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The Effect of Impermeable Groin Placement on Scour at River Bends

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Abstract
This research aims to determine the magnitude of relative scour depth (ds/t) in relation to the groin installation angle, as well as the coefficient of determination, in a meandering river and the impact of the most effective installation angle for permeable crib, based on the coefficient of determination observed in a meandering river. River modeling was conducted in a hydraulics laboratory using a channel tank measuring 6000 cm in length, 50 cm in width, and 30 cm in height; the channel model featured a single 90° bend equipped with five impermeable groins, utilized sediment-free water, and had an unbranched configuration. Observations involved six simulation runs based on varying groin installation angles—15°, 45°, and 90°—over durations of 30 and 60 minutes.
The study results show that the placement position of impermeable groins has a significant impact on flow patterns and erosion depth. Installing groynes at a 90° angle produces high and stable determination coefficient values, namely 0.9619 at 30 minutes and 0.9336 at 60 minutes, indicating a strong relationship between flow time and erosion depth. Meanwhile, at angles of 45° and 15°, even though the R^2 values were high at the start of the test, they dropped significantly over longer periods to around 0.7445, which indicaes unstable flow and increased erosion potential. It can be concluded that installing impermeable groynes at a 90° angle is the most effective setup for controlling erosion in meandering rivers.

***Keywords**: Groin, Gabion structure, discharge, scour depth*

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I. INTRODUCTION

Aristi (2012) notes that at channel meanders (bends), there are longitudinal velocity components aligned with the flow direction and transverse velocity components perpendicular to the flow direction—directed either toward the inner or outer bank of the bend. The superposition of these two velocity components results in helical flow (a screw-like flow pattern). Centrifugal force at the bend generates a transverse current which, combined with the main current, creates helical flow. Specifically, the centrifugal force at the bend induces a transverse current that interacts with the main current to form helical flow. The magnitude of this transverse current velocity ranges from 10% to 15% of the main flow velocity. Consequently, in meandering rivers, erosion occurs on the outer bank of the bend, while deposition takes place on the inner bank (Aristi, 2012).

According to Triatmodjo (2003), a river or open channel is a waterway in which water flows with a free surface. In open channels—such as rivers (natural channels)—flow variables are highly irregular in terms of both space and time. These variables include the channel's cross-section, roughness, bed slope, bends, and discharge rate. Sosrodarsono (1994) defines a river as a naturally formed, elongated channel on the Earth's surface that conveys rainwater and is continuously subjected to the flow of water.

In addition to centrifugal force, there is helical flow, which results in higher flow velocities along the outer bank of a bend compared to the inner bank. This phenomenon causes damage to existing infrastructure, erosion of the riverbank on the outer side of the bend, and sediment deposition on the inner side. If this process continues over time, it leads to changes in river morphology. River meandering is a highly complex phenomenon influenced by parameters such as bed sediment, river geometry, and flow discharge. (M. Galib Ishak et al., 2008)

Mudjiatko (2000) stated that water flowing through a bend experiences centrifugal force—a force that drives the water outward toward the outer bank. Centrifugal force acts when there is no transverse mass transfer of water. The vertical distribution of flow velocity—where surface velocity exceeds velocity near the riverbed—influences the distribution of this centrifugal force; consequently, the centrifugal force is greater at the surface than near the bed. Helical flow is a spiral movement of river water that causes erosion on the outer bank and deposition on the inner bank. The magnitude of the transverse current velocity ranges from 10% to 15% of the main flow velocity; notably, near the surface, the transverse current moves toward the inner side of the bend. Forces at the bend generate transverse river currents which, combined with the main flow, create helical flow. (Vita Dwi Febriani et al., 2015)

II. MATERIAL AND METHODS

This study was conducted with model simulations carried out at the Hydraulics Laboratory of Bina Darma University (Figure 1).

