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Effect of Permeable Groins on Scour at River Bends

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Abstract

This research aims to determine the influence of flow hydraulic parameters on the magnitude of scour occurring at permeable spur dike structures in river bends and to determine the magnitude of scour occurring at permeable spur dike structures in river bends.
A rectangular channel measuring 50 cm in width and 50 cm in height, with a 90° bend, constructed of brickwork that is plastered and painted.Four discharge variations of 1.05×10^{-4}, 1.1167×10^{-4}, 1.2167×10^{-4}, and 1.6167×10^{-4} m^3/s were applied to evaluate hydraulic characteristics and scour development.
The results indicate thata significant relationship between scour depth (ds) and flow duration (t), with a coefficient of determination (R^2) of 83.43% and a correlation coefficient (R) of 69.60%; R^2 of 75.57% with R of 57.10%; R^2 of 87.40% with R of 76.38%; and R^2 of 77.40% with R of 59.90%. This indicates a strong correlation between the two variables: scour depth (ds) and flow duration (t).For a permeable spur dike at a 90° angle and a flow duration of 15 minutes, the maximum scour was -3.4 cm and deposition/sedimentation were+1.5 cm, with an average scour of -0.82 cm. At a 90° angle and a flow duration of 30 minutes, the maximum scour was -3.6 cm and deposition/sedimentation were +0.5 cm, with an average scour of -0.71 cm. At a 90° angle and a flow duration of 45 minutes, the maximum scour was -3.4 cm and deposition/sedimentation were +1.5 cm, with an overall average scour of -0.82 cm. At a 90° angle and a flow duration of 60 minutes, the maximum scour were -3.8 cm and deposition/sedimentation were +1.5 cm, with an overall average scour of -0.88 cm.

***Keywords**: Permeable groin, flow hydraulics, discharge, subcritical flow, erosion*

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I. INTRODUCTION

A river is a natural channel that functions to collect precipitation from a watershed and convey it to a larger receiving water body, such as the sea. The dynamics of fluvial flow frequently induce morphological degradation in the form of erosion (scouring) and deposition (sedimentation). Significant damage can occur along the river course, including severe bank erosion and even bank collapse, particularly along the outer bank of river bends, while sediment deposition generally occurs along the inner bank.

The centrifugal force acting on flowing water is generally greater near the water surface than near the riverbed. Helicoidal flow is defined as a spiral motion of water that induces erosion along the outer bank and sediment deposition along the inner bank of a river bend. The magnitude of this transverse velocity ranges from approximately 10% to 15% of the primary flow velocity, with the transverse current moving toward the inner bank near the water surface. Collectively, the forces acting within a river bend generate transverse currents which, when combined with the primary flow, produce a helicoidal flow pattern (Febriani VD et al., 2015). Figure 1 illustrates the helicoidal flow pattern together with the associated erosion and deposition processes occurring in a river bend.

In addition to centrifugal force, helicoidal flow plays a significant role in the redistribution of flow velocity, resulting in higher velocities along the outer bank than along the inner bank of the bend. This phenomenon contributes to damage of existing river infrastructure, severe erosion of the outer riverbank, and sediment accumulation along the inner bank. If these processes continue over time, substantial changes in river morphology may occur. The morphology of meandering rivers is a complex hydraulic phenomenon influenced by the interaction of several parameters, including bed sediment characteristics, channel geometry, and flow discharge (M. Galib Ishak et al., 2008).

Permeable groins installed at an angle of 90° facing upstream have been reported to provide the best performance in minimizing bed deformation and local scour, as indicated by the lowest values of Bt/Bo and ds/y and an R^2 value approaching unity (Ayu MarlinaHumairah, 2014). Agung Wiyono et al. (2011) found that maximum scour around an abutment without wing walls occurred upstream of the structure, whereas for abutments with wing walls, maximum scour occurred at the center of the structure. The greatest sediment deposition was observed downstream of the abutment. Furthermore, the Laursen (1960) equation yielded the highest accuracy for abutments without wing walls (20.02%), while the Froehlich (1989) equation provided the best prediction for abutments with wing walls (28.17%).

