Analysis of Scour Depth Around Bridge Piers With Round Nose Shape by HEC-RAS 5.0.7 Software

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Abstract. Local scour of bridge piers is the main reason for the failure of a hydraulic structure like abutment, bridge piers, etc. Local scour is a complex phenomenon that depends on the discharge, depth of flow, shapes of the pier and distribution of sediment particle. The problems of local scours occurred in Krueng Ineng river, Nagan Raya Regency will cause a structural collapse which has the impact of decreasing the stability of the bridge structure. In this study, the software of Hydrologic Engineering Center River Analysis System (HEC-RAS) 5.0.7 is used to evaluate local scour around the bridge pier which employs the Colorado State University method as a default equation. Flow conditions were simulated using HEC-RAS flow modeling software estimated for 100-year flood. The Results of the analysis with used the peak discharge ($Q_{p100}$) that occurs in the Krueng Seunagan watershed is 1513 m$^3$/sec, pier width of Round Nose shape is 4m, and average grain size analysis $D_{50}$ and $D_{95}$ is 0.91mm and 4.35mm, show a maximum scour depth obtained is 5.04m. The results of this study will be a reference for the local government to planning appropriate handling for minimalizing local scours in the study area.

Keywords: local scouring, scour depth, bridge pier, HEC-RAS, CSU method

1. Introduction

Bridges are critical structures that require large investments and have an important role in economic development. Major damage to the bridge that occurred during the flood was caused by various reasons. The reason is the local scour that occurs due to the influence of pier and abutment. Local scour are occurs directly from the structure in the river channel. The process of local scour is usually triggered by the detention of sediment transport that is carried along with the flow by the building structure (Cambodia, 2018). Large amounts of local scour are dangerous to the bridge pier and cause a collapse of the bridge structure. Many researchers have investigated the phenomenon of local scouring around the bridge pier (Ahmad, 2017).

The collapse of bridges results in costly repairs, disruption of traffic and possible death of passengers traveling on the bridge when a collapse occurs. The scour phenomenon experimentally or theoretically around bridge piers and considered some parameters affected the phenomenon. There are generally three types of scours that affect the performance and safety of bridges, that is local scours, contraction scours and degradation scours. Factors affecting local scours development are flow intensity, flow shallowness, sediment coarseness, time and velocity distribution (Akib & Rahman, 2013).

One of the areas experiencing local scouring problems is the Alue Buloh bridge at a river crossing on the Krueng Ineng river, this bridge is located in the Latong area of Seunagan District, Nagan Raya...
Regency precisely in the Krueng Seunagan watershed. The construction of this steel frame bridge is one of the access links between the two villages namely Alue Buloh Village and Latong Village. Judging from the conditions at the study site, local scours cause the bridge pillars to have decreased even though on a small scale and if this problem is left then it can have an impact on the failure of the larger bridge structure.

Based on the condition of the above problems, it is necessary to studying and identifying the bridge located in the study location. The analysis in this study was simulated using the HEC-RAS 5.0.7 software. HEC-RAS 5.0.7 software created by the Hydrologic Engineering Center (HEC) which is a work unit under the US Army Corps Engineering (USACE). HEC-RAS 5.0.7 can analyze two-dimensional counts on the profile of a permanent water level (Steady Flow), simulation of non-permanent flow (Unsteady Flow), count of sediment transport, analysis of water quality, and hydraulic design features (FDOT, 2005).

The importance of finding the right calculation parameters to predict the amount of local scouring that occurs in the Krueng Ineng river due to the construction of water structures is expected to be a benchmark in planning the prevention of the structure of the bridge. Research on local scour on water structures, especially on bridges, needs to be done, because the impact of local scours can reduce the security of bridge structures. So that identification and analysis are needed in predicting the local scour that is around the bridge to minimize the impact that might occur. The Colorado State University (CSU) equation is the most widely used equation in America. The CSU equation is used to predict the maximum pier scour depths for both live-bed and clear-water scour conditions (by Richardson and Davis, 2010 in Osman Akan, 2006).

2. Experimental/Methods

The location of this research is carried out only in areas that experience local scouring problems under the bridge in Alue Buloh area, Nagan Raya Regency (Figure 1). The research period is conducted for 6 months starting from August 2019 - January 2020 and the type of research is quantitative and survey methods.

