Numerical Modeling With HEC RAS and Scour Empiric Equation To Estimating Scour Depth on Abutment (Batang Kalu River Bridge Case)

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Abstract. The riverbed around the abutment can experience scouring caused by flow, because its is always directly related to river flow. Abutment can obstruct the flow of rivers causing changes in flow characteristics which in turn will cause local scouring around these buildings. Toe Scour around abutment will be very dangerous and cause loss of stability on the bridge. The case of structure failure on Batang Kalu bridge in Korong Pasa Usang Nagari Kayu Tanam, Padang Pariaman Regency on Monday (10 December 2018) is a clear example of toe scouring. A case study of toe scour was on the Batang Kalu River bridge structure has been carried out. Rainfall data closest to the study location, Kandang Empat Station was used to minimize the errors in the calculation of flood discharge design. Numerical modeling with HEC RAS and scouring estimation with some empiric equation was conducted to predicting scour depth on abutment. Simulation results show scour depth results to an average of 2.731 m and close to the scour depth that occurred in the field (2.83 m). Results showed that the local scouring in the Batang Kalu River bridge structure can be suspected as the influence of the increasing river steepness. Discharge that is triggered by heavy rain with a long duration and increased river flow velocity due to steepness has the potential to create a very intense scouring. Increasing of steepness may have been caused by sand mining activities in the upper reaches. Further studies are needed to see the potential slope changes due to exploitation in the Batang Kalu River upper reaches.

1. Introduction

Changes in river morphology followed by changes in river characteristics can cause changes in flow patterns. If the river body has a building in the form of a bridge abutment, it will cause local scouring and a decrease in base elevation (degradation) around the bridge pillar. Scour is a natural phenomenon caused by the flow of water that usually occurs at the bottom of a river consisting of alluvial material but sometimes it can also occur in a hard river. Scouring can cause erosion of the soil around the foundation of a building located in a stream of water. Scour usually occurs as part of the morphological changes of the river and changes due to man-made buildings [1].

The process of erosion and deposition in rivers generally occurs due to changes in flow patterns, especially in alluvial rivers. Changes in flow patterns can occur due to obstacles or obstacles in the river flow which can be in the form of river buildings such as bridge abutments, river cribs, pillars, revetments, and so on. This kind of building is seen to be able to change the flow geometry and flow pattern, which is then followed by the emergence of local scouring around the building. Local scouring
events will always be closely related to the phenomenon of river flow behavior, namely river flow hydraulics in their interactions with river geometry, geometry and layout of bridge pillars, as well as the characteristics of the subgrade where the pillars were built [2].

Abutment is a part of bridge construction which is located in a river body that functions as a bridge load. The riverbed around the abutment can experience scouring caused by flow, because its structure is always directly related to river flow. Abutment of bridges or other water structures can obstruct the flow of rivers causing changes in flow characteristics which in turn will cause local scouring around these buildings. Scouring around the bridge abutment will be very dangerous and cause loss of stability so that the collapse occurs on the bridge. Shear velocity as a component of the mechanism of sediment transport and scouring at the foot of the abutment is strongly influenced by the flow velocity that occurs in the river body, especially at locations near the abutment structure itself. The occurrence of changes in the speed around this location is actually a common thing to happen as a result of contraction of the flow due to narrowing of the channel by the reduced appearance of the river due to the existence of the structure. In general, this condition has been predicted beforehand by the bridge designer and is anticipated by efforts to protect the feet around the bridge abutment. However, changes in the character and pattern of flow due to changes in flow regime by the influence of changes in the river environment are different outside the planning which threatens the stability of the structure under the bridge. The case of the Padang - Bukittinggi transport line cut off due to failure of the structure under the Batang Kalu bridge in Korong Pasa Usang Nagari Kayu Tanam, Padang Pariaman Regency on Monday, December 10th 2018 is a clear example of structural failure due to scouring of the feet. (Figure 1).

One of the causes of this structural failure can be hypothesized as the impact of changes in flow character due to disturbance in the environment of the river body, as well as by an increase in flow velocity due to the amount of discharge that occurred at that time. This research will answer the problem formulation to find out how much influence the changes in flow patterns and characteristics of the river environment on the increase in transport and scour mechanism that occurs at the foot of the bridge abutment structure.

