RES MILITARIS
REVUE EUROPEENNE D ETUDES EUROPEAN JOURNAL OF MILITARY STUDIES
Social Science Journal

Hydrodinamic Model of Flood Flow around Bridge in Ciujung River, Serang Regency, Banten

By

Gita Silvia Pamungkas
Master Program in Water Resources Management, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Bandung, Indonesia
Email: gitavia25@gmail.com

M.Syahril Badri Kusuma
Water Resources Engineering Research Group, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Bandung, Indonesia
Email: gitavia25@gmail.com

Widyaningtias
Water Resources Engineering Research Group, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Bandung, Indonesia
Email: gitavia25@gmail.com

Lezi Miartix
Master Program in Water Resources Management, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Bandung, Indonesia
Email: gitavia25@gmail.com

Abstract

Ciujung River is one of the most strategic river of Banten Province where it serves as natural drainage, water supply, irrigation, flood control and several national highway toward to the main Airport and Harbour should across it. In the same time, one of the highest risk problem could be generated is the breach of Ciujung Bridge on the highway of Tangerang-Merak. However, there is no previous study discuss about its potential hazard. This paper discuss the flood flow and the dependable flow pattern around Ciujung Bridge based on field observation, secondary data and mathematical model results. The flow pattern will be predicted by using Hecras 6.2 for 2d unsteady flow. The input hydrograph will be determined based on SNI 2415:2016 for a 50-year return period for the flood condition and Q90% for dependable flow condition. The model result is compared to the field data based on the previous observation of extreme flood in 2013. Model prediction of future extreme flood will be done using extreme rainfall of 100 years period. Based on this model result, a potential update of bridge pier that might be used to reduce the risk of the bridge or the river bank failure, could be discussed.

Keywords: Erosion, Flood, Scouring, Sedimentation

Introduction

Ciujung River is a river that provides benefits to residents around the river channel. There are several community facilities and businesses that depend on the Ciujung River such as irrigation water supply facilities, drinking water supply facilities, natural recreation facilities, freshwater aquaculture, and crossing bridge facilities. In addition, the Ciujung River also faces problems related to flooding, erosion, sedimentation, and water quality [1-3].

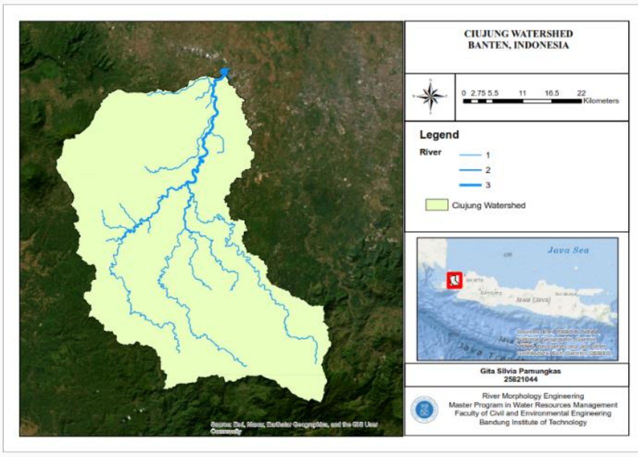

Fig. 1 *Ciujung Watershed in Banten Province, Indonesia*

The bridge on the Ciujung River, located on highway Tangerang-Merak toll road section, is an important facility for public transportation, private vehicles and logistics supply vehicles toward to the main Airport and Harbour. As we know that the only way that can be accessed quickly to Merak or to Jakarta is this route.

Fig. 2 *Lokasi Jembatan Ciujung*

Ciujung bridge is located in Serang Regency. It connects two surrounding villages, Undarandir and Kibin.

When there was a major flood in 2013 and 2020, the condition of the bridge was inundated, thus cutting off transportation connectivity from Java to Sumatra and vice versa. The flood caused a change in the lower structure of the bridge pillars.

Fig. 3 *Ciujung Bridge*

Previous study reported that the sedimentation rate and flood peak of Ciujung River has been increased during the last two decades, as it is commonly observed in another river located in built environment of Indonesia [4-9]. The safety and function of the bridge would then be decreased due to the increasing sedimentation and flood peak as discussed above. Further study to get a more reliable sedimentation rate, flood risk is then required as a counter measure to mitigate the potential disaster. Flood risk could be analyzed using BNPB standard [10]. Due to the lack of data observation, the analysis of sedimentation and water level on the bridge could be done by using Neural Network Method [11, 12]. The influence of additional sedimentation to bridge located in the upstream part of the bridge should be evaluated [13-16]. Flood risk should be predicted using the updated flood peak by using mathematical model [13-16]. The influence of the increasing flood peak of Ciujung River to the bridge stability, the sedimentation rate and river bed erosion should be studied [17-18]. However, this paper presents only the prediction of potential sedimentation distribution during the dry season and bed erosion pattern around the bridge based on mathematical model.

