International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 22, Issue 8 (August 2026), PP 144-150

Local Scour with Varying Discharge Around Bridge Piers

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Abstract
This study was conducted to determine the magnitude of local scour around bridge piers under various flow discharge conditions using a scaled model, and to establish the correlation between flow discharge and the resulting scour magnitude.
The equipment used in this experiment included a pump, a scour depth measuring device, a camera, and a measuring tape, while the materials consisted of river sand passing through a No. 10 sieve to form the riverbed and a concrete bridge pier model.
The conclusion of this study is Based on a flow rate of Q_{model} = 196.67 ml/s, a maximum local scour of -1.5 cm and sedimentation of +0.7 cm were observed, with an average scour of -0.31 cm; for Q_{model} = 358.33 ml/s, the maximum scour was -2.1 cm and sedimentation was +1.0 cm, with an average scour of -0.42 cm.
A correlation between the flow rate (Q_{model}) and the magnitude of local scour was found for Q_{model} = 196.67 ml/s and Q_{model} = 375 ml/s, whereas no correlation regarding the depth of scour was observed for Q_{model} = 357 ml/s. However, the data for Q_{model} = 375 ml/s (45-minute simulation) and Q_{model} = 421.67 ml/s (60-minute simulation) could not be used because they did not show a positive correlation, despite the occurrence of local scour.

Keywords: *Physical model, flow capasity,local scouring, sediment transport*

Date of Submission: 15-08-2026 Date of acceptance: 30-08-2026

I. INTRODUCTION

Natural rivers exhibit three distinct forms: straight, meandering, and braided. Water flowing through a bend experiences centrifugal force—a force that drives the water toward the outer side of the curve (Mudjiatko, 2000). This centrifugal force at the bend generates a transverse current which, combined with the main flow, creates a helical flow pattern. This spiral, helical movement of the river water is responsible for the erosion of the outer bank and the deposition of sediment along the inner bank.

A pier is a bridge component that connects directly to the riverbed. Piers embedded in the riverbed are subject to local scour. For bridges with piers situated at river bends, design criteria must ensure that if the channel bed surrounding the pier erodes, the depth of the scour hole does not compromise the pier's stability.

Research on scour around bridge piers—conducted via laboratory simulations and direct field observations—requires extensive preparations, such as setting up the flume, constructing bridge pier replicas, analyzing sediment grain-size gradation, and regulating flow discharge. These preparatory steps are time-consuming, whereas direct field observations are often hindered by the challenging terrain at the bridge sites where scour depth is to be measured (Barokah I and Purwantoro D, 2014).

Several laboratory experiments have focused on scour around cylindrical piers due to their geometric simplicity and practical relevance. A classic review of scour around cylindrical piers is the article by Breusers, Nicollet, and Shen (1977), which presents an experimental study and discusses the relationships between equilibrium depth, flow parameters, and sediment size. This article is frequently cited in the literature as a seminal, systematic reference on scour around cylindrical piers.

Melville and Coleman (2000) provide a comprehensive overview of bridge foundation scour phenomena, presenting the theories, experimental data, and empirical formulas used in engineering practice to predict scour depths at foundations, including piers and abutments.

Experimental studies indicate that the formation of bed forms (e.g., ripples, dunes) and grain-size distribution (sorting) influence scour mechanisms. In sediments that form ripples, scour patterns and the rate of scour-hole development can differ from those observed on smooth surfaces.

Several studies on scour around bridge piles have been conducted using numerical hydraulic modeling and computer-based simulation to evaluate scour processes around bridge foundations. Studies evaluating scour around bridge piles were conducted by Kamanbedast and Ghahremani (2014) and Ismail (2009).

Barokah and Purwantoro (2014) reported that the maximum scour around an abutment without wings occurred upstream of the abutment, whereas for an abutment with wings, the maximum scour occurred in the central section. The highest sediment deposition occurred downstream of the abutment.

The Laursen (1960) equation provided the most accurate prediction for abutments without wings, with an error of 20.02%, whereas the Froehlich (1989) equation was more accurate for winged abutments, with an error of 28.17%. Higher flow discharge resulted in greater maximum scour depth (Agung Wiyono et al., 2011).

II. MATERIAL AND METHODS

The location of this research was conducted at the river hydraulics field laboratory (featuring an open-channel flume) at Bina Darma University, Palembang, South Sumatra as shown in Figure 1.

