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Material Protection for Citarum River-Bed by Local Scour used What-If Analysis

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ABSTRACT

This paper presents scour protection measures at the Citarum riverbed due to obstruction of the Batujajar bridge piers used what-if analysis. Various studies have been carried out and developed for more than 30 decades, showing that the scour phenomenon causes many cases of bridge collapse in the world. The change in flow pattern caused a horseshoe vortex flow triggers local scour. What-if analysis helps in problem seeking, problem analysis, and problem-solving. Based on previous research, the data collected were maximum flood discharge (Nakayasu HSS method), topographic maps and engineering geological maps, soil property index in the Citarum river, and data on the Batujajar bridge. Topographic surveys and geoelectric tests were also carried out. This research used flexible applicative approaches carried out according to conditions in the field. The mathematical modeling with the HEC-RAS application was a choice for predicting the scour depth. The scour simulation was carried out under existing conditions and with alternative riverbed material protections (protective plates, gabions, and pile caps). The minimum scours depth was achieved in the simulation using a gabion of 0.57 mm. It could minimize scour of depth until 1.73 m from existing conditions. This research can contribute to scour analysis, especially to minimized hazards on bridges crossing rivers.

Keywords: *Bridge pier, Citarum river, Local scouring, Scour protection, What-if analysis.*

1. INTRODUCTION

The river is a water drainage system from the spring to the estuary with limited on the right and left and along its flow by a borderline [1]. The Citarum River is one of the main rivers and one of the largest rivers in West Java with a length of 269 km and a watershed area of 6,080 km². This river flows from the Mount Wayang spring in Bandung Regency and empties into the Java Sea, Karawang Regency. The Citarum river area is divided into the Upper Citarum, Middle Citarum, and Lower Citarum areas. Based on data from the Citarum River Basin Center (BBWSC), the total area of the Citarum river reaches 11,323.4 km². The following is a map of the Citarum river area in Figure 1.

A watershed is a land area that is an integral part of a river and its tributaries, which functions to accommodate, store, and drain water from rainfall to a lake or to the sea naturally, whose land boundary is a topographical separator and a natural boundary. In the sea to water areas that are still affected by land activities [2]. The Citarum River watershed included in the study review location (Batujajar) is the Upper Citarum watershed and the Cimahi sub-watershed. The following is a map of the review locations in Figure 2.

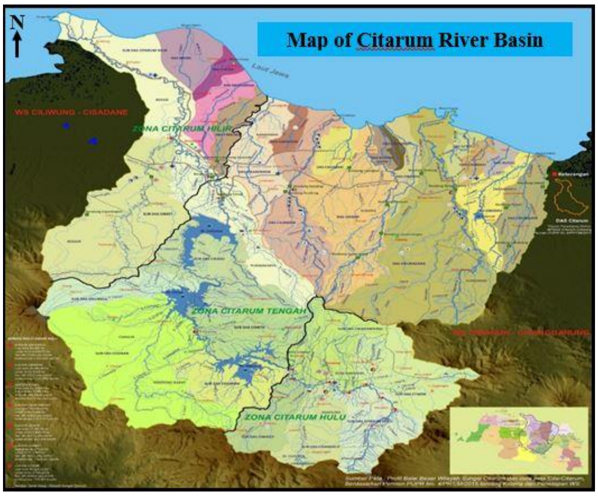

Figure 1 Map of Citarum River Basin (Source: BBWS Citarum).

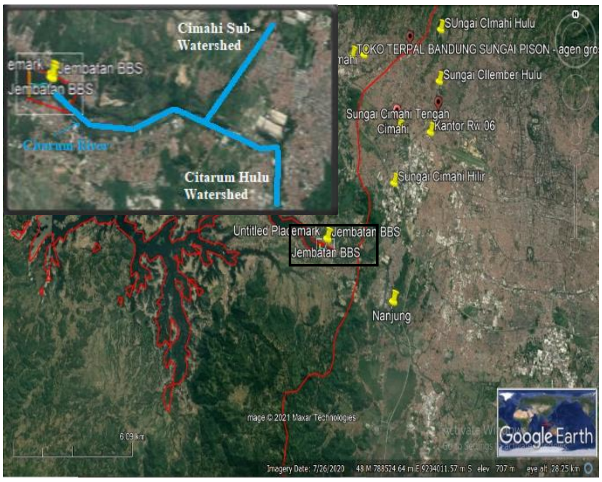

Figure 2 Research Location Map (Source: Google Earth, 2021)

The most common reasons bridges eventually fail during floods are lifting water from their supports, and extreme scour destroying foundations. Many bridges crossing rivers have collapsed in the world due to the phenomenon of scouring. The flow obstructed by water structures will erode the riverbed so that the pillars become weak in their ability to hold the structure [3]. At the same time, floodwater and the elements carried in it put pressure on the bridge, as shown in the following figure.