So, it is necessary to study the bridge pillars on the morphology of the Ciujung River to determine the local scour that may occur on the pillars of the two bridges. So that from the results of the analysis can provide recommendations for handling that can be done in the future.

Methodology

2.1. Spatial Analysis

The first step is to delineate the Ciujung watershed. The aim is to obtain characteristics of watershed [19]. such as watershed area (A), river length (L), and river slope (S). In addition, an analysis was also carried out to determine the slope of the land and land cover which would later be used in calculating the composite Curve Number (CN) value used for the hydrological analysis process. The calculation of the composite CN value uses the following formula [20]:

$$\mathrm{CNcomposite} = \frac{\Sigma(A_1CN_1 + A_2CN_2 + \cdots + A_nCN_n}{\Sigma A}$$

With:
CN composite = Composite Curve Number
A = Land Use Area
CN = Curve Number for Each Land Use

So that the CN value for the Ciujung watershed is 71.42. This value is used for hydrological analysis process.

2.2. Hydrological Analysis

Before the hydrological analysis is carried out, the outlier test and consistency test are carried out first from the available rain heading data. Hydrological analysis refers to SNI 2415: 2016 [21], which in this study used the frequency analysis method with return periods of 2, 5, 10, 20, 25, 50, 100, 200, 500 and 1000 years. The frequency distribution analysis that will be used in this study is the normal distribution method, the normal log distribution method, the Gumbel distribution method, and the Pearson III log distribution method, where the distribution to be used is the distribution that meets the Simrnov-Kolmogorov test and the Chi-Square test.

Next is to calculate regional rainfall using the Thiessen Polygon method. So it is necessary to determine the area of influence of each rain post in the Ciujung watershed. The formula for calculating regional rainfall using the Thiessen method is as follows:

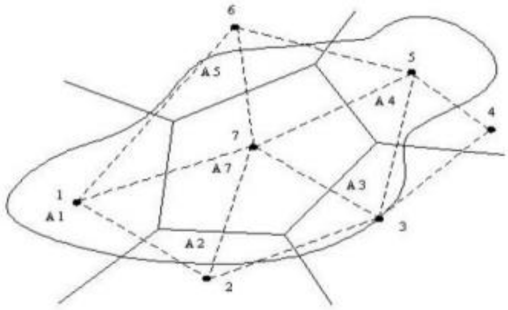

Fig.4 *Thiessen Polygon Rainfall Calculation [22]*

$$d = \frac{A_1 d_1 + A_2 d_2 + A_3 d_3 + \cdots + A_n d_n}{A}$$

Where:
A = Area (km2) ,
d = High Average Rainfall Area,
d1, d2, d3, dn = High Rainfall In Post 1, 2, 3,n
A1, A2, A3, An= The Area Of Influence Of Post 1, 2, 3,n

Repeated flood analysis was carried out using the SCS synthetic unit hydrograph (SUH) method [23]. Then the next step is to carry out a hydrological analysis using the HEC-HMS software. The following is a synthetic unit hydrograph of 2 years and 50 years return period flood discharge using the SCS method.