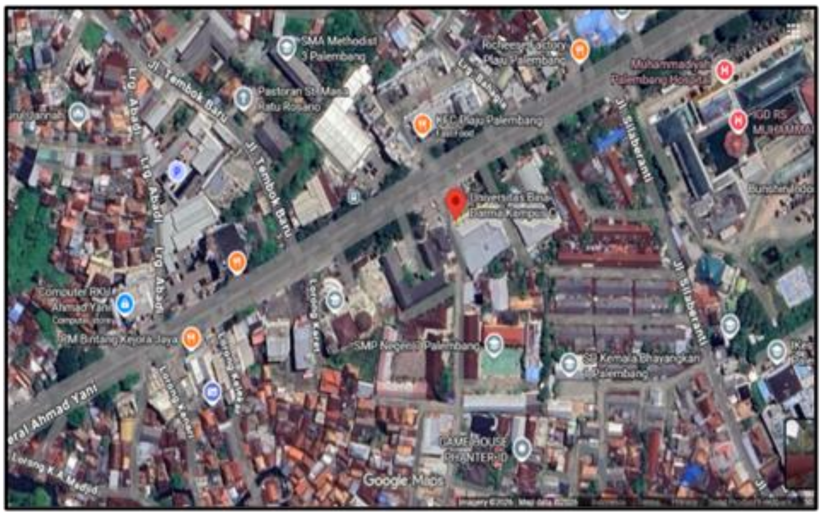

Figure 1: Research location

2.1 River Modeling

River modeling is conducted in the Hydraulics laboratory using a flume measuring 600 cm in length, 60 cm in width, and 30 cm in height. The model features a single 90° bend and includes a cylindrical pier installed within the open channel (standard flume).

Testing is planned to consist of four simulation runs based on varying discharge rates around the bridge pier. Observed data includes flow velocity, water surface elevation, changes in channel bed elevation upstream, channel bed width, and measured discharge. The collected data will be analyzed to determine the effect of discharge variations on the scour depth around the cylindrical pier (Q/t) and the scour depth upstream of the pier (ds/t).

The laboratory modeling aims to calibrate or compare results against numerical calculations based on a fixed-bed condition. The experimental equipment and procedures are as follows:

1. A rectangular channel (60 cm wide, 30 cm hight) with a 90° bend, constructed of brickwork that is plastered and painted.
2. Point gauge: Used to measure water surface elevation. Measurements are taken after the simulation run across the transverse section of the channel/river at the bend.
3. Stopwatch: Used to measure the time required to collect the 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/river can be determined.
4. Laser Doppler (laser-based flow velocity meter) and current meter: Used to measure flow velocity distribution (vertical and horizontal) in both straight sections and bends of the channel. These instruments are movable, allowing for the measurement of vertical velocity distribution, particularly at the channel bend.
5. Water source (Pump): Water discharge is supplied by a previously calibrated pump. Simulation runs were conducted using various discharge rates.

