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Scour Depth Estimation on Abutment With HEC RAS and Some Empirical Equation

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Abstract

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.

Keywords:Scour, Numerical Modeling, HEC RAS, Batang Kalu River

Abstrak

Gerusan kaki di sekitar abutment dapat mengancam dan menyebabkan hilangnya stabilitas jembatan. Kasus kegagalan struktur jembatan Batang Kalu di Korong Pasa Usang Nagari Kayu Tanam, Kabupaten Padang Pariaman, pada 10 Desember 2018adalah contoh penggerusan kaki di abutment. Studi kasus gerusan kaki pada struktur jembatan Sungai Batang Kalu telah dilakukan. Data curah hujan Stasiun Kandang Empat yang terdekat dengan lokasi penelitiandigunakan untuk meminimalkan kesalahan dalam perhitungan desain debit banjir. Pemodelan numerik menggunakan HEC RAS dan estimasi gerusan dengan beberapa persamaan empiris dilakukan untuk memprediksi kedalaman gerusan. Hasil simulasi menunjukkan kedalaman gerusan rata-rata 2,731 m dan mendekati kedalaman gerusan \lapangan (2,83 m). Hasil penelitian menunjukkan gerusan lokal pada struktur jembatan Sungai Batang Kalu dapat diduga sebagai pengaruh meningkatnya kecuraman sungai. Debit yang dipicu oleh hujan lebat dengan durasi yang lama dan peningkatan kecepatan aliran sungai karena pengaruh kecuraman dasar berpotensi menciptakan gerusan yang sangat tinggi. Peningkatan kecuraman dasar berpotensi disebabkan oleh aktivitas penambangan pasir di hulu. Diperlukan studi lebih lanjut untuk melihat potensi perubahan kemiringan dasar akibat eksploitasi di hulu Sungai Batang Kalu.

Kata kunci :Gerusan, Model numerik, HEC RAS, Sungai Batang Kalu

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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 bed elevation (degradation) around the bridge abutment. 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).

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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.

Figure 1. Condition of Batang Kalu Bridge damage caused by massive toe scouring occurred due to increasing flow at the bottom.

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[7]. Also the effect of partial blockage on multi-vents bridge pier scour was studied with experimentally and numerically methods[8]. 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[9]. The multi-span masonry arch bridges subjected to scour was modelled with three-dimensional mesoscale modelling[10]. Mathematical modeling approach also was performed to evaluating local scour around bridge piers for various geometrical shapes[11]. Study to investigate the responses of caisson-piles foundations to long-term cyclic lateral load and scouring was conducted[12]. 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[13]. Local scouring at bridge pier will affecting the behavior these structure subjected to flood-

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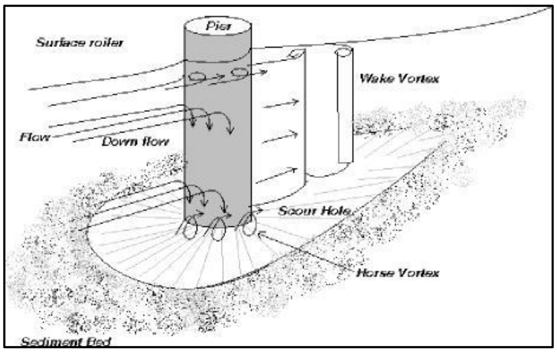
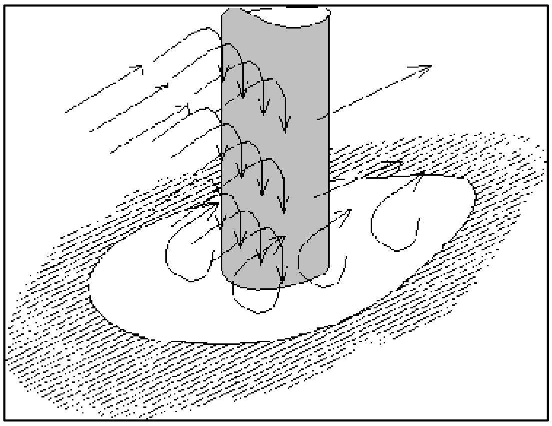
induced loads[14]. Also, case study of bridge scour in the UK was performed. Study was related into the effects of uncertain asset stock data on the assessment of climate change risks[15]. Some methods to reducing scour hole around bridge pier was proposed. Review on the methods used to reduce the scouring effect and also the effects of height and vertical position of slot on the reduction of scour hole depth around bridge abutments were conducted[16], [17]. Investigation related the effect of submergence ratio of parallel wall on bridge abutment scour also conducted[18].