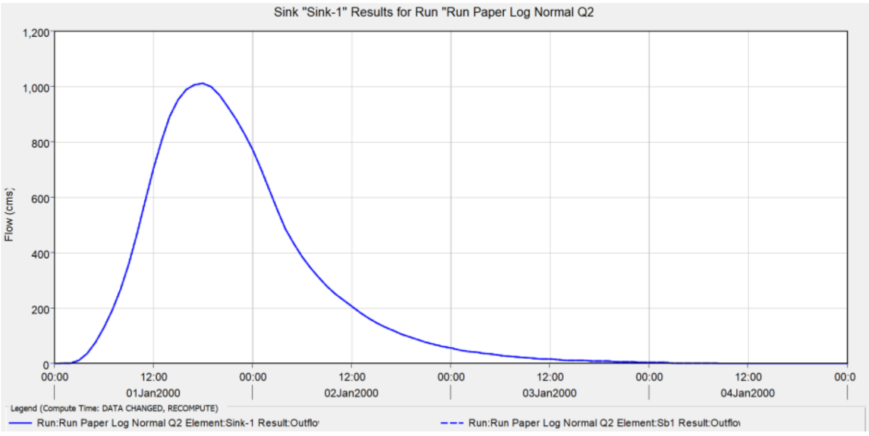

Fig. 5 *Synthetic Unit Hydrograph 2 year Return Periode*

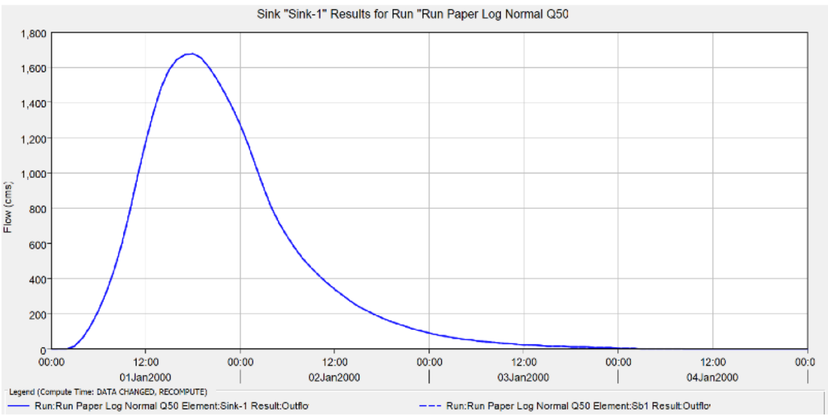

Fig. 6 *Synthetic Unit Hydrograph 50 year Return Periode*

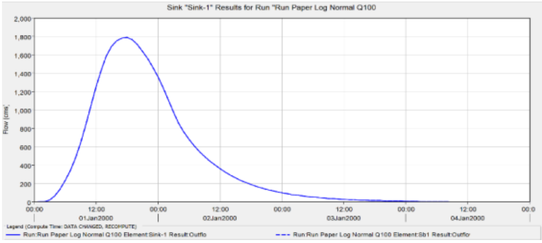

Fig. 7 *Synthetic Unit Hydrograph 100 year Return Periode*

Based on the results of the analysis using the HEC-HMS software, the peak discharge for return periods of 2 years, 50 years and 100 years is as follows:

Table 1. *Discharge value of return periods*

Return Period	Planned Flood Discharge Q (m3/s)
2	86.54
50	117.85
100	122.78

The hydrograph flow for each return period will be used as input flow in the HEC-RAS 2D Unsteady Flow software.

2.3. Hydrodynamic Analysis

For the hydraulics analysis process, it is necessary to obtain the Manning (n) value using the following equation:

$$n = \frac{1}{V} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

Where:

V = Average Velocity (m/s)
R = Hydraulic Radius (m)
S = Slope
n = Manning value

The following is a list of manning values according to [24]:

Table 2. *Roughness coefficient value*

Channel type and material type	Roughness coefficient value (n)		
	Min.	Normal	Max.
Concrete			
Straight Water Tunnel and Free of Obstructions	0.01	0.011	0.013
Polished Concrete	0.011	0.012	0.014
Water Drainage with Control Tub	0.013	0.015	0.017
Soil			
Clean and New	0.016	0.018	0.020
Clean and weathered	0.018	0.022	0.025
Pebbled	0.022	0.025	0.030
Short grass, few nuisance plant	0.022	0.027	0.033
Natural channel			
Clean and Straights	0.025	0.03	0.033
Clean and meandering	0.033	0.04	0.045
Many nuisance plant	0.050	0.070	0.080
Floodplain with short/tall grass	0.025	0.030	0.035
Channel in ticket	0.035	0.050	0.070

Based on the table, the Ciujung River is a natural channel with lots of plants, so the roughness coefficient (n) for modeling is 0.03.