Figure 3 How bridge can be damaged by floods (Bridge Master, 2017)

This effect is magnified in bridges with multiple supports because each support causes scour, weakening many parts of the structure [3]. Some supports can also increase the “damping effect” on the bridge. Objects are more likely to get stuck in narrowly spaced piers, being a larger mass that puts more stress on the structure.

So, how to protect the bridge from water damage? This study aims to determine the existing scour depth, the scour depth prediction method used, and the application of protection.

1.1. Related Reference

1.1.1. What-If Analysis

What-if analysis studies the effect of parameters on the output of a complex system [4]. What-if analysis involves a set of input parameters whose values are selected by the user; a simulation model that produces results by providing a set of values for the input parameters and goals according to which some outcomes are preferable to others [4]. What-if analysis allowed users to understand the dependencies between parameters and outcomes, exploring how results improved (depending on the given objective) when changing certain parameters [4].

Although goals are often defined as optimization problems, their actual solutions are usually not a user’s primary concern. Instead, the user seeks to gain insight beyond knowing the optimal solution to take the right decision [5].

Types of what-if analysis vary in how complex systems are modeled, including hypothetical modifications [6], stochastic simulations [7], or statistical methods [8]. [5] study what-if analysis for data exploration, where the model of a system is non-trivial. Although the setting is similar to the sensitivity analysis [9], the traditional technique considers only one dimensional and, thus, one objective outcome. The [5] use case is a scenario with many conflicting purposes.

What-If Analysis is a structured brainstorming method to determine what things could go wrong and assess the likelihood and consequences of the situation occurring. The answers to these questions form the basis for assessing the acceptance of these risks and determining the recommended actions for those risks that are judged to be unacceptable [10]. Experienced review teams can effectively and productively discern key issues regarding a process or system. Led by an energetic and focused facilitator, each review team member participates in assessing what could go wrong based on their past experience and knowledge of similar situations [10].

There is a 0.5% probability that the 200 year flood level can be reached or exceeded in any given year [3]. In extreme weather conditions such as today, it is important to plan water levels not only using current flood guidelines but also potential future events. Especially to protect the abutment from erosion.

Scouring occurs in the soil layer with small granules [11]. Scouring can be affecting bridge stability and has the potential to collapse the bridge. Scour protection is required to formulate mitigation such as a protective plate [11].

1.1.2. Scour Protection

Bridge Management System (BMS) used scour protection [12] with various types and used conditions, such as Table 1. Computer simulation has the advantage of simulating situations in a full-scale scenario, and it can easily change the geometry as needed [11]. HEC-RAS (River Analysis System) is bridge scour prediction software developed by the Army Corps of Engineers Hydrologic Engineering Center (HEC). There was various manning value at scour simulation used HEC-RAS [14]. The value was showed at Tabel 2.

Table 1. How to Handling Scouring Protection (BMS, 1993) [13]

Type	Conditions of Use
Sheet pile	Deep river water and/or soft soil. Used for the foundation protection of the substructure.
Gabions	Shallow river water and strong foundation.
Concrete wall	Shallow river water and strong foundations on which water flows can be displaced during implementation.
Groyne	Near the cliffs to protect the cliffs and direct the flow of the river.
Bottom controller (Riverbed protection)	For the occurrence of degradation that is not too deep and made a full cross as wide as the river. It can be made of concrete, gabions, double fencing with stone filling in between, sheet piles and others.
Cleaning groove pavement	Shallow streams where streams can be displaced during implementation. Usually only used on bridges with small spans.
Tetrahedrons	If there is a hole due to scouring and its use is for the erosion that occurs.
Rip-rap/cobblestone couple	To protect the foundation around the pillars.