![Figure 1. Location of Study In Alue Buloh Area](image)

The data that will be used in this study are primary and secondary data. The primary data obtained from direct observation in the field while secondary data is obtained from relevant agencies where the data is needed to support the results of the research later. The primary data in this study will be obtained from direct observation in the field in the form of crosssection river data, the distance between piers, pier shape, pier dimensions, sediment samples, distance of the bridge to the downstream section, bridge deck width, bridge elevation, the elevation of decks under bridges. As for
the secondary data in the study in the form of watershed map data that contains information on the area of the watershed and the length of the main river, as well as rainfall data to determine the magnitude of the flood discharge plan. The data processing steps to be carried out in this study follow the research flowchart (Figure 2):

1. Field survey;
2. Obtain field data:
   a. The distance between piers is done by determining the center point of the pier and measuring the distance between the piers;
   b. Pier shape and dimension data can be done by looking at the pier shape visually and measuring the length and width of the pier;
   c. The distance of the bridge to the downstream cross-section is done by measuring the distance between the bridge starting point to the end of the bridge section;
   d. Bridge deck width is done by measuring the width of the bridge located at the study site;
   e. Elevation of the bridge is done using a water pass.
3. Measurement of grain size analysis:
   a. The sediment sample was tested with a sieve analysis to obtain the percentage of sediment passed through a sieve;
   b. Make a filter analysis chart, the correlation between a sieve diameter and percentage of sediment escaped;
   c. The grain size used is the average grain size D50 and D95 from the graph.
4. Hydrological analysis to determine the design flood discharge from a watershed:
   a. Monthly Maximum Rainfall Data;
   b. Analysis of rainfall frequency and testing the suitability of distribution to produce planned rainfall with a 2, 5, 10, 25, 50, and 100 year return period;
   c. Calculation of the flood discharge plan with the synthetic unit hydrograph of Nakayasu with a return period of 50 and 100 years in the Krueng Seunagan watershed. The Nakayasu Synthetic unit hydrograph equation is as follows (Soewarno, 1995):

   \[
   Q_p = \frac{A \cdot R}{3.6 \left(0.3T_p + T_{0.3}\right)}
   \]  

   Where: \(Q_p\) = design flood discharge \((m^3/s)\); \(R\) = unit rain \((mm)\); \(T_p\) = time lag from the beginning of the rain to the peak of the flood \((hour)\); \(T_{0.3}\) = the time required for a decrease in discharge, from peak discharge to 30% of peak discharge \((hour)\).
5. Processing of data using HEC-RAS software 5.0.7.
   The software also calculates the scour depth of the bridge piers constructed on rivers using hydraulic flow data, shape and geometric characteristics of the bridge pier, as well as the material and shape of the substrate around the river. The default software model for estimating the local scour depth around the bridge piers is the CSU model defined as follows (Richardson and Davis, 1995 in Ghaderi, 2019).

   \[
   Y_s = 2.0 K_1 K_2 K_3 K_4 \alpha^{0.65} Y_1^{0.35} F_{r1}^{0.43}
   \]  

   Where: \(Y_s\) = the maximum scour depth; \(\alpha\) = width or diameter of the pier; \(Y_1\) = the flow depth in the pier upstream; \(k_1\) = the pier shape coefficient; \(k_2\) = the coefficient of the impact angle; \(k_3\) = the bed condition coefficient; \(k_4\) = the bed's coefficient of reinforcement by the sediment particles; \(F_{r1}\) = Froude number. Correction factor table \(k_1\), \(k_2\), and \(k_3\) can be seen in tables 1 to table 3 below (Suma, 2018).

   The bridge scour computations are performed by opening the Hydraulic Design Functions window and selecting the scour at bridges function. Once this option is selected the program will automatically go to the output file and get the computed output for the approach section, the section just upstream of the bridge, and the sections inside of the bridge. Input data, a graphic, and a window for summary results. Input data tabs are available for contraction scour, pier scour, and abutment scour. Entering contraction scour data: all of the variables except \(K_1\) and \(D_{50}\) are obtained automatically from the
HEC-RAS output file. To compute contraction scour, the user is only required to enter the $D_{50}$ (mean size fraction of the bed material) and a water temperature to compute the $K_1$ factor. And then entering pier scour data: the user is only required to enter the pier nose shape ($K_1$), the angle of attack for flow hitting the piers, the condition of the bed ($K_3$), and a $D_{95}$ size fraction for the bed material. All other values are automatically obtained from the HEC-RAS output file. The user has the option to use the maximum velocity and depth in the main channel, or the local velocity and depth at each pier for the calculation of the pier scour (Graduado, 2001).

