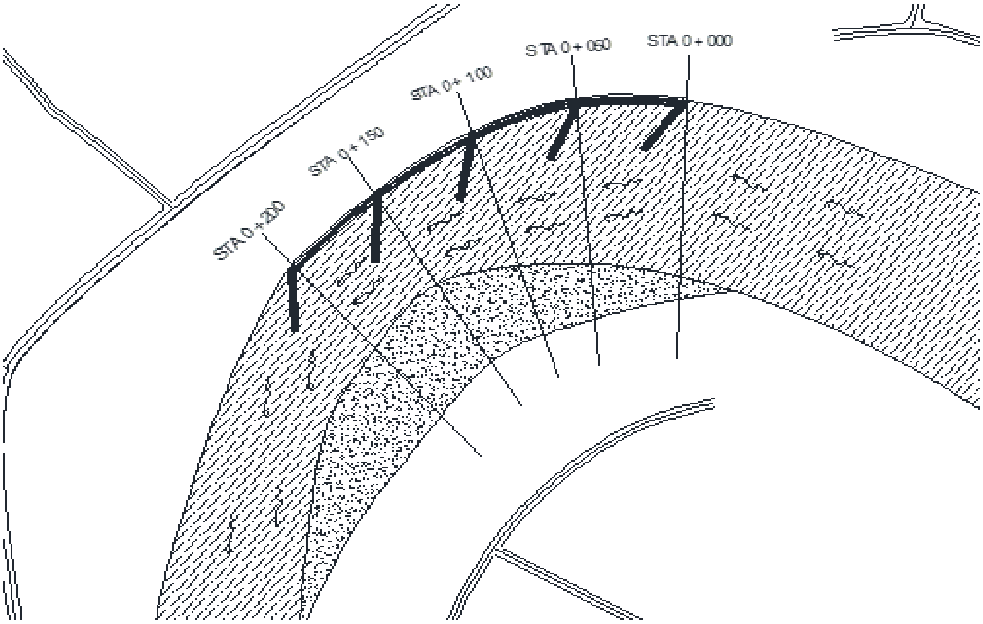
ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399



Source: Calculation Result (2024)

Figure 2. Planned Discharge Graph Using the Snyder HSS Method

Groin Dimension Planning. The planning for constructing a groin consists of determining the dimensions of the groin structure and the selection of the groin's location. This planning is carried out to obtain groin dimensions that are appropriate for the study location and safe against sliding, overturning, and stable concerning soil bearing capacity. Based on the results of field surveys, the groin structure will utilize more than two groin units, with a spacing of 50 meters between each groin structure



Source: Drawing Result (2024)

Figure 3. Planning the Placement of the Groin Structure on the Riverbank at the Bend

The results of the analysis for the groin structure dimensions at STA 0+000 – STA 0+100 are as follows:

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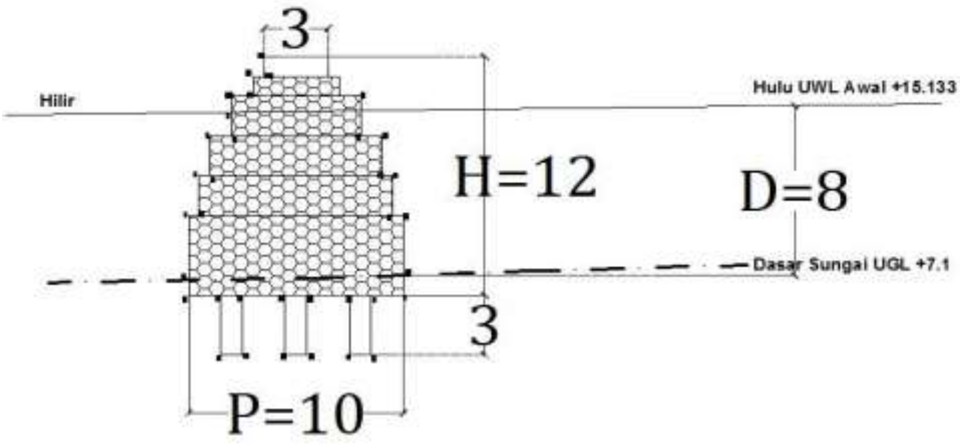
ISSN (*Print*) 2503-2399