Table 2. Manning's 'n' Values [15]

Type of Channel: Natural Streams	Manning's 'n' Values		
Main Channels Description	Minimum	Normal	Maximum
a. Clean, straight, full, no rifts or deep pools	0.025	0.03	0.033
b. Same as above, but more stones and weeds	0.03	0.035	0.04
c. Clean, winding, some pools and shoals	0.033	0.04	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.05
e. Same as above, lower stages, more ineffective slopes and sections	0.04	0.048	0.055
f. Same as "d" but more stones	0.045	0.05	0.06
g. Shluggish reaches, weedy, deep pools	0.05	0.07	0.08
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.07	0.1	0.15
Type of Channel: Lined or Built-Up Channels	**Manning's 'n' Values**		
Gravel Bottom with Sides of:	**Minimum**	**Normal**	**Maximum**
a. Formed concrete	0.017	0.02	0.033
b. Random stone in mortar	0.02	0.023	0.026
c. Dry rubble or rip rap	0.023	0.033	0.036

1.2. Paper Structure

This paper is structured as follows. The first introduction covers research sites, general research phenomena, and previous literature on what-if analysis and scours protection. Section 2 introduces background what-if analysis to assist problem finding and problem analysis. The research method is shown in Section 3 which includes the research flow chart. Then, the results of the scour simulation are shown in Section 4 with recommendations for scour protection.

2. BACKGROUND

2.1.1. What-If Analysis

What-If Analysis is used so that research can run well, safely, and smoothly. The purpose of What-If Analysis in this study is to:

1) problem seeking on the phenomenon of bridge collapse due to scour. This leads to a description of the research background, problem formulation, and research objectives;

2) problem analysis, including taking the method used to predict the scour depth. Where there are three alternative methods to predict the scour depth as follows:

   1. Empirical Method: perform manual calculations with formulas. This would be very easy to do but would be difficult to validate the results.

   2. Physical modeling in a hydrotechnical laboratory. This is risky because of the existing material's geometrical scale and character, which is difficult to model. So the scour depth cannot be obtained accurately from physical scour modeling. However, the observation of the scour phenomenon will be clearer (clear condition).

   3. Mathematical simulation with HEC-RAS. The mathematical modeling has advantages because the modeling is carried out on a full scale (according to field conditions);

3) problem-solving in minimizing the scour depth. There are two general alternatives: with barrier materials and changing flow conditions. In this study, an alternative was carried out with protective materials in the form of protective plates, gabions, and pile caps. The flow conditions can be done by making weirs downstream of the bridge.

There is the form of What-If Analysis in Table 3.

Table 3. What-If Analysis

What If?	Answer	Likeli-hood	Consequences	Recommendations
The flow of the Citarum river is blocked by the pillars of the Batujajar bridge	There is a horseshoe vortex flow (change in flow pattern) around the pillars of the Batujajar bridge	There was scour at the base of the Citarum river around the pillars of the Batujajar Bridge (there was erosion and filling of the innate material from the upstream of the river in the scouring hole)	Many bridges collapse due to scouring. So the Batujajar bridge has the risk of collapsing due to local scour at the bottom of the Citarum river.	It is necessary to carry out preventive maintenance to minimize the depth of local scour
There is scouring	Prediction of the total scour depth on the river bed	1. Using the empirical method	Simple equation, needs validation	Mathematical methods are used with field data adjustments
		2. Using mathematical methods	Full scale, data follows field conditions	
		3. Using physical methods	The scale is too small, it is difficult to validate the results	

What If?	Answer	Likeli-hood	Consequences	Recommendations
there is local scour at the bottom of the Citarum river due to horseshoe vortex around the pillars of the Batujajar bridge	Creating a scour barrier at the bottom of the Citarum river	1. Gabions	Basic resistance is less uniform	It is necessary to simulate scour with alternative safety (variation of basic resistance and manning value).
		2. Protective Plate	Corrosion-resistant steel plate	
		3. Pilecap	Concrete material is strong enough	

3. RESEARCH METHOD

The scour depth is influenced by many factors, and there are many methods for predicting it. This affects the application of protection from scouring. Based on previous research, data were collected in the form of discharge, profile, and index of soil properties in the Citarum River as well as data on the Batujajar bridge [11]. The research flowchart is shown in Figure 4.