### Table 1. Correction Factors $K_1$ for pier shape

| No | Shape of pier nose | $K_1$ |
|----|--------------------|-------|
| 1  | Square nose        | 1,1   |
| 2  | cylinder           | 1,0   |
| 3  | Round nose         | 1,0   |
| 4  | Circular cylinder  | 1,0   |
| 5  | Sharp nose         | 0,9   |

### Table 2 Correction factor $K_2$ for pier angle of flow

| No | Pier angle of flow | $L/b = 4$ | $L/b = 8$ | $L/b = 12$ |
|----|--------------------|-----------|-----------|------------|
| 1  | 0                  | 1,0       | 1,0       | 1,0        |
| 2  | 15                 | 1,5       | 2,0       | 2,5        |
| 3  | 30                 | 2,0       | 2,75      | 3,5        |
| 4  | 45                 | 2,3       | 3,3       | 4,3        |
| 5  | 90                 | 2,5       | 3,9       | 5,0        |

### Table 3. Correction factor $K_3$, for bed condition

| No | Bed condition                  | Dune height      | $K_3$ |
|----|--------------------------------|------------------|-------|
| 1  | Clear-water scour             | Not applicable   | 1,1   |
| 2  | Plane bed and antidune flow   | Not applicable   | 1,1   |
| 3  | Small dunes                   | 0.6 – 3.0 m      | 1,1   |
| 4  | Medium dunes                  | 3.0 – 9.1 m      | 1,1–1,2 |
| 5  | Large dunes                   | >9.1 m           | 1,3   |

The equation developed by Dr. David Froehlich (Froehlich, 1991) was added to the HEC-RAS software as an alternative to the CSU Equation (Ghaderi et al., 2019).

$$Y_s = 0.32 \varnothing (\alpha')^{0.62} Y_1^{0.47} F_1^{0.22} D_{50}^{-0.09} + \alpha$$

(3)

Where: $Y_s$ = the maximum scour depth; $\varnothing$ = the coefficient of correction for the nose; $Y_1$=the depth of flow at the upstream of the pier; $D_{50}$=the average diameter of the bed particles; $\alpha$=the width or diameter of the base; $\alpha'$=width of the lateral bridge pier that imported to flow path.
Figure 2. The flowchart of research implementation

Figure 3. Map of the situation the study area
3. **Result and discussion**

This measurement is carried out to determine the dimensions of the piers that will be used in research. From measurements in the field, pier dimension data obtained such as pier width, the distance between piers, and pier shape (are shown in Table 4 and Table 5).

**Table 4 Pier Dimension Data**

| Measurement of Pier                      | Data                |
|-----------------------------------------|---------------------|
| pier width and length                   | 4 m and 10m         |
| the distance between piers              | 60 m                |
| pier shape                              | Round nose          |
| Bridge deck width                       | 7.05 m              |
| Bridge length                           | 180 m               |
| Distance of bridge to cross section     | 1,475 m             |
| upstream /downstream                    |                     |
| Bridge length                           | 50 m                |

**Table 5. Sediment Grain Size Analysis**

| Diameter | soil retained on each sieve (gram) | % soil retained on each sieve | soil retained finer | % Finer |
|----------|------------------------------------|------------------------------|---------------------|---------|
| 4.75     | 5.46                               | 2.73                         | 194.54              | 97.27   |
| 2.36     | 27.14                              | 13.57                        | 167.40              | 83.70   |
| 1.18     | 39.14                              | 19.57                        | 128.26              | 64.13   |
| 0.6      | 60.68                              | 30.34                        | 67.58               | 33.79   |
| 0.3      | 47.49                              | 23.74                        | 20.09               | 10.05   |
| 0.15     | 17.57                              | 8.78                         | 2.53                | 1.26    |
| 0.075    | 2.53                               | 1.26                         | 0.00                | 0.00    |

**Figure 4. Sediment Grain Size Analysis**
The grain size analysis to obtain the required grain diameter as a parameter in the scour depth calculation. The variable to be obtained is the average particle size diameter of D50 and D95 sediment grain. Sediment grain size analysis are shown in Table 4 and figure 4 above. The results analysis of the sediment grain that has been carried out (figure 4 above) obtained the average values of sediment grain size for D50 is 0.91 mm and D95 is 4.35 mm.