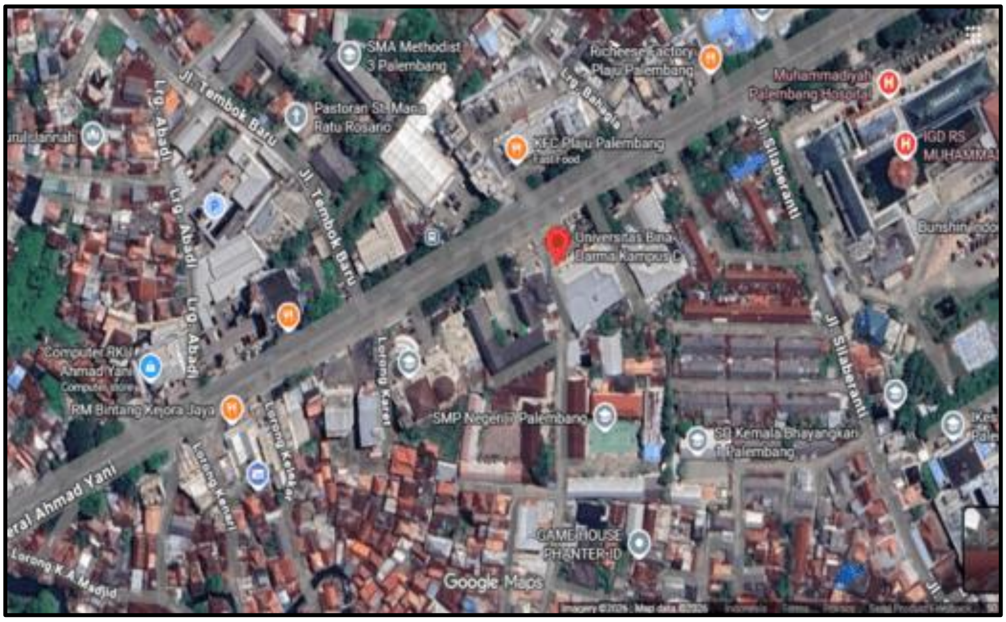

Figure 1: Map of the research area

2.1. Laboratory Modeling

The laboratory model was constructed as shown in Figure 3.2 to calibrate or compare numerical calculation results against a fixed-bed baseline.Laboratory Experimental Setup

Figure 2: Position of a spur dike at a 90° angle at a river or channel bend

The experimental equipment and procedures are as follows:

1. A rectangular channel model (50 cm wide, 30 cm high, and 600 cm long) with a 90° bend, constructed with brick walls.
2. A point gauge for measuring water surface elevation. Measurements are taken across the channel's transverse section at the bend during the simulation run.
3. A stopwatch to measure the time required to collect the flow discharge at the channel outlet. For this purpose, the water discharge is collected, and both the collection time and volume are measured. Based on the time and volume data, the average flow velocity in the channel can be determined.

4. Laser Doppler (a laser-based flow velocity measuring device) and a current meter to measure flow velocity distribution (vertically and horizontally) in both straight sections and at the bend. These instruments are movable, allowing for the measurement of vertical velocity distribution, particularly at the bend.
5. Water source (pump). Water is supplied via a previously calibrated pump. Simulation runs are conducted using various discharge rates.

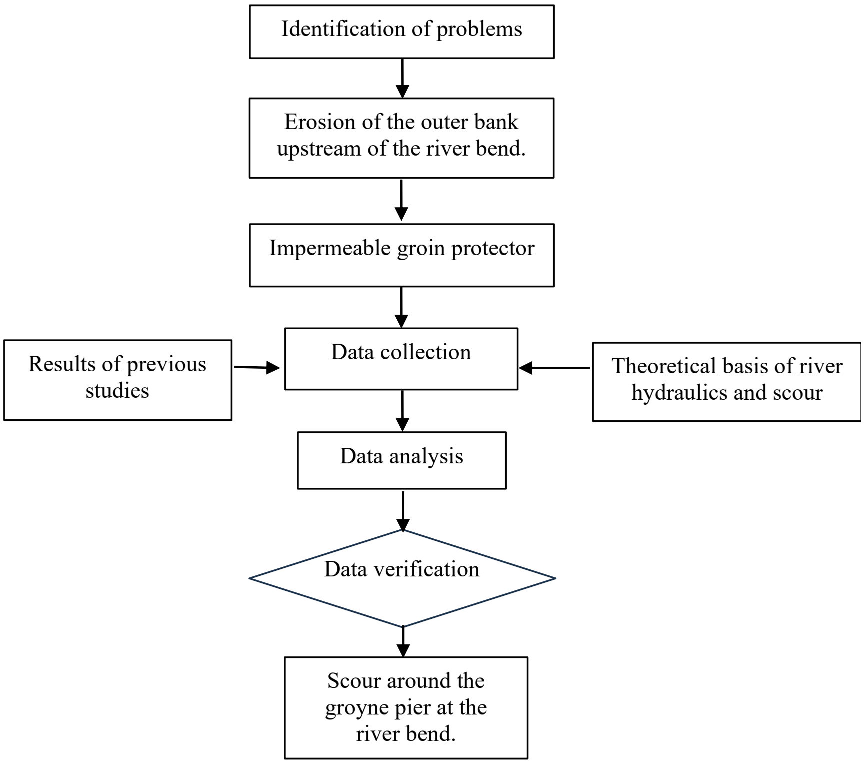

Figure 3: Research framework

III. RESULTS AND DISCUSSION

2.2 Model Scale Analysis

The dimensional analysis in this study employs Langhaar's method; this approach is considered more suitable because it involves relatively few parameters and is typically used for relatively simple problems. Dimensionless numbers are derived directly from the relationships between the existing parameters. However, this method would encounter difficulties in complex problems involving a large number of parameters.