The scour is defined as an enlargement of a flow that is accompanied by the transfer of material through fluid motion [3], [4]. Local scouring occurs when the flow capacity to erode and transport sediments is greater than the sediment supply capacity [5]. Pier is part of the bridge construction which is located in the middle of the river and functions as a bridge load. Although the pier is located in the middle of the river, the river bed around the pier can also experience scouring caused by the flow, because these piers are always directly related to the river flow. Piers and abutments of bridges and other water structures can obstruct the flow of rivers, causing changes in flow characteristics which in turn will cause local scouring around these buildings. Experimental and numerical studies have been
performed to investigate the flow mechanism around a bridge pier. Turbulent flow around a complex bridge pier on the scoured bed was conducted by numerical simulation approach [6]. Characterization of horseshoe vortex in a developing scour holes study was performed at a cylindrical bridge pier. Also the effect of partial blockage on multi-vents bridge pier scour was studied with experimentally and numerically methods [7]. Study that describing the effect of shape geometry of bridge pier on several conditions related on scours was conducted. Local scour around two side-by-side cylindrical bridge piers under ice-covered conditions was performed. The multi-span masonry arch bridges subjected to scour was modelled with three-dimensional mesoscale modelling [8]. Mathematical modeling approach also was performed to evaluating local scour around bridge piers for various geometrical shapes [9]. Study to investigate the responses of caisson-piles foundations to long-term cyclic lateral load and scouring was conducted [10]. The problem of flood-induced scour was evaluated with a numerical model. Model was performed to calculating the level of scour which led to the bridge failure and the corresponding collapse mechanism, and to assess the sensitivity of the bridge’s modal properties (vibration frequencies and mode shapes) to different levels of scour [11]. Local scouring at bridge pier will affecting the behavior these structure subjected to flood-induced loads [12]. Also, case study of bridge scour in the UK was performed. Study was related into the effects of uncertain asset stock data on the assessment of climate change risks [13]. Some methods to reducing scour hole around bridge pier was proposed. Review on the methods used to reduce the scouring effect and also the effects of height and vertical position of slot on the reduction of scour hole depth around bridge abutments were conducted [14], [15]. Investigation related the effect of submergence ratio of parallel wall on bridge abutment scour also conducted [16]. The use of RMA2 for simulating flooding at river flow has been carried out [17].

Scouring around the piers of the bridge will be very dangerous and cause loss of stability of the piers so resulting in collapse of the bridge. The scour hole that occurred starting from the upstream of the pier, when the flow component that leads to the downstream. Near the bottom of the flow component, the direction will be reversed upstream, followed by the carrying of basic material so that a spiral flow is formed in the area of the scour hole that results in the scouring of the river bed around the pier as shown in Figure 2 (a). The scouring process around piers or abutments is very complex because it involves three-dimensional flow. When the flow passes through the pier, there will be a flow separation and this separation will extend to the downstream of the pier. The vortex system that occurs has a shape or characteristic such as a vortex of horse shoes so it is called the vortex horse vortex as shown in Figure 2 (b).

![Figure 2. Current Patterns Around Round Bridge Pillars and Horseshoe Vortex](image-url)
The maximum scour depth occurs when the shear velocity \( (u^*) \) is equal to the shear velocity of the critics in the transition area between clear-water scour and live-bed scour as shown in the following figure.

![Figure 3. Depth of Scour (ds) as a Function of Shear Speed (u *) (Breusers and Raudkivi, 1991)](image)

2. Methodology

The research location is in the Batang Kalu river, Padang Pariaman Regency. At this location there is a bridge connecting Padang - Bukittinggi, as shown in Figure 4. Toe scour is caused by the acceleration of the flow that occurs due to contraction of the flow when passing through the bridge structure. The flow pattern that occurs is influenced by the characteristics of the river profile and discharge that occurs. Determination of discharge is calculated with using the Rational, Hasper and Weduwen methods. The results of the theoretical discharge are validated against field measurement data so that the discharge values will be used in the simulation.

![Figure 4. Research Location](image)

Calculation of profile and flow character using HECRAS by applying the standard step method for steady flow [18] as shown in Figure 5 with the energy equations as follow:

\[
\begin{align*}
\frac{V^2}{2g} + z_1 &= \frac{V^2}{2g} + z_2 + h_L \\
\frac{V^2}{2g} + z_1 &= \frac{V^2}{2g} + z_2 + S_e \Delta L
\end{align*}
\]
The values of the flow variables obtained are used to determine scour predicted using Froehlich, Lacey, Blench equations and Bridge Scour Manual Method. Some of these equations as follow [4], [5], [19], [20].

- Froehlich (1987):
  \[
  \frac{y_s}{y_1} = 0.78 \times K_1 \times K_2 \times \left(\frac{\alpha'}{y_1}\right)^{0.63} \times Fr^{1.16} \times \left(\frac{y_1}{d_{50}}\right)^{0.43} \times G^{-1.87} + 1
  \]
  Where \( K_1 = 1.0 \) (vertical wall abutment); \( K_2 = \left(\frac{\theta}{g y_1}\right)^{0.13} \); \( Fr = V_e / (g y_1)^{0.5} \); \( G = (D_{84}/D_{16})^{0.5} \)

- Lacey (1930):
  \[
  y_{ms} = 0.47 \left(\frac{q}{f}\right)^{1/3}
  \]
  Where \( f = 1.76 d_{50}^{0.5} \) (mm); \( y_{ms} \) = depth of scour from flood waters

- Blench (1969)
  \[
  y_{ms} = 1.20 \left[\frac{q^{2/3}}{d_{50}^{1/6}}\right] \text{ for } 0.06 \text{ mm} < d_{50} > 2 \text{ mm}
  \]
  \[
  y_{ms} = 1.23 \left[\frac{q^{2/3}}{d_{50}^{1/12}}\right] \text{ for } d_{50} > 2 \text{ mm dan } G = 2.65
  \]