In this study, the debit that will be used in the calculation of the scour depth is the peak discharge with Synthetic Unit Hydrograph Nakayasu method. The rainfall plan can use the Log Pearson Type III distribution is acceptable (are shown in Table 6 and figure 5).

### Table 6. Parameters of the Krueng Seunagan River Basin

| Parameters of Nakayasu | Data and Result |
|------------------------|----------------|
| Watershed Area         | 995.86 km²     |
| length of the longest channel | 132.92 km |
| Tₚ = 0.40 + 0.058 * L | 7.749 hours |
| Tₚ = Tₚ + 0.8 * Tᵣ | 12.399 hours |
| Tᵣ = 0.75 * tₚ | 5.812 hours |
| T₀.₃ = α * Tₚ | 15.499 hours |
| Qₚ = \frac{1}{3.6 \left( \frac{A.Re}{0.3Tₚ + T₀.₃} \right)} | 14,394 m³/det |

![Figure 5. Hydrograph Nakayasu](image-url)

The hydraulic analysis was carried out using the HEC-RAS 5.0.7 program. This type of simulation for hydraulic analysis uses a steady flow analysis. The first step to develop HEC-RAS model is to create a HEC-RAS geometric file. The basic geometric data consists of establishing how the various river reaches are connected: Enter river cross-section data including distance, elevation, manning coefficient, the distance between cross-sections, and levee.
Enter the bridge deck data next is to enter the pier data. The trick is to select the pier in the pier data editor window, fill in the pier spacing in the upstream centerline station and the downstream centerline station.

The discharge value entered is the discharge value obtained from the Nakayasu calculation (100 years of 1513 m$^3$/sec). Select the reach boundary conditions and fill the boundary conditions for downstream and upstream as normal depth, then fill in the riverbed slope of 0.022 for downstream and upstream of 0.042. Modeling carried out is a condition in which a bridge already exists. This modeling
is intended to determine the prediction of local scour depth due to contraction scour and piers. The pier shape analyzed in this modeling is the pier with round nose shape. The data needed to calculate contraction scour almost all have been automatically simulated by HEC-RAS based on the steady flow analysis. Data to be entered in the form of sediment diameter $D_{50}$ on each left and right overbank and channel. The coefficient $K_1$ value will be automatically calculated by the HEC-RAS program. The contraction scours calculated with the Laursen equation of the clear-water scour or live-bed scour version. But in this study, Equation is selected in the Default position.

![Figure 8. Input Menu of Contraction Data](image)

![Figure 9. The coefficient $K_1$](image)

Then the depth scouring analysis was carried out on the pier by HEC-RAS with CSU equation. The data entered there are 4 types with their respective values, pier shape with round nose shape, flow angle of attack to the pier is 0, river bed shape ($K_3$) is small dunes, and sediment diameter ($D_{95}$) 4.35mm.
The next step is to compute the data based on the predetermined debits, which are 100 years peak discharge of 1513 m³/sec. Then the modeling of local scour depth can be seen in the Figure 11 and Figure 12 below. The results of depth scoursing analysis on the return period of 100 years return with HEC-RAS 5.0.7 modeling were obtained at 5.04 m.

4. Conclusions

In this study, the peak discharge that occurred in the Seunagan Krueng watershed using the Nakayasu HSS method was \( Q_{p100} = 1513 \text{m}^3/\text{sec} \). Analysis of sediment grains obtained the average value of sediment grain size for \( D_{50} \) is 0.91 mm and \( D_{95} \) is 4.35 mm. Analysis of local scour depth using HEC-RAS 5.0.7 software with round nose pillar shape at peak discharge when 100 years return is equal to 5.04 m. Further research can be done by examining the depth of local scours through experiments in the laboratory using a different piers shape.
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