

Modeling Local Scour Characteristics on The Batujajar Bridge Pillar Using HEC-RAS Software

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ABSTRACT

The bridge collapse is often the result of scouring. The potential for flooding can increase riverbed degradation and local scouring, which adds to the bridge threat sub-structures. Batujajar Bridge, located in Batujajar District, West Bandung Regency, has two pillars within the Citarum river. The 150 m long bridge is at risk of collapse due to local scouring of the pillars. So it's necessary to evaluate the depth of the scours with mathematical modeling using the HEC-RAS application in live-bed scour conditions. In general, scour modeling is obtained by modeling river geometry, bridge design, and river flow. Scour modeling used the CSU method and the Froechlich method in the HEC-RAS 5.0.7 application. Topographical conditions were obtained from the DEM of the study area using Global Mapper 2.0 software and river geometry modeling using RAS Mapper. Discharge data is used for steady flow modeling and hydrograph data for unsteady flow modeling from the Upper Citarum Watershed and Cimahi Sub Watershed. The bridge design used existing data. Index properties (grain size analysis, specific gravity test, and soil content weight test) were tested at the Bandung State Polytechnic Soil Testing Laboratory from soil samples around the existing Batujajar bridge's pillars. The hydraulic simulation shows that the scour depth reaches 1.89 m, affecting the bridge stability. So, scour protection is required. The scouring depth of the live bed can be used as a parameter for handling bridges in the dry and rainy seasons.

Keywords: HEC-RAS, live-bed scour, pillar, Batujajar bridge

1. INTRODUCTION

Bridges are important structures that can collapse if there are no monitoring or safety precautions for local scouring during major floods [1]. The bridge collapse is often caused by scouring [2]. Several bridges in Indonesia collapsed due to scouring, such as the Plompong bridge in Brebes [3] in Figure 1. This occurs due to changes in the flow pattern (horseshoe vortex flow). The flow that is blocked by water structures (bridge pillars) will descend and erode the material on the riverbed. Then the flow slowly rises around the side of the building, accompanied by the transportation of eroded material [4].

Over time, scouring can reach a maximum depth (reach the bottom of the pier). This unsafe condition has the potential to cause the bridge to collapse [5]. Batujajar Bridge, located in Batujajar District, West Bandung Regency, such in Figure 2, has two pillars located on the Citarum river. The 150 m long bridge is at risk of collapse due to local scouring of the pillars. The risk is to be increased due to the high rain intensity that reaches 700 mm/hour [6]. Two primary causal factors of the problem are the land used changes in the upstream area and the reduction of river capacity. The river capacity continuously reduced due to the sedimentation resulting from upstream erosion [7]. So it's necessary to evaluate the scour's depth with mathematical modeling using the HEC-RAS application in live-bed scour conditions.



Figure 1 The collapse of the Plompong Bridge, Brebes
Source: Sucipto I.(2019).

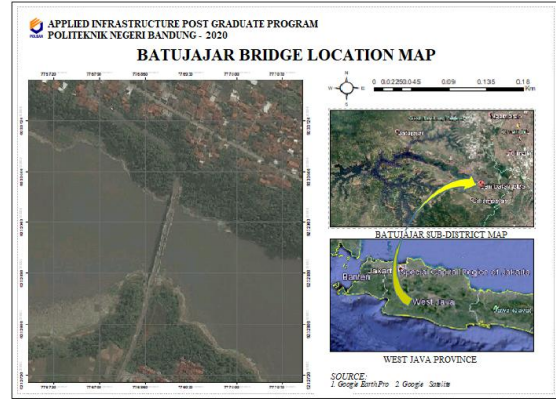


Figure 2 Batujajar Bridge location map
Source: Google Earth (2019).