2.5. Model Simulation

The model simulation is using software HEC-RAS 2D Unsteady software [25]. The modeling scheme used is as follows:

Fig. 8 *Modeling Scheme HEC-RAS 2D Unsteady*

HEC-RAS modeling is carried out with the upstream boundary conditions in the form of flow hydrographs. The flow hydrographs used are the 2 years, 50 years, and 100 years return periods which have been analyzed previously. In addition to modeling using flood discharge, the mainstay discharge Q80% is also used at 19 m3/s and Q90% at 9.35 m3/s. The reliable discharge is obtained using the Weibull method with the equation [26]:

P = m/(n+1) x 100%
Where:
P = Probability (%)
m = data sequence number
n = amount of data

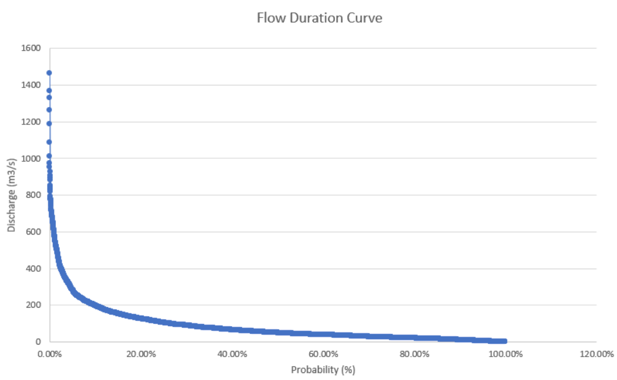

Fig. 9 *Flow Duration Curve Weibull Method*

Result and Discussion

The flow pattern is modeled using two types of flow, namely: normal discharge and flood discharge which are obtained from the hydrological analysis results. Modeling was done using Hec-Ras Unsteady 2D software. By using fully 2D, the perimeter used on the land is grid

20, on the river body is used grid 10, and for the area around the pillars is used grid 1. So that the flow velocity vector can be seen in more detail.

3.1. Secondary and Field Data Analysis

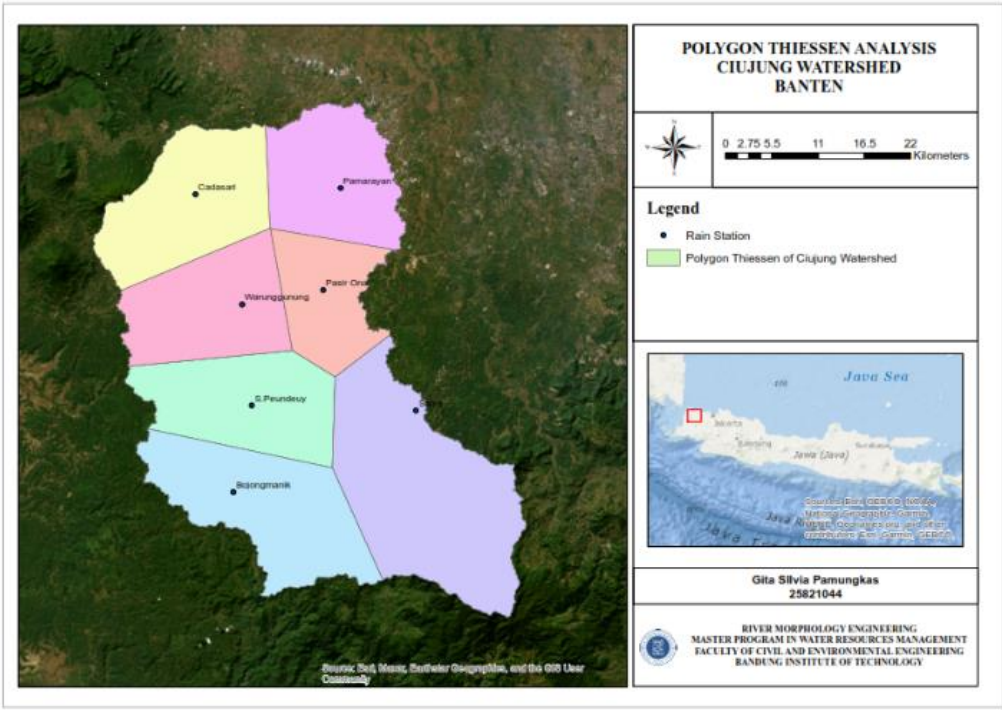

Fig. 10 *Poligon Thiessen of Ciujung Watershed*

The area of influence of each rain post will later be used to calculate regional rainfall. Rainfall data from 2001 to 2020 shows that the maximum daily rainfall occurred in 2020 with a value of 114 mm.

On the banks of the Ciujung River there is no erosion so that it is relatively stable at the time of measurement. The depth of the Ciujung River also varies between -1.4 m to -10.4 m. The deepest river body is downstream of the bridge pillar. The depth of the river also varies, especially around the bridge piers. This change in depth tends to be greater around the left and right of the pillars in the bridge.