The study also demonstrated that increasing flow discharge significantly increased maximum scour depth. BangunSugito et al. (2017) reported that the highest flow discharge (Q3) generated the largest vortices and the longest vortex radius, whereas the lowest discharge (Q1) combined with a groin orientation of 15° (S2) produced the most stable flow conditions. The position of the groin influenced the location of vortex formation, while higher discharges expanded the vortex region. James Zulfan et al. (2018) demonstrated that groins effectively reduced flow velocity along the outer bend of a river. Their second alternative design, consisting of six groins spaced 20 m apart, reduced the flow velocity from 5.5 m/s to 3.6 m/s and significantly decreased local scour. A spacing-to-length ratio of $d = 2L$ was identified as the optimum configuration, and the addition of riprap was recommended as supplementary bank protection.

M. Galib Ishak et al. (2008) further reported that scour along the outer bank increases with increasing flow velocity and Froude number. Both physical and numerical models consistently indicated that cross-sectional deformation and water level rise along the outer bank are the primary factors contributing to scour in the Palu River. Sunaryo et al. (2010) found that groin installation effectively reduced riverbank failure along a 120° bend. The optimum groin spacing was approximately equal to the bank height, while the most effective groin orientation was 135° directed upstream.

Vita Dwi et al. (2015) observed that increasing flow discharge intensified erosion along the outer bend and sediment deposition along the inner bend, resulting in more rapid morphological changes, particularly in the downstream section of the bend. Therefore, investigating the influence of permeable groin structures on scour patterns along the outer bank of river bends is essential to support the development of effective riverbank protection and river management strategies.

II. MATERIAL AND METHODS

This study was conducted in the Hydrology and Hydraulics Laboratory of Bina Darma University, as shown in Figure 1.

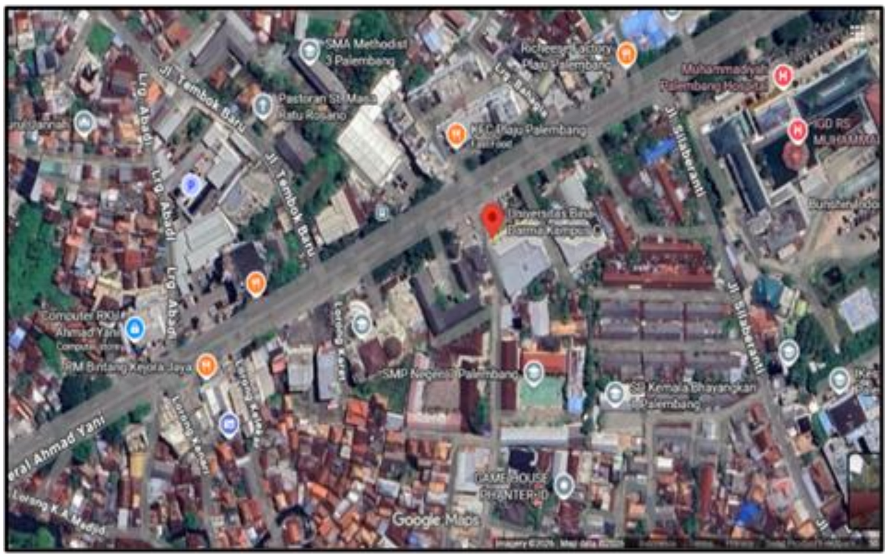

Figure 1: Research location

2.1. Laboratory Experimental Setup

To support this study, the following materials and equipment were used:

1. An experimental flume with a movable sand bed composed of sediment having a median grain diameter d_{50} of 0.47 mm.
2. Freshwater as the flow medium.
3. Bottom-panel permeable groins constructed using coral stones with diameters ranging from 2 to 3 cm.

4. A flow velocity measuring device.
5. A water depth measuring device.
6. Instruments for measuring changes in the channel cross-sectional profile, along with other supporting equipment.
7. The flow simulation was conducted five timesby varying the flow discharge and the spacing between the permeable groins.
8. The data collected included observations of flow depth, flow velocity, and changes in the channel cross-section after each simulation.

This study involved several research variables, as presented in Table 1.