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 revers]ed 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).



(a)



(b)

Figure 2. Current Patterns Around Round Bridge Pillars (a) and Horseshoe Vortex (b)

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 3. 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

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measurement data so that the discharge values will be used in the simulation.

Figure 3. Ressearch Location

Calculation of profile and flow character using HECRAS by applying the standard step method for steady flow [19] as shown in Figure 4.

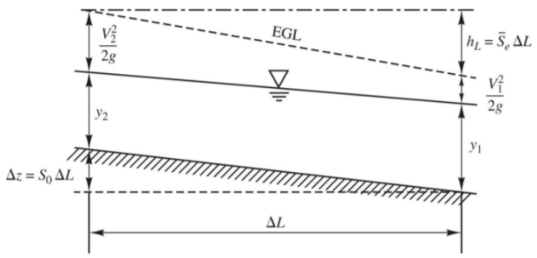

Figure 4. Standard Step Method For Steady Flow

with the energy equations as follow ;

$$y_1 + \frac{V^2}{2g} + z_1 = y_2 + \frac{V^2}{2g} + z_2 + h_L \quad (1)$$

$$y_1 + \frac{V^2}{2g} + z_1 = y_2 + \frac{V^2}{2g} + z_2 + S_e \Delta L \quad (2)$$

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 equation as follow [4], [5], [20], [21].

Froehlich (1987) :

$$\frac{y_s}{y_1} = 0{,}78 \times K_1 \times K_2 \times \left(\frac{a'}{y1}\right)^{0{,}63} \times F_r^{\,1{,}16} \times \left(\frac{y1}{d_{50}}\right)^{0{,}43} G^{-1{,}87} + 1 \quad (3)$$

Where K_1 = 1,0 (vertical wall abutment) ;

$K_2 = \left(\frac{\theta}{90}\right)^{0.13}$; $Fr_e = V_e / (g\, y_1)^{0.5}$; $G = (D_{84}/D_{16})^{0.5}$

Lacey (1930) :

$$y_{ms} = 0{,}47\left(\frac{Q}{f}\right)^{1/3} \quad (4)$$

Where f = $1{,}76 d_m^{0{,}5}$ (mm) ; y_{ms} = depth of scour from flood waters

Blench (1969) :

$$y_{ms} = 1{,}20\left[\frac{q^{2/3}}{d_{50}{}^{1/6}}\right]$$

for 0,06 mm < d50 >2 mm (5)

$$y_{ms} = 1{,}23\left[\frac{q^{2/3}}{d_{50}{}^{1/12}}\right]$$

for d50 >2 mm dan G = 2,65 (6)

Bridge Scour Manual Method :

$$\frac{y_s}{y_1} = 4\, Fr^{0.33}\, \frac{K_1}{0.55} K_2 \quad (7)$$

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 Figure 5.

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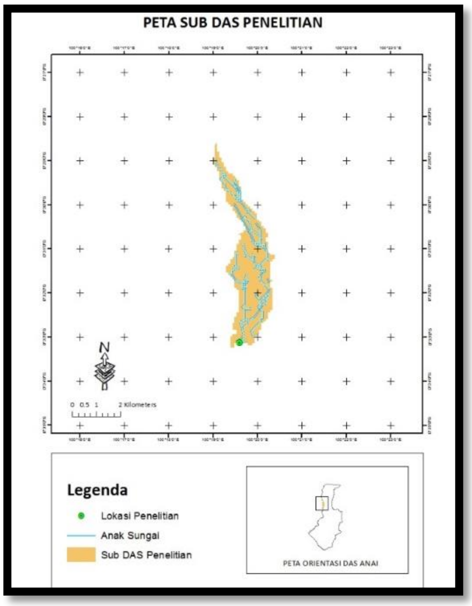

Figure 5. Location of the Batang Kalu River Against the Batang Anai watershed

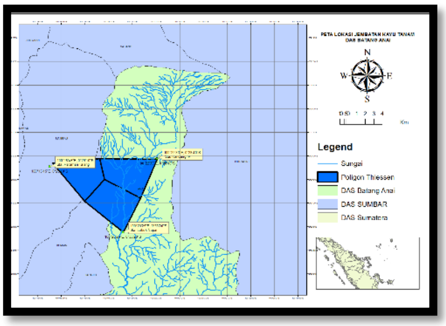

Figure 6. Position of Rainfall Station and Polygon Thiessen in Batang Anai Watershed

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 (0̊ 30’ '48 "South and 100○ ˚20' 6" East) with maximum rainfall data as shown in the following figure.