1.1. Related Reference

Based on FHWA, scour analysis is related to flow conditions to determine maintenance on the bridge [8]. Field data collection in the form of flow and geometry is presented in HEC-20. Then hydrological, hydraulics, and scour analysis are presented in HEC-18. Meanwhile, HEC-23 is a guideline for inspection and maintenance. Reliable prediction of local scour depth in bridge piers is essential for proper bridge pier design and maintenance [9]. Mathematical scour modeling can be done using the HEC-RAS application. The HEC-RAS (Hydrologic Engineering Center-River Analysis System) software is a free hydraulic simulation modelling software released by the US Army Corps of Engineering [10]. HEC-RAS is an application program for modeling flow in rivers. The River Analysis System was created by the Hydrologic Engineering Center. HEC-RAS is a one-dimensional model of permanent or non-permanent flow [11]. HEC-RAS provides 2 (two) equations/formulas that can be used to analyze the depth of scouring on the pillars. Two of the scour prediction formulas (i.e., Froehlich equation (Eq. (1)) and HEC-18 equation (or CSU equation, Eq. (2)) available in both programs are introduced below.

$$Y_s = 0.35 \phi (\alpha')^{0.62} y^{0.47} Fr^{0.22} D50^{-0.09} + a \quad (1)$$

Where:

- Ys = the depth of pier scour;
- ϕ = correction factor for pier nose shape:
 $\phi = 1.3$ for square nose piers; $\phi = 1.0$ for rounded nose piers; and $\phi = 0.7$ for sharp nose (triangular) piers;
- α' = the projected pier width with respect to the direction of the flow, feet (m);
- y1 = the flow depth directly upstream of the pier in feet (m);
- Fr1 = Froude Number directly upstream of the pier;
- D50 = median diameter of the bed material, feet (m);
- a = the pier width.

$$Y_s = 2 K_1 K_2 K_3 K_4 a^{0.65} y^{0.35} Fr^{0.43} \quad (2)$$

Where:

- Ys = depth of pier scour
- K1 = pier shape factor,
- K2 = flow alignment factor,
- K3 = bed condition factor,
- K4 = bed armoring factor,
- b = pier width,
- ya = approach flow depth,
- Fra = approach flow Froude number, and
- Va = depth-averaged velocity of the approach flow.

Computer simulation has the advantage of being able to simulate situations in a full-scale scenario, and it can easily change the geometry as needed [12]. Estimation of sedimentation in reservoirs helps in the management and design of the reservoir's useful capacity [13].

1.2. Our Contribution

This research is aimed to show the local scour behavior in Batujajar bridge, which can be used to formulate mitigation. This study is expected to be useful in anticipating the impact of the Batujajar bridge's collapse due to erosion of the pillar by the Citarum river flow.

1.3. Paper Structure

The rest of the paper is organized as follows. Section 1 introduces scouring. Section 2 presents the methodology. Section 3 presents the result of scour depth. Section 4 presents a scour depth evaluation. Finally, Section 5 concludes the paper and presents direction for future research.

2. BACKGROUND

2.1. Methodology

In general, scour modeling is obtained by modeling river geometry, bridge design, and river flow. The research flowchart is presented in Figure 3.