Table 1. Research Variables

Variable	Variable Type
Flow discharge (Q	Independent variable
Flow velocity (V)	Dependent variable
Flow depth (y)	Dependent variable
Permeable groin spacing (L)	Controlled variable
Channel bed slope (S)	Controlled variable
Channel bottom width (b)	Controlled variable

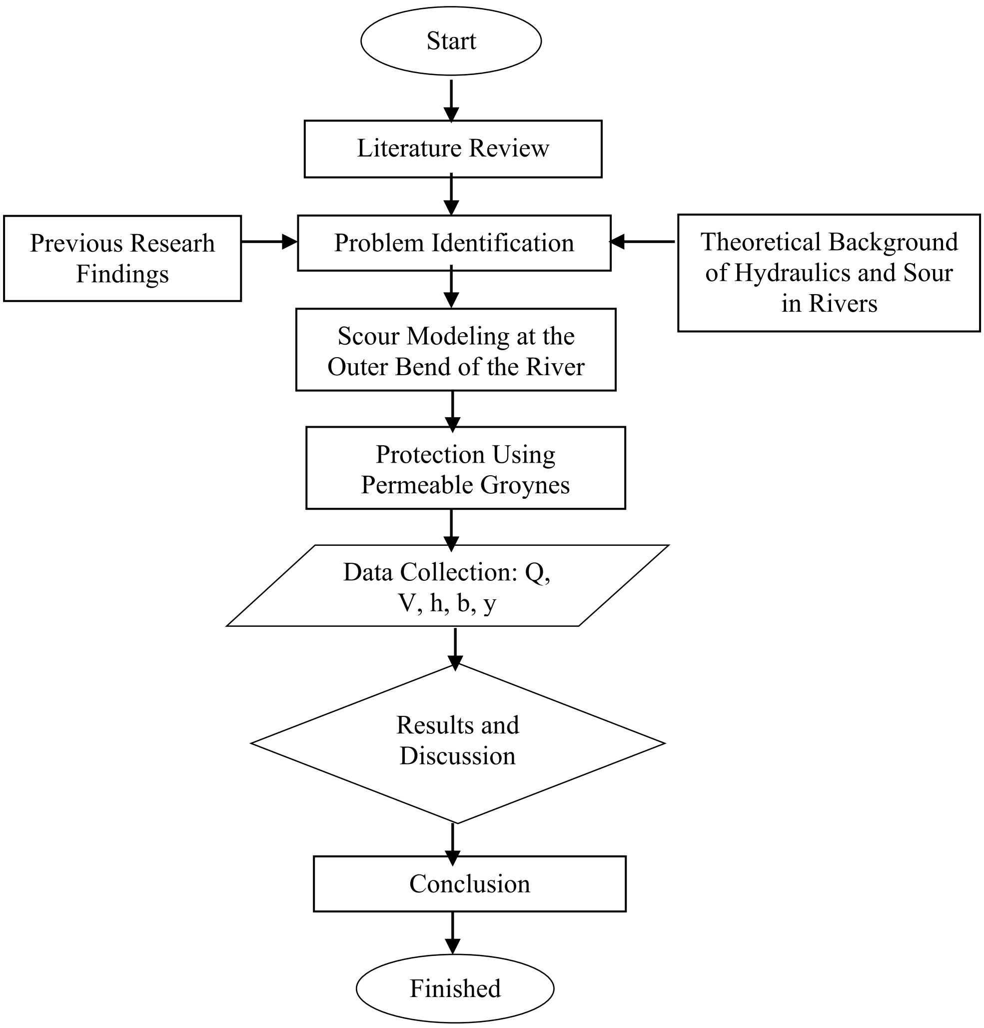

Figure 2: Flowchart

III. RESULTS AND DISCUSSION

3.1 Hydraulic Analysis

The experiments were conducted using an experimental flume with a width of 0.60 m and a total length of 6.0 m. The flume incorporated a 90° bend located 3.0 m downstream and oriented toward the right. A 5-cm-thick sediment layer was placed within the test section between 3.0 and 5.0 m. Permeable groins were installed sequentially along the outer bank at longitudinal positions of 3.0, 3.5, 4.0, 4.5, and 5.0 m. Hydraulic characteristics were evaluated under four different discharge conditions, as presented in Table 2

Table 2. Experimental Discharge Conditions

Simulation	Discharge (ml/s)	Discharge (m^3/s)
1	111.67	1.1167×10^{-4}
2	105.00	1.05×10^{-4}
3	121.67	1.2167×10^{-4}
4	161.67	1.6167×10^{-4}

The sediment used in the experiments consisted of sand collected from the Tanjung Lubuk area, Inderalaya Regency, South Sumatra Province. Based on the particlesize analysis conducted in the Soil Laboratory, the sediment characteristics were d_{10} = 0.320 mm, d_{50} = 0.670 mm, and d_{90} = 1.200 mm.