L : 30 m (Length of the groin structure)
H : 12 m (Height of the groin structure)
P : 10 m (Width of the foundation at STA 0+175 - STA 0+200)
B : 85 m (Average width of the river from STA 0+000 – STA 0+150)
D : 8 m (Depth of the river at STA 0+000 - STA 0+100)
A : 1705,41 m^2 ((Watershed area)
Fr : 1,115
v : 1,925 m/s
g : 9,81 m/s^2



Source: Drawing Result (2024)

Figure 4. Groin Structure Details STA 0+000 - STA 0+100

Stability Analysis of the Groin Structure. The stability analysis calculations aim to determine the forces acting on the related construction. This analysis includes stability against sliding and overturning, as well as soil bearing capacity. The forces acting on the groin structure include horizontal forces from water pressure and vertical forces from soil pressure and the weight of the structure. The calculation results are shown in Table 9.

Tabel 9. Calculation Results of Lateral Forces

Force	R_H [kN]	R_V [kN	M_H [kN.m]	Mg [kN.m]
Hydrostatic	4725,59		-9074,1	
Soil Pressure		11515,0		-5679,7
Self-Weight		-2568,1		1284,07
Total	4725,59	8946,9	-9074,1	-4395,6
		∑Mt	-13469,71	

Source: Calculation Result (2024)

From the analysis, the stability of the groin structure against overturning is determined as follows:

SF = ∑Mt / ∑Mg > 1,5

SF = -13469,71 / -4395,6 > 1,5

SF = 3,06 > 1,5 (Meets Requirements)

Based on the calculation results, it can be seen that the structural construction of the groin at the river bend is safe against overturning. An analysis of the hydrostatic force is then conducted,

$P_{air} = 0,5 . H^2 . \gamma_w$

$P_{air} = 0,5 \times 8,31^2 \times 10$

$P_{air} = 345,281$ kN/m^3

This results in a hydrostatic moment acting on the groin structure wall :

ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

$M_{air} = P_{air} \times H/3$
$M_{air} = 345{,}281 \times 8{,}31/3$
$M_{air} = 956{,}427$ kN/m.

For the calculation of stability against sliding due to water pressure impacting the groin structure wall, the following is calculated:

$SF = R_V / R_H > 1{,}5$
$SF = 8946{,}9 / 4725{,}59 > 1{,}5$
$SF = 1{,}89 > 1{,}5$ (Meets Requirements)

Based on the calculation results, it can be seen that the structural construction of the groin at the river bend is safe against sliding.

Next, physical and mechanical property tests were conducted on soil samples from the research location at the Soil Mechanics Laboratory of the Civil Engineering Department at Unsyiah. The soil bearing capacity analysis for the groin structure can be seen in Table 10.

Table 10. Soil Bearing Capacity Calculation Results for the Foundation

t_{max}=	20.756	t/m^2 =	2.076	kg/cm^2	< t_{izin}=	7.71675	kg/cm^2
t_{min}=	6.123	t/m^2 =	0.612	kg/cm^2	< t_{izin}=	7.71675	kg/cm^2

Source: Calculation Result (2024)

From the results in the table above, it can be seen that the soil bearing capacity calculation for the foundation in the groin structure planning as a riverbank protector at the bend is safe against failure.

5. Conclusion and Suggestion

Based on the data analysis results, several conclusions can be drawn as follows:

1. The planned groin structure is designed for a flood with a return period of 50 years, with a discharge of 2885,307 m^3/s.
2. The design obtained from the calculations is for a groin length L=30 m, foundation width B=10 m, top surface width B'=3 m and groin height T=12 m.
3. The control calculation for overturning has met the requirement with $SF_{overturning} > 1.5$.
4. The control calculation for sliding has met the requirement with $SF_{sliding} > 1.5$.
5. The soil bearing capacity calculations are safe and can support the load of the groin structure, meeting the calculation requirement that $t_{max} < t_{izin}$

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ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

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