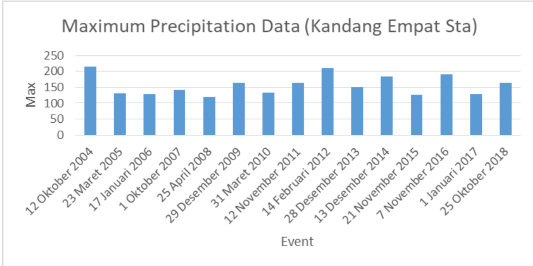

Figure 7. Maximum Precipitation Data at Kandang Empat Station

Theoretical discharge was calculated using Rational, Hasper and Weduwen methods on various Return Period with the results as shown in Table 1. 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.

Table 1. Flood Discharge at Batang Kalu River for variation of Return Period

T	Discharge (m³/sec)		
	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 8), velocity values at various discharge were obtained. Figure 8 showed the boundary conditions that taken at 50 meters each towards the upstream and downstream from bridge location with a total of 12 cross sections in the model domain. Numbering was

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done by placing cross number 12 at the upstream and cross number 1 at the downstream boundaries respectively. The modeling results in Figure 8 show the water level profile at each cross section by using of 95,542 m^3/sec discharge (Q at Return Period as 5 years) as a discharge that results in the scour depth closest to the real conditions.The velocity and discharge variables obtained are input to calculate the theoretical scour depth using the empirical equation as shown in the Table 2.

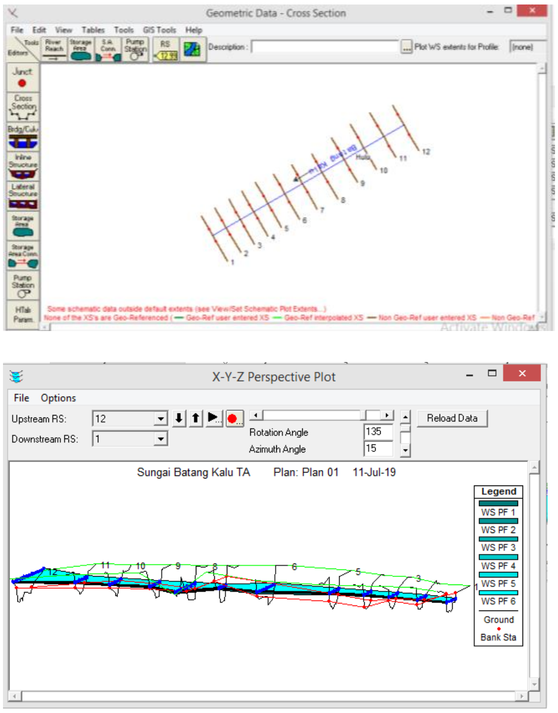

Figure 8. Layout and cross section of the river around the bridge location with HEC RAS

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 9.

Table 2. 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

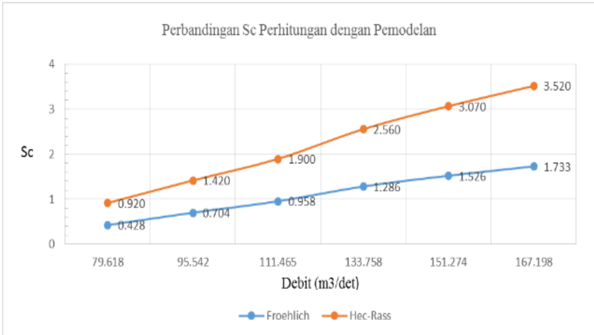

Figure 9. Comparison of Scour Depth (Sc) Against Flood Discharge (Q)

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. Limitation of the results from this modelis only limited to illustrating the riverbed dislocation caused by scouring at the abutment location to the river section in general, and has not

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provided local scouring results at the both position of the abutment. The depth of the local scour in the both position of the abutment can be predicted using physical modeling in the laboratory. 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.

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References

[1] Breusers, H.N.C. and Raudkivi, A.J., 1991, “Scouring, IAHR, Hydraulic Structure Design Mannual“, A.A. Balkema, Rotterdam.

[2] Legono D, 2001, “Hidraulika Bangunan Sungai“ , Universitas Gadjah Mada, Yogyakarta

[3] Hoffmans, G.J.C.M., Verheij., H.J., 1997, “Scour Manual”, A.A. Balkema, Rotterdam.