3.2 Hydraulics Parameter Analysis

Several parameters were obtained from the laboratory measurements conducted during the experiment. These parameters included the flow depth (y), wetted cross-sectional area (A), channel width (b), hydraulic radius (R), wetted perimeter (P), specific weight of water (ρw), and gravitational acceleration (g). These parameters were used to analyze the measurement data obtained from the open-channel flume. The wetted cross-sectional area was calculated using the following equation:

$A = b \text{ x } y$

$A = 0.60 \times 0.05$

$A = 0.03 \text{ m}^2$

Given a flow depth of (y) = 0.05 m and a channel width of = 0.6 m, the wetted cross-sectional area of the channel was 0.03 m^2

The wetted perimeter of the channel was calculated using:

$P = b + 2y$

$P = 0.60 + (2 * 0.05)$

$P = 0.70 \text{ m}$

Thus, with a flow depth of (y) = 0.05 m and a channel width of = 0.60 m, the wetted perimeter was 0.70 m. The hydraulic radius was subsequently determined using the following equation:

$$R = \frac{A}{P}$$

$R = 0.03 / 0.70$

$R = 0.0429 \text{ m}$

Given a wetted cross-sectional area of A = 0,03 m and a wetted perimeter of p = 0,7 m, the hydraulic radius of the channel was 0.0429 m. The specific weight of water was 9.810 N/m^3 nd the gravitational acceleration was 9.81 m/s^2.

In Experiment 1, several research variables were obtained analytically, including the flow discharge, $Q_1 = 1.1167 \times 10^{-4}$ m^3/s. Subsequently, the flow velocity (V) was determined from the measurement results.

$$V_1 = \frac{Q_1}{A}$$

$V_1 = (1.1167 \times 10^{-4}) / 0.03$

$V_1 = 0.00372 \text{ m/s}$

The calculated flow velocity was relatively low and indicated a flow condition approaching the transition regime. After determining the flow velocity, the Froude number was calculated. The Froude number is a dimensionless parameter used to characterize the flow regime.

$$Fr = \frac{v}{\sqrt{gy}}$$

$=\sqrt{(9.81 \times 0.05)} = \sqrt{(0.4905)} = 0.700 \text{ m/s}$

$$Fr = \frac{0.00372}{0.700}$$

$Fr_1 = 0.0053$

Since Fr<1, the flow was classified as subcritical flow. Under subcritical conditions, the flow behavior is predominantly controlled by gravitational forces. The hydraulic disturbance generated by the permeable groins may propagate toward the upstream section$\tau = \gamma R S$

Because the channel-bed slope in the laboratory flume was relatively small, with an energy slope of S=0.001, the bed shear stress was calculated as follows:

$\tau_1 = 9810 \times 0.0429 \times 0.001$

$\tau_1 = 0.421$ N/m²

The hydraulic parameters obtained from simulations 1–4 are presented in Table 3

Tabel 3. Obtained from Experiments

Parameter	P1	P2	P3	P4
Velocity, (V) (m/s)	0.00372	0.00350	0.00406	0.00539
Froude number, (Fr)	0.0053	0.0050	0.0058	0.0077
Bed shear stress, (\tau) (N/m²)	0.421	0.421	0.421	0.421

3.3 Dimensional Analysis

3.3.1 First Simulation

Based on the analysis presented in Figure 5, the first experimental simulation was conducted with the permeable groins installed at a 90° angle to the channel bank for a flow duration of 15 minute. The maximum scour depth observed during the experimental run was 3.8 cm. The coefficient of determination (R^2) was 0.8343, indicating that 83.43% of the variation in the observed scour data could be explained by the fitted regression relationship. The correlation coefficient (R) was 0.6960, corresponding to 69.60%, indicating a relatively strong relationship between the two variables.