$$ds = f(Q, v, h, \rho w, g, t) \qquad (2.1)$$

The steps for the dimensional analysis are as follows:
1. The problem formulation identifies the parameters influencing sedimentation (bedload) as follows: flow discharge (Q), flow distance (x), water depth (h), scour depth (ds), gravity (g), water density (ρw), and time (t).
2. These parameters are categorized as follows:
a. Dependent parameter: ds
b. Parameters that vary during the experiment: Q, x, h, and t
c. Another parameter: g and ρw

3. The values of α1, β1, and γ1 are determined via tabulation

Grup	**1**	**2**			**3**		**Note**
Parameter	**Q**	**x**	**t**	**ρ**	**g**		
M	3	0	0	1	0		α1
L	0	1	1	-3	1		β1

T	-1	0	1	0	-2		γ1
	k1	k2	k3	k4	k5		ki

Equations related to the parameters
k5 = 0
k1 + k2 +2k3 -3k5 + k6 = 0
k3 +k4 – 2k6 = 0

Eliminate k6
2k5 + k6 = 0 k6 = -2k5
k1 + k2 + k3 + 2k5 = 0
2k5 = - k1 - k2 - k3

Determination of the dimensionless numbers:

ki	k1	k2	k3	k4	k5
Parameter	**ds**	**x**	**t**	**ρ**	**g**
π1	1	0	-1	0	0
π2	0	1	-1	0	0
π3	0	1	-1	0	0
π4	0	0	1	1	0,5

π1 = ds/t
π2 = x/t
π3 = x/t
π4 = 0.5gt = √ 2g x t
(x/t) x (√2gt)
x/t x (g1/2 t1/2) is equivalent to v = √2gh
f (ds/t; x/t; v) = 0 (v ≈ 0)
(ds/t) = f (x/t)

3.2 Discussion
3.2.1. Experiment with a 90° groyne angle and a duration of 30 minutes

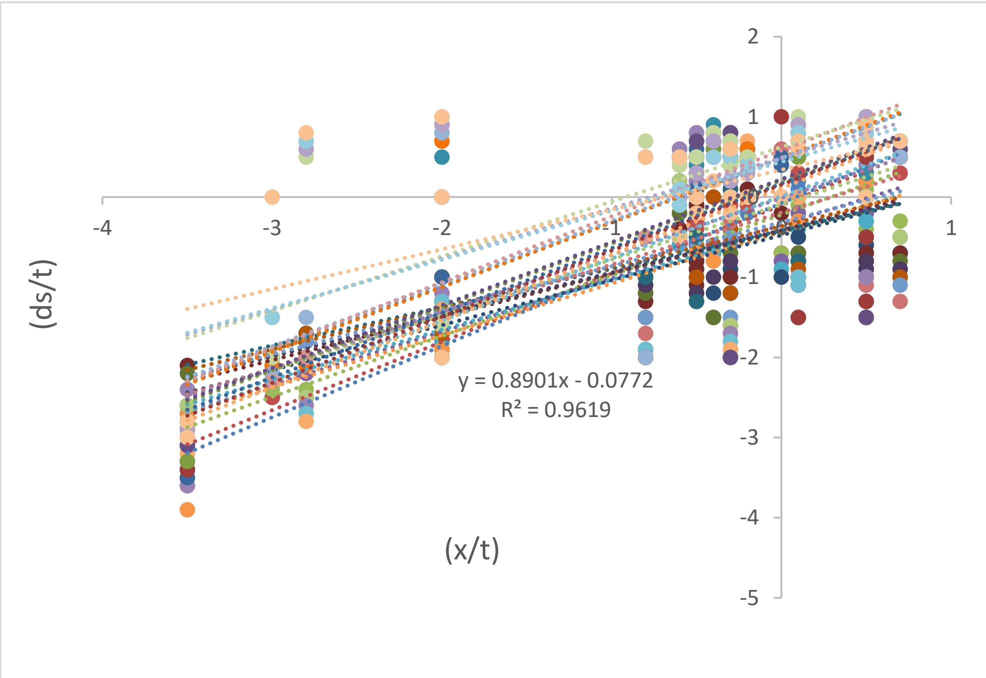

Figure 4: Relative scour (ds/t) vs. (x/t) for a 90° crib and a 30-minute simulation time.