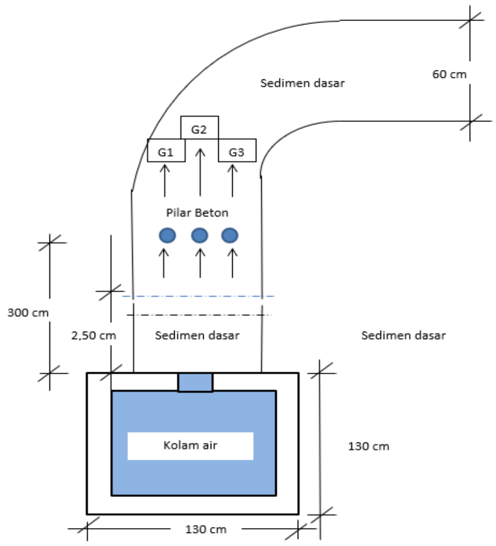

Figure 2: Research model sketch

2.1 Research Flowshart

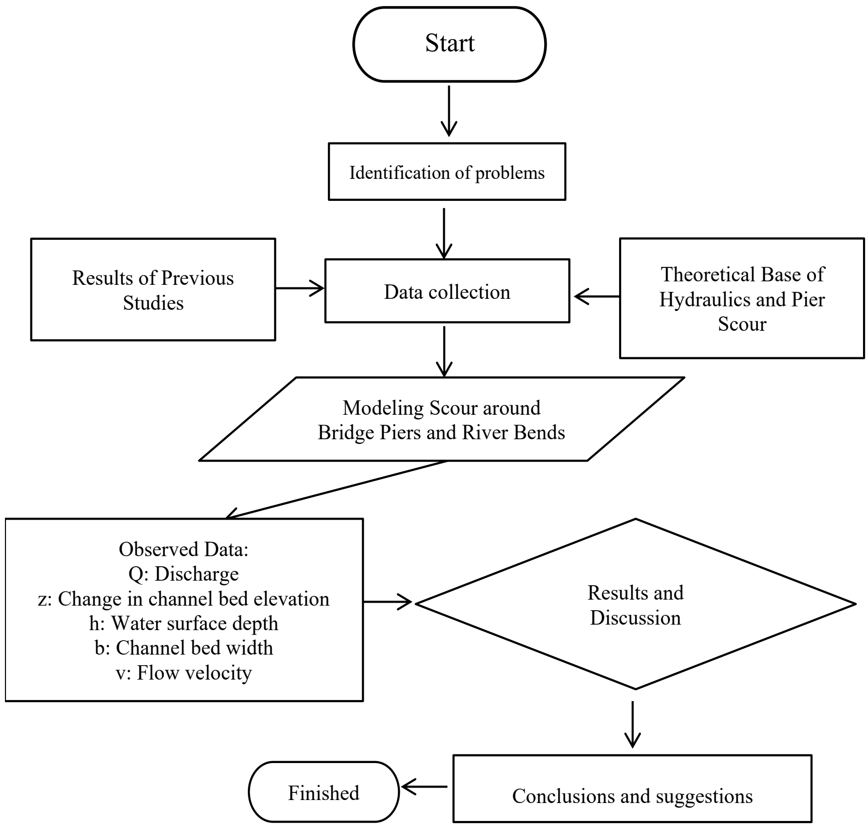

Figure 2: Research flowchart

III. RESULTSAND DISCUSSION

3.1 Hydraulic parameter dimensions

Experimental data yielded the following:

- Channel width B = 60 cm = 0.6 m
- Channel height = 40 cm
- Flume length = 6 m
- Bend = 90° at a distance of 3 m
- Sediment thickness = 5 cm
- Pier diameter = 8 cm = 0.08 m
- Pier height = 26 cm
- Pier positions: 15 cm (inner bank), 30 cm (center), and 45 cm (outer bank).

Table 1. Experimental Discharge

Test	Q_{model} (ml/det)	$Q_{prototipe}$ (m^3/det)
1	196.67	0.0001967
2	358.33	0.0003583
3	375.00	0.000375
4	421.67	0.0004217

3.2 Results of scaled model analysis

3.2.1 Experiment with Q_{model} = 196.67 ml/sec and a duration of 15 minutes

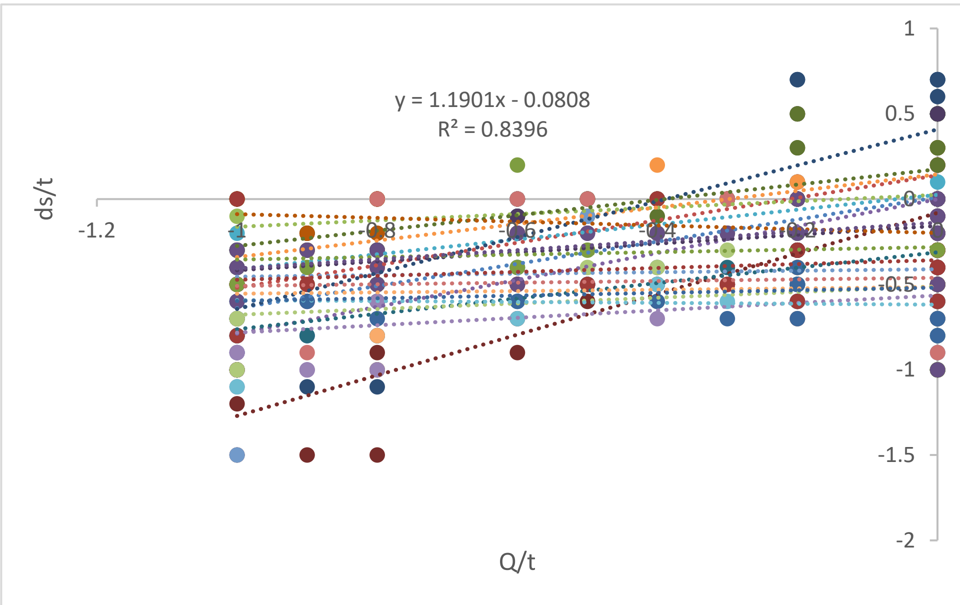

Figure 3: Scour with Q_{model} = 196.67 ml/s and a simulation duration of 15 minutes.