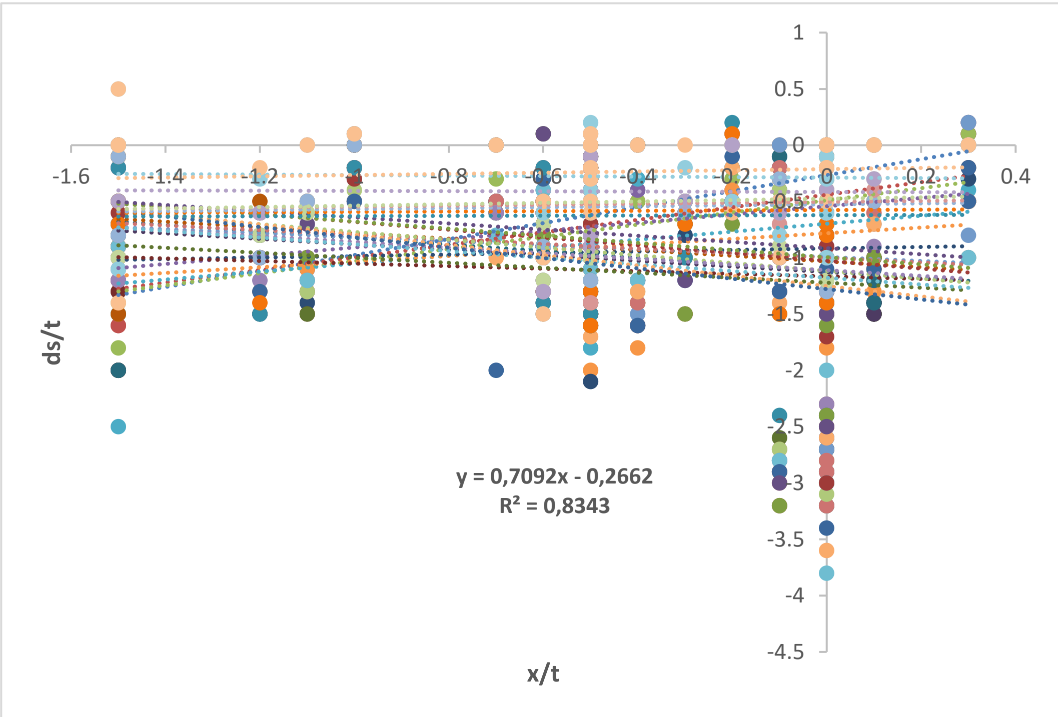

Figure 3: Relative scour depth (ds/t) vs (x/t) for the 90º groin configuration after 15 min of flow

Based on the analysis results shown in Figure 3 specifically for the first simulation where the spur dike was installed perpendicular (at a 90° angle) and subjected to a 15-minute "running test"—the maximum scour observed was -3.9 cm. The coefficient of determination (R^2) was 0.8343, indicating that 83.43% of the data variation could be explained by the model, while the correlation coefficient (R) was 0.6960 (69.60%), signifying a reasonably strong relationship between the two variables: scour depth (ds) and flow duration (t).

3.3.2 Second Simulation

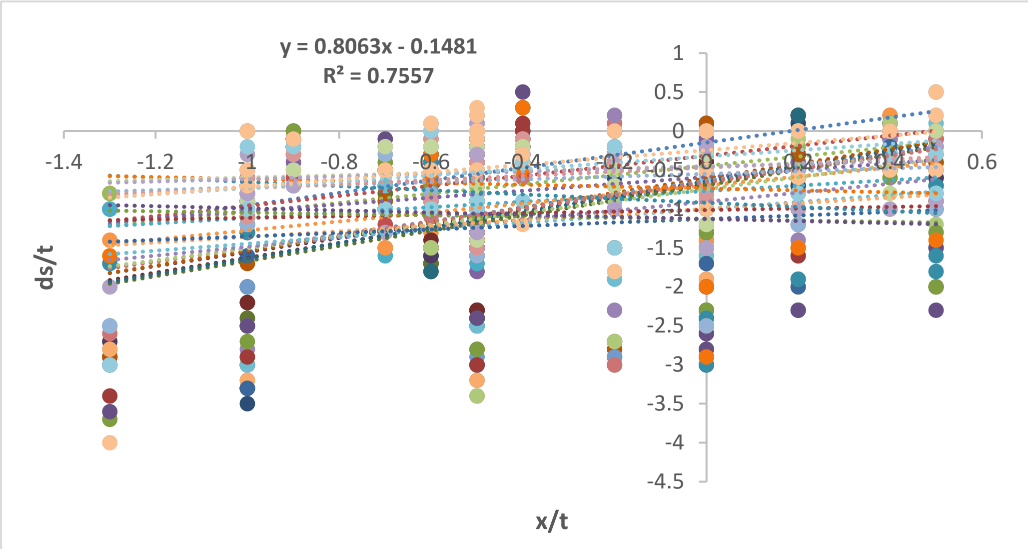

Figure 4: Relative scour depth (ds/t) vs (x/t) for the 90° groin configuration after 30 minutes of flow

Based on the analysis results shown in Figure 4where the second simulation involved a spur dike installed perpendicular (90°) to the flow and a simulation duration of 30 minutes—the maximum scour depth recorded was -4.0 cm. The coefficient of determination (R^2) was 0.7557, indicating that 75.57% of the data variation could be explained by the model, while the correlation coefficient (R) of 0.5710 (or 57.10%) signifies a strong relationship between the two variables: scour depth (ds) and flow duration (t).