Based on the analysis results shown in Figure 4.1—specifically for the first simulation where the spur dike was installed perpendicular (at a 90° angle) during a 30-minute test run—the maximum scour observed was -2.0 cm. The coefficient of determination (R^2) was 0.9619, indicating that 96.19% of the data variation could be explained by the model, while the correlation coefficient (R) was 0.9252 (92.52%), signifying a strong relationship between the two variables: scour depth (ds) and flow duration (t).

3.2.2 Experiment with a 90° groyne angle and a duration of 60 minutes

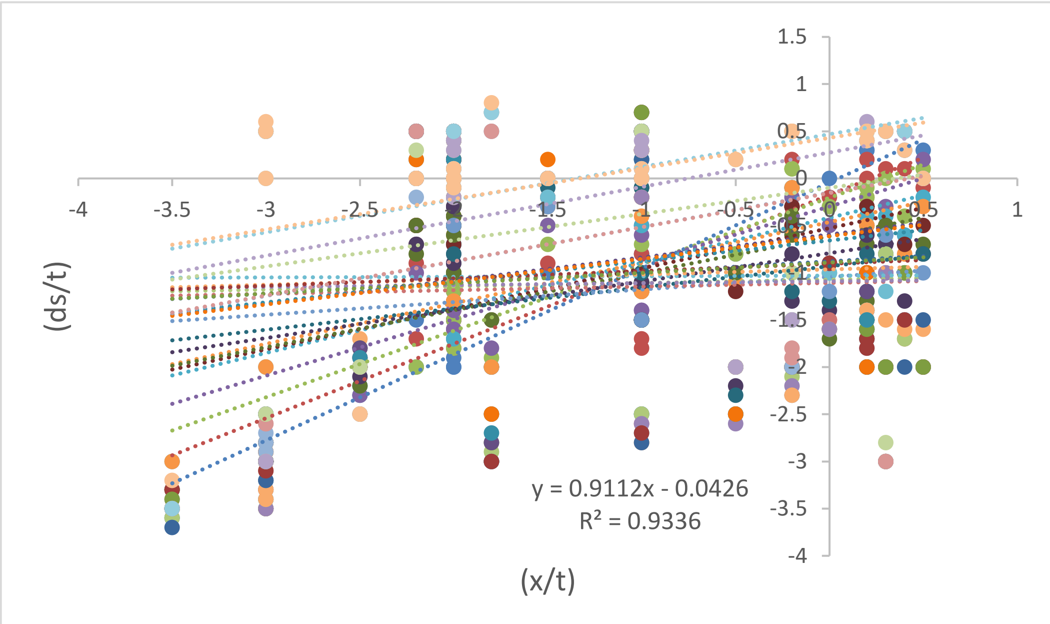

Figure 5: Relative scour (ds/t) vs. (x/t) for a 90° spur dike at 60 minutes.

The analysis results are as shown in Figure 6; the second simulation, which utilized a combination of groin and gabions, produced a scour depth of 5.0 cm. The coefficient of determination (R^2) was 0.8713—indicating that 87% of the data variation could be explained by the model—while the correlation coefficient (R) was 0.759164 (or 76%), signifying a strong relationship between the two variables: scour depth (dg) and flow discharge (Q).

IV. CONCLUSION

Based on the data analysis and discussion, the conclusions of this study are as follows:

1. 1. The magnitude of scour depth relative to flow duration (ds/t) in meandering rivers depends heavily on the installation angle of the spur dikes; a perpendicular angle (90°) is the most recommended design, as it limits scour to minimal levels (ranging from -2.0 cm to 1.8 cm) while maintaining high model consistency throughout 60-minute simulations, evidenced by very strong coefficients of determination (R^2) ranging from 0.9336 to 0.9619.
2. Installing permeable groynes at a 90° angle represents the most effective configuration for controlling scour in meandering rivers, as it generates flow conditions that are relatively stable and consistent in managing the scouring process. With the 90° groyne installation (perpendicular to the flow), the coefficient of determination was found to be 0.9619 at 30 minutes and 0.9336 at 60 minutes.

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