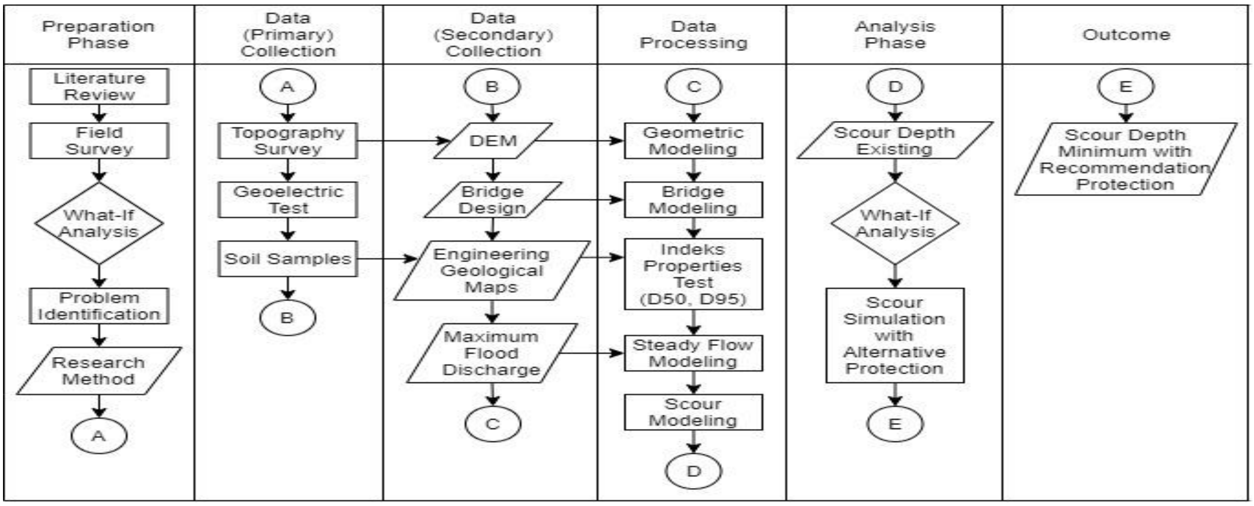

Figure 4 Research Flowchart.

In this study, a topographic survey and a topographic approach from Digital Elevated Model (DEM) were carried out to obtain a river profile. Geoelectric tests were also carried out around the pillars of the Batujajar bridge, with soil lithology interpretation based on engineering geological maps. A property index test was conducted on the Citarum river sediment sample. The maximum flood discharge used is based on the results of the hydrological analysis approach using the Nakayasu HSS method.

Scour simulation used HEC-RAS application version 5.0.7. The application used HEC-18 from the Federal Highway of Administration (FHWA) and has two equations: Equation (1) Colorado State University (CSU) or HEC-18 and Equation (2) Froechlich equation.

$$d_{sl} = 2.0K_1K_2K_3K_4b^{0.65}y_a^{0.35}Fr_a^{0.43} \quad (1)$$

$$y_s = 0.35\phi(a')^{0.62}y_1^{0.47}Fr_1^{0.22}D_{50}^{-0.09} + a \quad (2)$$

Where y_s and d_{sl} is the depth of pier scour; K1 is pier shape factor; K2 flows alignment factor; K3 is bed condition factor; K4 is bed armoring factor; a, b, and a′ the projected pier width with respect to the direction of the flow, feet (m); ya and y_1 is approach the flow depth directly upstream of the pier in feet (m); Fra and Fr_1 is approach Froude Number directly upstream of the pier; φ is Correction factor for pier nose shape: φ = 1.3 for square nose piers; φ = 1.0 for rounded nose piers; and φ = 0.7 for sharp nose (triangular) piers; D_{50} is median diameter of the bed material, feet (m).

Evaluate the depth of the scours with mathematical modeling using the HEC-RAS application in live-bed scour conditions are required. In general, scour modeling is obtained by modeling river geometry, bridge design, and river flow. Perspective plot modeling results (display of X-Y-Z) showed in Figure 5.

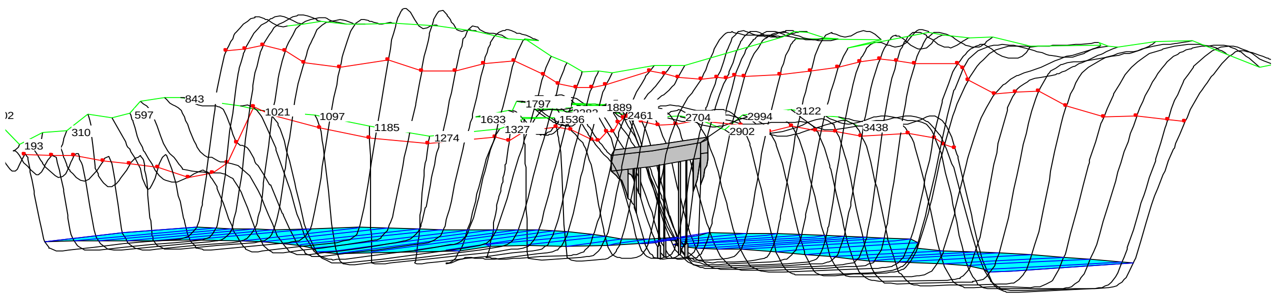

Figure 5 Display of X-Y-Z Perspective Plot Modeling Results.