3.3.3Third Simulation

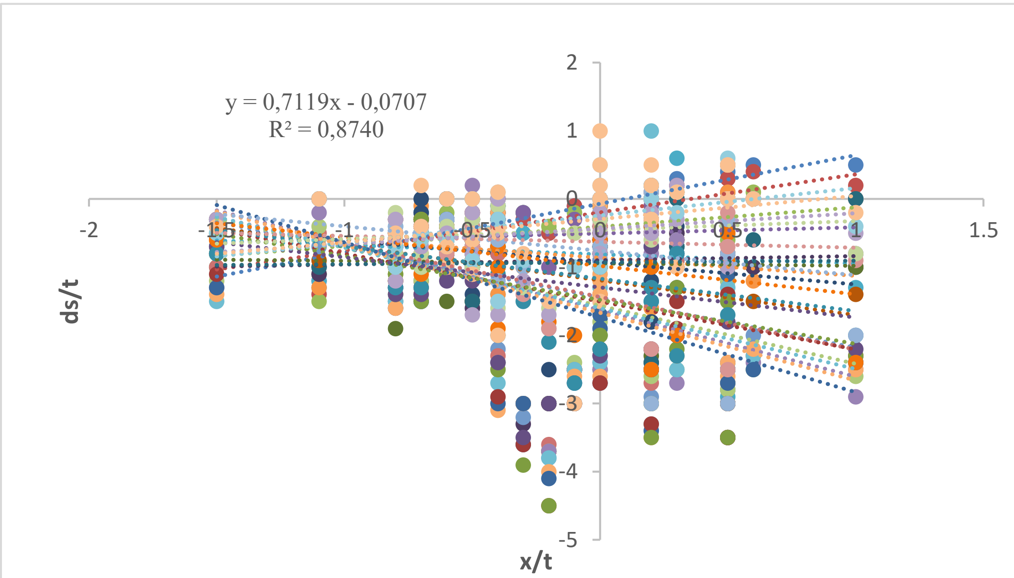

Figure 5: Relative scour depth (ds/t) vs (x/t) for the 90° groin configuration after 45 minutes of flow

Based on the analysis results shown in Figure 5 where the second simulation utilized a spur dike set at a 90° angle over a 30-minute duration—the maximum relative scour depth was -3.0 cm. The coefficient of determination (R^2) was 0.8740, indicating that 87.40% of the data variation could be explained by the model, while the correlation coefficient (R) of 0.7638 (or 76.38%) signifies a strong relationship between the two variables: scour depth (ds) and flow duration (t).