Based on the statistical analysis results shown in Figure 3, the first simulation—conducted with a discharge of Q_{model} = 196.67 ml/s—resulted in a maximum scour of -1.5 cm. The coefficient of determination (R^2) was 0.8396, indicating that 83.96% of the data variation could be explained by the model, while the correlation coefficient (R) was 0.7054 (or 70.54%). This signifies a strong correlation between scour depth (ds) and the model flow discharge (Q_{model}).

3.2.2 Experiment with discharge of Q_m = 358.33 ml/sec and a simulation duration of 30 minutes

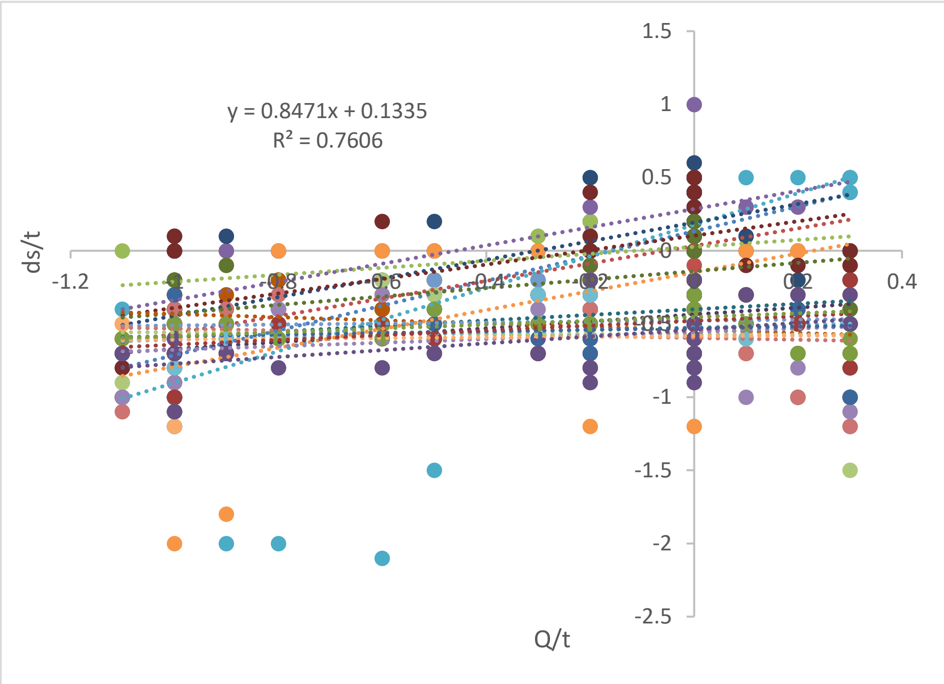

Figure 3: Scour with Q_{model} = 358.33 ml/s and a simulation duration of 30 minutes.

Based on the statistical analysis results shown in Figure3, the first simulation—conducted with a discharge of Q_{model} = 358.33 ml/s—resulted in a maximum scour of -2.1 cm. The coefficient of determination (R^2) was 0.7606, indicating that 76.06% of the data variation could be explained by the model, while the correlation coefficient (R) was 0.5785 (57.85%). This signifies a reasonably strong correlation between scour depth (ds) and the model's flow discharge (Q_{model}).