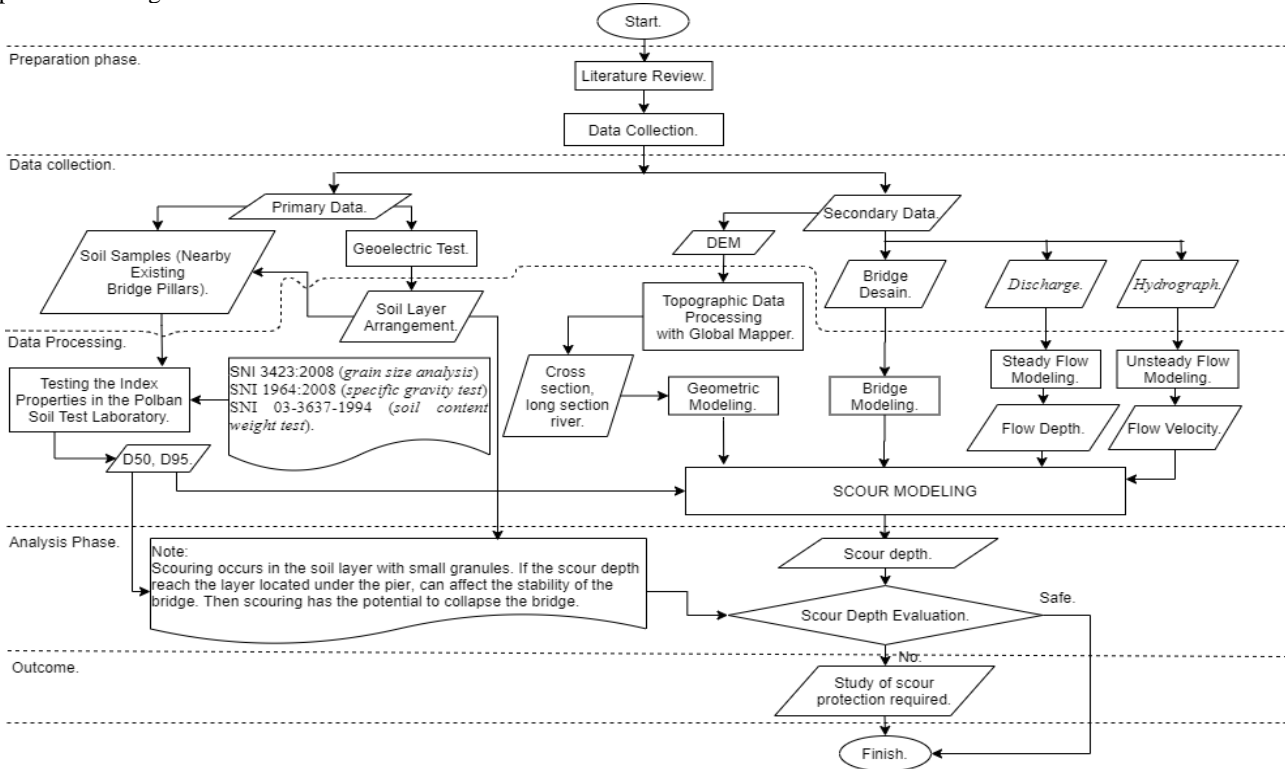


Figure 3 The research flowchart

Scour modeling uses the CSU method and the Froechlich method in the HEC-RAS 5.0.7 application. Topographical conditions were obtained from the DEM of the study area using Global Mapper 2.0 software and river geometry modeling using RAS Mapper. Bridge design used existing data, as shown in Figure 4 and Figure 5.

Discharge data is used for steady flow modeling and hydrograph data for unsteady flow modeling from the

Upper Citarum Watershed and Cimahi Sub Watershed, presented in Figure 6 and Figure 7.

Index properties testing (grain size analysis, specific gravity test, and soil content weight test) was conducted at the Bandung State Polytechnic Soil Testing Laboratory from soil samples around the pillars of the existing Batujajar bridge shown in Figure 8.



Figure 4. Geometric modeling (river and bridge)