3.3.4Fourth Simulation

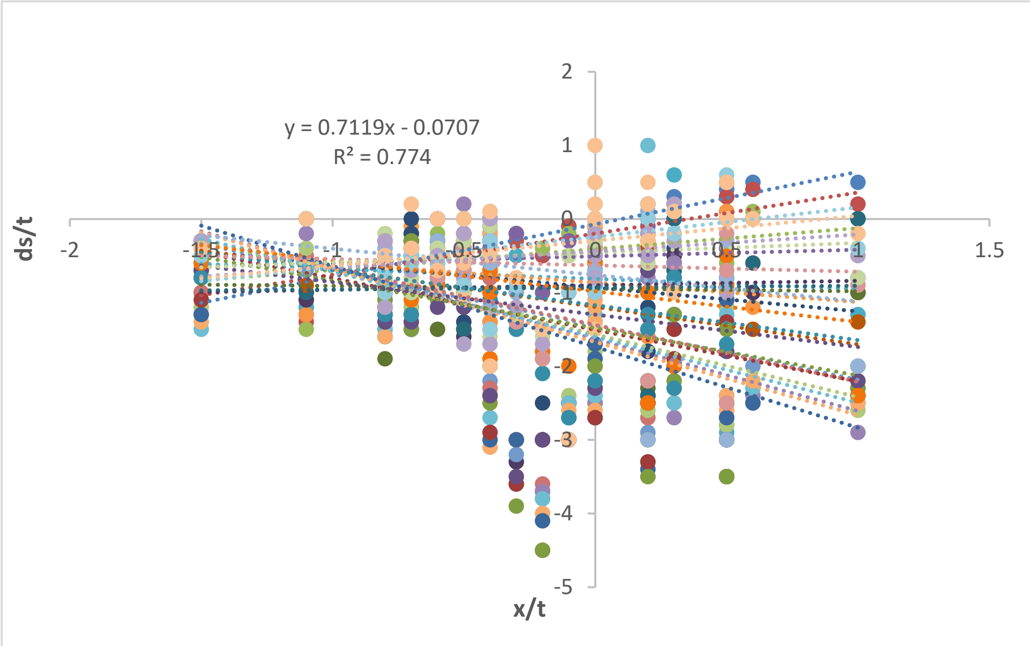

Figure 6: Relative scour depth (ds/t) vs (x/t) for the 90° groin configuration after 60 minutes of flow

Based on the analysis results shown in Figure 6 where the simulation involved a spur dike set at a 90° angle and a duration of 60 minutes—the maximum scour depth observed was 3.8 cm. The coefficient of determination (R^2) was 0.7740, indicating that 77.40% of the data variation could be explained by the model, while the correlation coefficient (R) was 0.5990 (59.90%), signifying a strong correlation between the two variables: scour depth (ds) and flow duration (t).

IV. CONCLUSION

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

1. There is a significant relationship between scour depth (ds) and flow duration (t), with a coefficient of determination (R^2) of 83.43% and a correlation coefficient (R) of 69.60%; R^2 of 75.57% with R of 57.10%; R^2 of 87.40% with R of 76.38%; and R^2 of 77.40% with R of 59.90%. This indicates a strong correlation between the two variables: scour depth (ds) and flow duration (t).
2. For a permeable spur dike at a 90° angle and a flow duration of 15 minutes, the maximum scour was -3.4 cm and deposition/sedimentation was +1.5 cm, with an average scour of -0.82 cm. At a 90° angle and a flow duration of 30 minutes, the maximum scour was -3.6 cm and deposition/sedimentation was +0.5 cm, with an average scour of -0.71 cm. At a 90° angle and a flow duration of 45 minutes, the maximum scour was -3.4 cm and deposition/sedimentation was +1.5 cm, with an overall average scour of -0.82 cm. At a 90° angle and a flow duration of 60 minutes, the maximum scour was -3.8 cm and deposition/sedimentation was +1.5 cm, with an overall average scour of -0.88 cm.

REFERENCES

[1]. Achmad Syarifudin, 2017, The influence of Musi River Sedimentation on the Aquatic Environment, DOI: 10.1051/matecconf/201710104026, MATEC Web Conf, 101, 04026, [published online 09 March 2017]
[2]. Achmad Syarifudin and Dewi Sartika, Scouring Patterns Around Pillars of Sekanak River Bridge, Journal of Physics: IOP Conference Series, volume 1167, 2019, IOP Publishing
[3]. Achmad Syarifudin, 2018, Environmentally Conscious Urban Drainage, Penerbit Andi, pp. 38-42
[4]. Ayu Marlina Humairah, 2014, Hydraulic analysis of permeable spur dikes in earthen channels (Laboratory model test), Journal of Civil and Environmental Engineering, Vol. 2 No. 3, September 2014
[5]. Bangun Sugito Riski Hasibuan, Mudjiatko, and Rinaldi, 2017, Laboratory model of flow patterns around impermeable spur dikes regarding discharge variations and spur dike positioning in a meandering river, Jom FTEKNIK Volume 4 No. 1, February 2017
[6]. Cahyono Ikhsan, 2017, The effect of flow discharge variations on open channel beds with uniform flow, Media Teknik Sipil
[7]. Chow V.T., D.R. Maidment, and L.W. Mays, (1988), Applied Hydrology, McGraw-Hill Co. Department of Public Works, Guidance for Landslide Management Planning, SKBI - 2.3.06, 1987, PU Publication Agency Foundation
[8]. Holdani Kurdi, Ulfa Fitriati, Robertus Chandrawidjaya, 2019, Hydraulic Modeling, Lambung Mangkurat University Press