3.2.3 Experiment with discharge of Q_m = 375 ml/sec and a simulation duration of 45 minutes

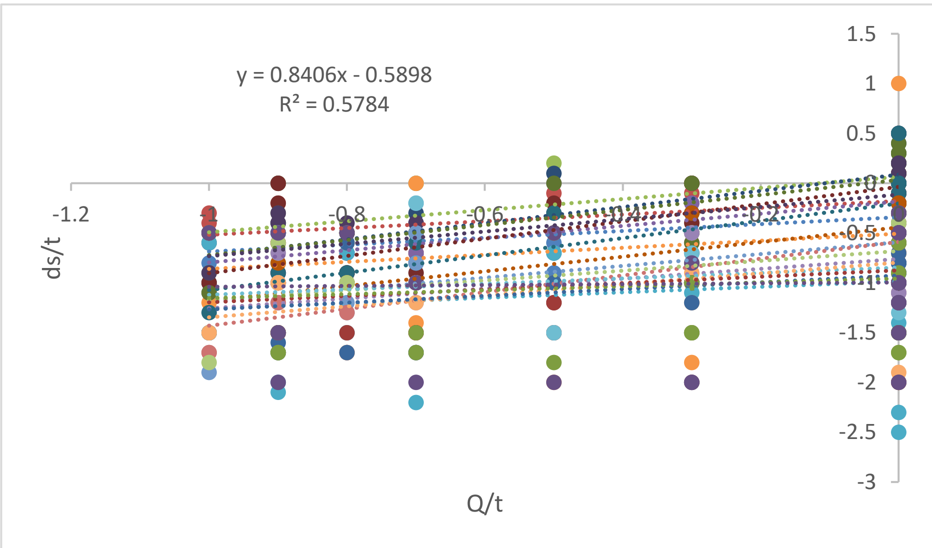

Figure 4: Scour with Q_{model} = 375 ml/s and a simulation duration of 45 minutes.

Based on the statistical analysis results shown in Figure 4, the first simulation—conducted with a discharge of Q_{model} = 375 ml/s—resulted in a maximum scour of -2.1 cm. The coefficient of determination (R^2) was 0.5784, meaning 57.84% of the data variation could be explained by the model, while the correlation coefficient (R) was 0.3345 (or 33.45%). This indicates that there is no correlation between scour depth (ds) and the flow discharge in the model (Q_{model}).

3.2.3 Experiment with discharge of Q_m = 421.67 ml/sec and a simulation duration of 60 minutes

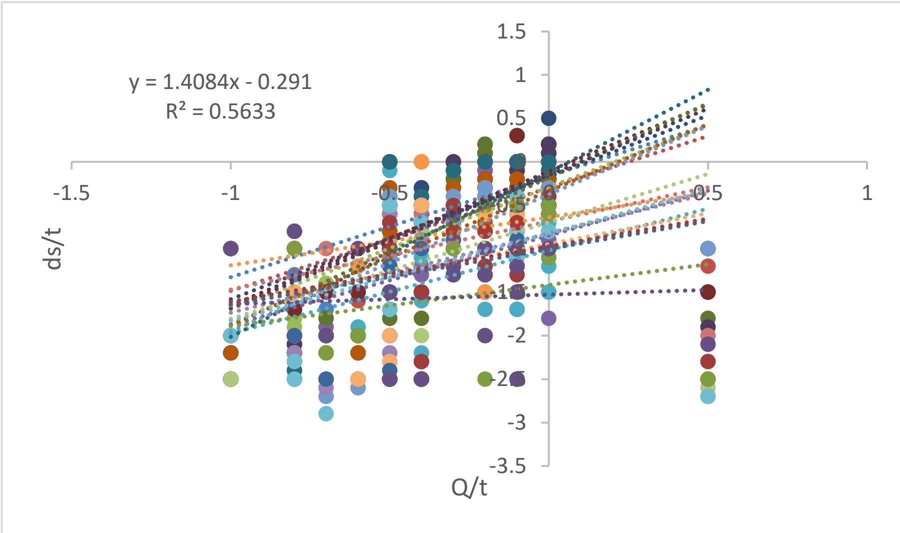

Figure 5: Scour with Q_{model} = 421.67 ml/s and a simulation duration of 60 minutes.

Based on the statistical analysis results shown in Figure 5, the first simulation—conducted with a discharge (Q_{model}) of 421.67 ml/s—resulted in a maximum scour of -2.9 cm. The coefficient of determination (R^2) was 0.5633, meaning 56.33% of the data variation could be explained by the model, while the correlation coefficient (R) was 0.3173 (or 31.73%). This indicates that there is no correlation between scour depth (ds) and the flow discharge (Q_{model}) of 421.67 ml/sec.

IV. CONCLUSION

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

1. Based on a flow rate of Q_{model} = 196.67 ml/sec, a maximum local scour of -1.5 cm and sedimentation of +0.7 cm were observed, with an average scour of -0.31 cm; for Q_{model} = 358.33 ml/sec, the maximum scour was -2.1 cm and sedimentation was +1.0 cm, with an average scour of -0.42 cm. Meanwhile, the data for Q_{model} = 375 ml/sec (45-minute simulation) and Q_{model} = 421.67 ml/sec (60-minute simulation) could not be utilized because they did not show a positive correlation, despite the occurrence of local scour.
2. A correlation between the flow rate (Q_{model}) and the magnitude of local scour was found for Q_{model} = 196.67 ml/sec and Q_{model} = 375 ml/sec, whereas no correlation regarding the depth of scour was observed for Q_{model} = 357 ml/sec.

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