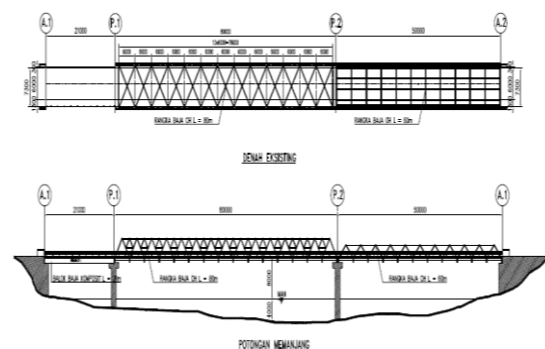


Figure 5. Batujajar Bridge design

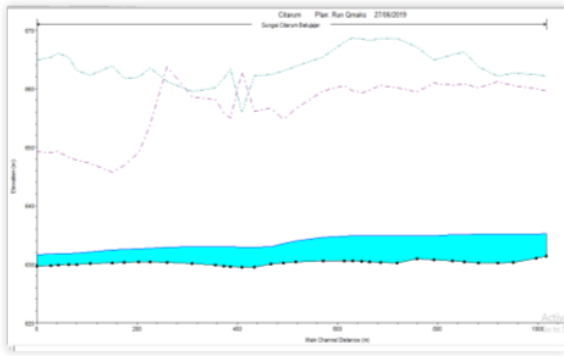


Figure 6. Result of steady flow modeling



Figure 7. Result of unsteady flow modeling

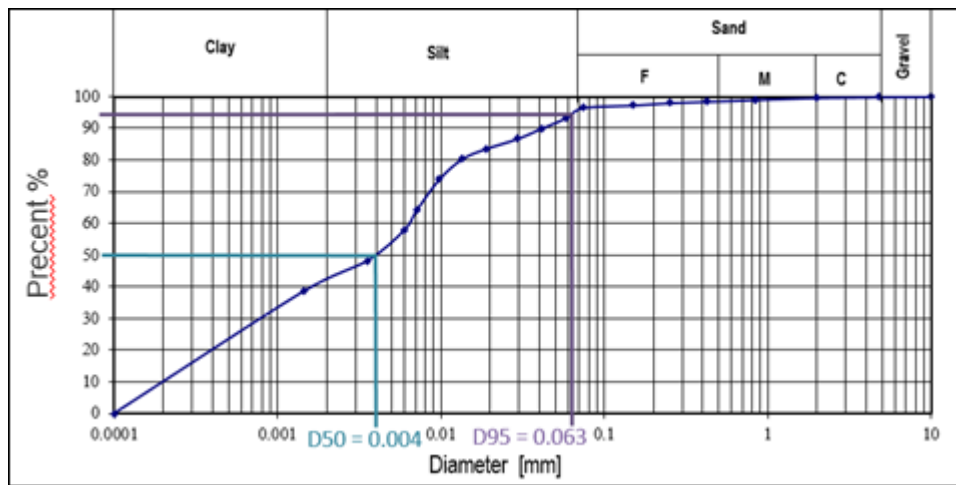


Figure 8. Result of grain size analysis

2.2. Scour Depth Evaluation

Hydraulic Design Data: Pier Scour
(All piers have the same scour depth)
Input Data

Pier Shape	: Round nose
Pier Width (m)	: 2.50
Grain Size D50 (mm)	: 0.00300
Depth Upstream (m)	: 3.01
Velocity Upstream (m/s)	: 3.29
K1 Nose Shape	: 1.00
Pier Angle	: 0.00
Pier Length (m)	: 7.00
K2 Angle Coef	: 1.00
K3 Bed Cond Coef	: 1.10
Grain Size D90 (mm)	: 0.06300
K4 Armouring Coef	: 0.40

Results	
Scour Depth Y_s (m)	: 1.89
Froude #	: 0.61
Equation	: CSU equation

This study conducted geoelectric testing, and the result of soil layer composition is shown in Table 1. The interpretation of the geoelectric testing show layers 2 are the clay. The granular of clay is very small. Scouring occurs in the soil layer with small granules. And pier is located in that layer. So, the scouring has the potential to collapse the bridge.

Table 1. The interpretation of geoelectric testing

Layer	Lithology Estimates	Thickness (m)
1	River sediment	1.01
2	Tuff clay	0.96
3	Tuffed sand	2.28
4	Tuff clayey sand	13.7
5	Tuffed sand	2.05

3. CONCLUSION

Scouring occurs in the soil layer with small granules. The hydraulic simulation shows that the scour depth reaches the bottom of the pier, 1.89 m. The pier is located in the clay layer. So, scouring can be affecting bridge stability and has the potential to collapse the bridge; therefore, scour protection is required. The scouring depth of the live bed can be used as a parameter for handling bridges in the dry and rainy seasons.

Scour protection is required to formulate mitigation (anticipating the impact of the collapse of the Batujajar bridge due to erosion of the pillar by the Citarum river flow), such as a protective plate. A research report in the field of engineering by Sudiyono, et al. (2015) titled "Scouring Around Two Bridge Pillars and Control Efforts" [14]. One of the objectives of this study is to determine the level of effectiveness of using protective plates to reduce the depth of local scour that occurs in the placement of two pillars. With the physical modeling carried out, the results of this study indicate that the milling process is increasing with increasing time until one day, it will reach a balanced condition. The use of pillars with protective wings is very effective in reducing scour. The protective wing can reduce scour at both upstream of the first pillar and downstream of the second pillar for multiple pillars. The distance between pillars four times of pillars diameter will give a minimum scour depth.

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