The geometry of the Citarum River, Batujajar bridge, and flow depth are shown in Figure 5. The scour simulation was carried out under existing conditions and with alternative riverbed material protections (protective plates, gabions, and pile caps).

4. CONCLUSION

Based on the simulation, the result of scouring modeling with modified piers protection showed in Tabel 4.

Table 4 Results of Scouring Modeling with Modified Piers Protection

Protection	Depth of Scour Ys_2 (m)	Existing Condition Ys_1 (m)	Delta Ys (m)
Gabions	0.57	2.3	1.73
Protective Plate	2.27	2.3	0.03
Pilecap	2.28	2.3	0.02

The protective recommendation piers at Batujajar bridge used gabions. It can minimize the depth of scour until 1.73 m from the existing condition. The following is a side view of the initial scouring conditions and after protection is carried out in Figure 6 and Figure 7.

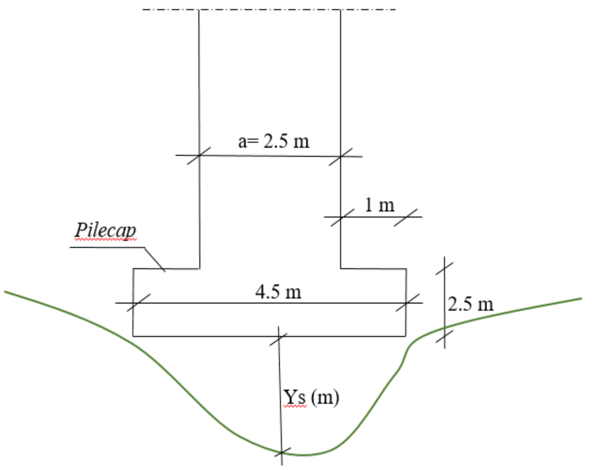

Figure 6 Initial scouring condition

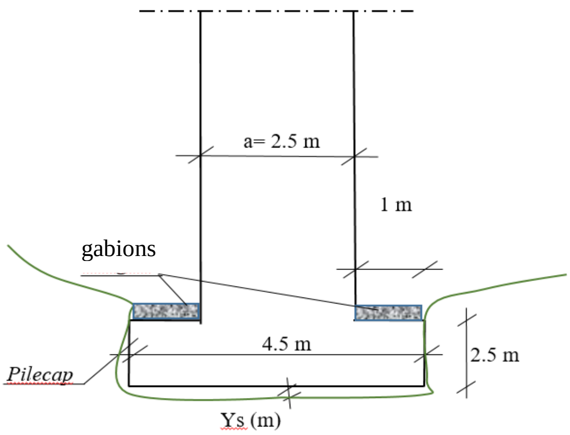

Figure 7 Modified protection with gabions.

The simulation result shows that the protective plate and pile cap are not really good for reducing scour depth. It is because modified bridge at HEC-RAS application just for bridge modeling. So, this research used the dimension of piers to modified alternative protection even though the three alternatives have different manning and resistance values.

In this study, What-If Analysis helps to filter alternative scour protection at HEC-RAS simulation. So, this method can be implemented when predicting the scour depth on other bridges, especially at the extreme condition like the covid-19 pandemic today, where collecting data is so difficult because of limited access. Mathematical simulation development is very helpful and necessary.

AUTHORS' CONTRIBUTIONS

This paper is a continuation of the research of Rustawa et al. [11] who has performed scour simulation in existing conditions using the HEC-RAS application. Present scour protection efforts at the Citarum riverbed due to obstruction of the Batujajar bridge piers used what-if analysis.

Based on the high risk of bridge collapse due to local scour in Indonesia, the largest archipelagic country. This research uses a flexible applicative approach which is carried out according to the conditions in the field. This research can contribute to scour analysis, especially to minimized hazards on bridges crossing rivers.

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