- Bridge Scour Manual Method:
  \[
  \frac{y_s}{y_1} = 4 Fr^{0.33} \frac{K_1}{0.55} K_2
  \]

3. Result and Discussion

Batang Kalu River is a tributary of the Batang Anai River which belongs to the Batang Anai watershed. There are three closest rainfall stations within the Batang Anai watershed, namely Paraman Talang Station, Kandang Station IV and Lubuk Napar Station. Observation of the position of the Batang Kalu river on the location of the rainfall station found that conditions were too small to influence of the
Paraman Talang and Lubuk Napar Stations on the determination of theoretical discharge at the study location, as shown in the following figure.

**Figure 6.** Location of the Batang Kalu River Against the Batang Anai watershed

**Figure 7.** Position of Rainfall Station and Polygon Thiessen in Batang Anai Watershed

Considering the influence of the Paraman Talang and Lubuk Napar Stations on the study location, the hydrological analysis to obtain the flood discharge design was determined using the Kandang Empat Station (0 30' 48" South and 100 20' 6" East) with maximum rainfall data as shown in the following figure.
Figure 8.

Theoretical discharge was calculated using Rational, Hasper and Weduwen methods on various Return Period with the results as shown in the following table. With calibration test by calculating the maximum capacity of river cross wet area as assume 2 years return period resulting Weduwen as the good fitted.

| T    | Discharge (m³/dt) | Rasional | Hasper | Weduwen |
|------|-------------------|----------|--------|---------|
| 2    | 72.644            | 99.206   |        | 79.618  |
| 5    | 84.914            | 112.944  |        | 95.542  |
| 10   | 91.340            | 119.859  |        | 111.465 |
| 25   | 97.621            | 126.439  |        | 133.758 |
| 50   | 102.587           | 131.522  |        | 151.274 |
| 100  | 106.677           | 135.631  |        | 167.198 |

HEC RAS simulations were carried out to get the values of variable velocity and water level at several cross sections of the river being modeled. By using an actual river bed slope of 0.04 and a cross-section of the measurement river (Figure 9), velocity values at various discharge were obtained. The velocity and discharge variables obtained are input to calculate the theoretical scour depth using the empirical equation as shown in the Table 1.

Validation is done by comparing the theoretical scour depth and the actual scour depth. The results of observations show that the scour depth is 2.83 m. From the results of the validation of the model, it is obtained the condition that is close to simulation results using flood discharge with 5 years return period. This shows that flood discharge is not the main factor causing scour. Increased velocity due to increased river bed steepness can be expected as a variable that results in velocity increase resulting increasing of scour depth. The graph of the relationship of scour value to flood discharge can be seen in the graph at Figure 10.
Figure 9. Layout and cross section of the river around the bridge location with HEC RAS

Table 1. Empirical Scour Depth with Several Scour Equation

| Return Period (year) | Discharge (m³/s) | Velocity (m/s) | Scour Depth (m) |
|----------------------|------------------|----------------|-----------------|
|                      |                  |                | Froehlich | Bridge Scour | Blench | Lacey | Average |
| 2                    | 79.618           | 3.317          | 1.561     | 2.532      | 3.082  | 2.532 | 2.427   |
| 5                    | 95.542           | 3.981          | 1.673     | 2.691      | 3.868  | 2.691 | 2.731   |
| 10                   | 111.465          | 4.644          | 1.774     | 2.833      | 4.612  | 2.833 | 3.013   |
| 25                   | 133.758          | 5.573          | 1.903     | 3.010      | 5.595  | 3.010 | 3.380   |
| 50                   | 151.274          | 6.303          | 1.996     | 3.136      | 6.330  | 3.136 | 3.650   |
| 100                  | 167.198          | 6.967          | 2.076     | 3.242      | 6.974  | 3.242 | 3.884   |
4. Conclusion

This study was a preliminary illustration to see the effect of variable flow that occurs on toe scour at the bridge abutment structure. A case study of toe scour was on the Batang Kalu River bridge structure has been carried out. Rainfall data closest to the study location, Kandang Empat Station was used to minimize the errors in the calculation of flood discharge design. Simulation results show the closeness of the scour depth results to an average of 2.731 m and close to the scour depth results that occur in the field (2.83 m). From the results of this study shows that the local scouring in the Batang Kalu River bridge structure can be suspected as the influence of the increasing river steepness. Increased discharge that is triggered by heavy rain with a long duration and increased river flow velocity due to bed steepness has the potential to create a very intense scouring around the abutment. Increasing of river steepness may have been caused by sand mining activities in the upper reaches of the river. Further studies are needed to see the potential for river slope changes due to exploitation in the Batang Kalu River upper reaches.

5. Acknowledgment

The author would like to thank Politeknik Negeri Padang for funding this research through the Hibah Unggulan Perguruan Tinggi.

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