[9]. Hydraulic Engineering Circular Number 18, 2001, Evaluating Scour at Bridges, May 2001 - 4th edition, Publication No. FHWA-NHI-01-001, Errata Sheet October 6, 2001 – version 1.0
[10]. Hydraulic Engineering Circular No. 18, 2012, Evaluating Scour at Bridges Fifth Edition, April 2012 Publication No. FHWA-HIF-12-003, U.S. Department of Transportation Federal Highway Administration
[11]. Istiarto, 2012, River Engineering: Sediment Transport, Universitas Gadjah Mada, Yogyakarta
[12]. Istiarto, 2012, River Engineering, Universitas Gadjah Mada, Yogyakarta
[13]. Okubo K, Muramoto Y, and Morikawa H, 1994, "Experimental Study on Sedimentation over the Floodplain due to River Embankment Failure," Bulletin of the Disaster Prevention Research Institute, Kyoto University, 44 (2), pp. 69-92
[14]. Paimin et al., 2012, Watershed Management Planning System, Center for Research and Development of Conservation and Rehabilitation (P3KR), Bogor, Indonesia
[15]. Robert J. Kodoatie & Sugiyanto, 2002, Flood Causes and Methods of Control from an Environmental Perspective, Yogyakarta
[16]. Robert J. Kodoatie & Sugiyanto, 2002, Flood Causes and Methods of Control from an Environmental Perspective, Yogyakarta
[17]. Suripin, 2004, Sustainable Urban Drainage Systems, Andi Publishers, pp. 176-179. Suripin, *Sustainable Urban Drainage Systems*, 2004, Andi Publishing Company, pp. 176-179
[18]. Syarifudin A., Destania H.R., "IDF Curve Patterns for Flood Control of the Air Lakitan River, Musi Rawas Regency," *IOP Conference Series: Earth and Environmental Science*, Volume 448, 2020 (The 1st International Conference on Environment, Sustainability Issues and Community Development, 23–24 October 2019, Central Java Province, Indonesia)
[19]. Syarifudin A., 2014, The 2nd International Conference on Informatics, Environment, Energy, and Applications (IEEA 2013), Bali, Indonesia, March 16–17, 2013; *JOCET (Journal of Clean Energy and Technology)*, ISSN: 1793-821X, Vol. 2, No. 1, January 2014
[20]. Van Rijn, L.C., 2007, "Unified View of Sediment Transport by Currents and Waves II: Suspended Transport," *Journal of Hydraulic Engineering*, Vol. 133, Issue 6, pp. 668-689.
[21]. Wanshun Zhang, Yanhong Xu, Yanru Wang, and Hong Peng, 2014, "Modeling Sediment Transport and River Bed Evolution in River Systems," *Journal of Clean Energy Technologies*, Vol. 2, No. 2, April 2014
[22]. Yang, C.T., *Sediment Transport: Theory and Practice*, McGraw-Hill, Singapore, 1996.
[23]. Achmad Syarifudin, 2023, *Sistem Drainase Perkotaan Berwawasan Lingkungan* [Environmentally Conscious Urban Drainage Systems], Bening's Publisher, pp. 38-42
[24]. Agung Wiyonno, Joko Nugroho, Widyaningtias, and Eka Risma Zaidun, 2011, "Comparison of Local Scour Occurring Around Vertical-Wall Abutments Without Wings and With Wings in Straight Channels, 90° Bends, and 180° Bends (Laboratory Study)," *Jurnal Teknik Sipil* [Journal of Civil Engineering], Vol. 18 No. 1 April 2011
[25]. James Zulfan and Yiniarti Eka Kumala, 2018, Effectiveness of groynes in reducing scour at the outer bend of the Bengawan Solo River, *Jurnal Teknik Hidraulik*, Vol. 9 No. 2, December 2018: 115–126
[26]. M. Galib Ishak and Rudi Herman, 2020, *River Engineering*, Untad Press, Palu
[27]. M. Galib Ishak and I Gede Tunas, 2008, Flow analysis at channel bends (physical and mathematical model study to explain scour phenomena in the Palu River), *Jurnal "MEKTEK"* Year X No. 3, September 2008
[28]. Sunaryo, Darwizal Daoed, and Febby Laila Sari, 2010, Effect of groyne installation in a channel with a 120° bend, Volume 6 No. 1, February 2010
[29]. Sumiadi, 2014, Flow in meandering rivers with flat and scoured beds, Dissertation, Doctoral Program in Civil Engineering, UGM, Yogyakarta
[30]. SNI 3965:2008, 2008, Procedure for constructing physical river models with fixed beds, National Standardization Agency (BSN)
[31]. Vita Dwi Febriani, Mudjiatko, and Siswanto, 2015, Laboratory model of the effect of discharge on morphological changes in a double-bend river, JOM FTEKNIK Volume 2 No. 1, February 2015