[4] Garde,R.J. and Raju,K.G.R., 1977, ”Mechanics of Sediment Transportation and Alluvial Stream Problem”, Willy Eastern Limited, New Delhi.

[5] Graf, W. H., 1998,”Fluvial Hydraulics”, John Wiley & Sons Ltd, England.

[6] Mahdi Alemi, João Pedro Pêgo, Rodrigo Maia, “Numerical simulation of the turbulent flow around a complex bridge pier on the scoured bed”, European Journal of Mechanics - B/Fluids, Volume 76, July–August 2019, Pages 316-331

[7] Dawei Guan, Yee-Meng Chiew, Maoxing Wei, Shih-Chun Hsieh “Characterization of horseshoe vortex in a developing scour hole at a cylindrical bridge pier”, International Journal of Sediment Research, Volume 34, Issue 2, April 2019, Pages 118-124

[8] Yasser Abdallah Mohamed Moussa, Tarek Hemdan Nasr-Allah, Amera Abd-Elhasseb, “Studying the effect of partial blockage on multi-vents bridge pier scour experimentally and numerically”,Ain Shams Engineering Journal, Volume 9, Issue 4, December 2018, Pages 1439-1450

[9] Mohammad reza Namaee, Jueyi Sui , “Local scour around two side-by-side cylindrical bridge piers under ice-covered conditions”, International Journal of Sediment Research, Volume 34, Issue 4, August 2019, Pages 355-367

Informasi Artikel

Diterima Redaksi : 18-02-2020 | Selesai Revisi : 15-04-2020 | Diterbitkan Online : 30-04-2020

[10] Enrico Tubaldi, Lorenzo Macorini, Bassam A. Izzuddin, "Three-dimensional mesoscale modelling of multi-span masonry arch bridges subjected to scour", Engineering Structures, Volume 165, 15 June 2018, Pages 486-500

[11] Ahmed Moustafa, Ahmed Moussa, "Evaluation of local scour around bridge piers for various geometrical shapes using mathematical models", Ain Shams Engineering Journal, Volume 9, Issue 4, December 2018, Pages 2571-2580

[12] Chenrong Zhang, Xun Zhang, Maosong Huang, Huawei Tang, "Responses of caisson-piles foundations to long-term cyclic lateral load and scouring", Soil Dynamics and Earthquake Engineering, Volume 119, April 2019, Pages 62-74

[13] Fabrizio Scozzese, Laura Ragni, Enrico Tubaldi, Fabrizio Gara , "Modal properties variation and collapse assessment of masonry arch bridges under scour action", Engineering Structures, Volume 199, 15 November 2019, Article 109665

[14] Chung-Chan Hung, Wen-GiYau, " Behavior of scoured bridge piers subjected to flood-induced loads", Engineering Structures, Volume 80, 1 December 2014, Pages 241-250

[15] Hristo Dikanski, Boulent Imam, Alex Hagen-Zanker , "Effects of uncertain asset stock data on the assessment of climate change risks: A case study of bridge scour in the UK", Structural Safety, Volume 71, March 2018, Pages 1-12

[16] Mohamed Zaid, Zeinab Yazdanfar, Harun Chowdhury, Firoz Alam , "A review on the methods used to reduce the scouring effect of bridge pier", Energy Procedia, Volume 160, February 2019, Pages 45-50

[17] Mehdi Osroush, Seyed Abbas Hosseini, Amir Abbas Kamanbedast, Amir Khosrojerdi , "The effects of height and vertical position of slot on the reduction of scour hole depth around bridge abutments", Ain Shams Engineering Journal, Volume 10, Issue 3, September 2019, Pages 651-659

[18] Fatane Sadeghi, Yousef Ramezani, Hossein Khozeymehnezhad, "Effect of submergence ratio of parallel wall on bridge abutment scour", Alexandria Engineering Journal, Volume 57, Issue 4, December 2018, Pages 2659-2665

[19] U.S. Army Corps of Engineer, 1984, HEC-RAS River Analysis System

[20] Graf, W. H., 1984,"Hidraulics of Sedimen Transport", Water Resources Publications, Colorado.

[21] Raudkivi,A.J. and Ettema, 1982 ,"Scour at Bridge Piers", Third Congres of the Asian and Pasific Division of the International Association for Hydraulics Research IAHR

Informasi Artikel

Diterima Redaksi : 18-02-2020 | Selesai Revisi : 15-04-2020 | Diterbitkan Online : 30-04-2020