The structure of the Ciujung Bridge (piers and abutments) has a contractionary effect on river flow, so that the river flow downstream of the bridge has the highest velocity, while the upstream part of the Ciujung Bridge has a lower flow velocity than the downstream part.

Based on the analysis of the size distribution of the bottom sediment samples, the vicinity of the bridge is classified as Silt. The diameter of the bottom sediment grains at a diameter of 50 (d50) is 0.025 mm.

3.2. Velocity Pattern

Flow velocity pattern modeling was carried out for two types of initial flow conditions, namely normal flow and flood flow. The amount of discharge is determined based on the synthetic discharge obtained by the Synthetic Unit Hydrograph method. The normal current pattern is predicted for the sedimentation pattern in the study area. While the pattern of flood flow is predicted to predict the maximum scour depth around bridge piers and abutments. For analysis of sedimentation and scour around the pillars will be carried out in further studies.

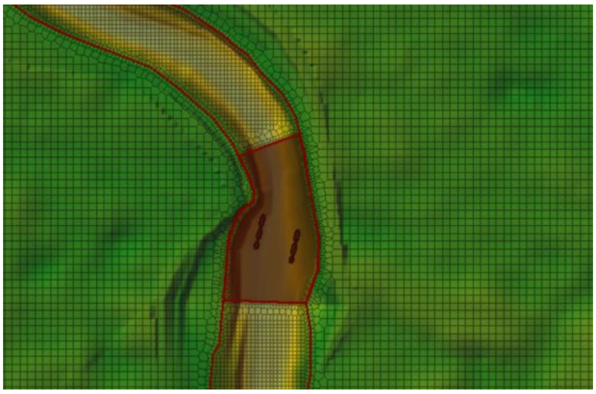

Fig. 11 *Bathymetry and mesh modelling with bridge pier*

Modeling is done with the bridge pier in fig. 11.

Based on the simulation of the normal flow model with discharges of around 9.35 m3/s and 19 m3/s, the velocity vector of the Ciujung river around the bridge pillars is obtained as follows:

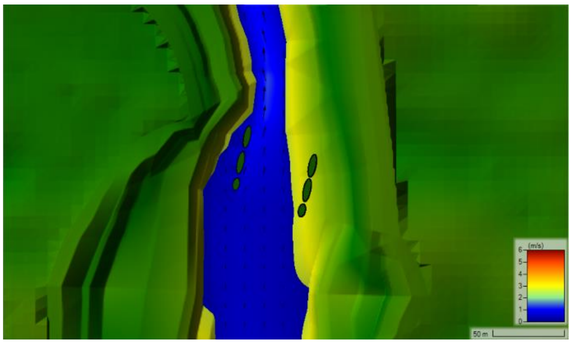

Fig. 12 *Current velocity pattern around the bridge pier at Q80% discharge condition*

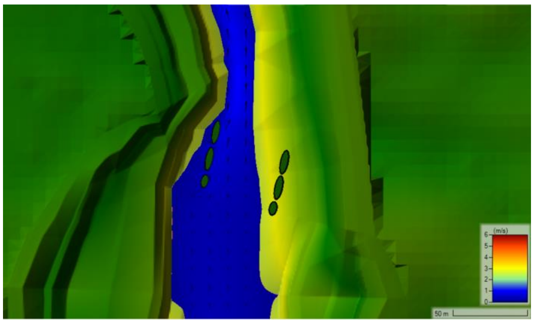

Fig. 13 *Current velocity pattern around the bridge pier at Q90% discharge condition*

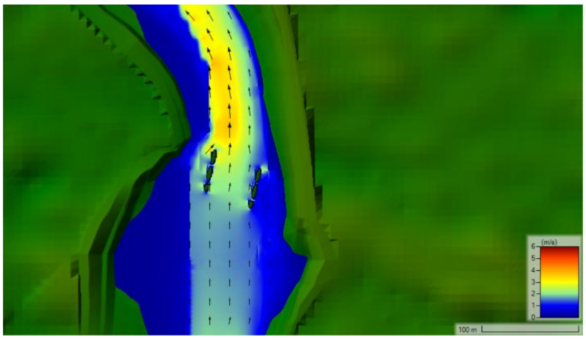

Fig. 14 *Pattern of current velocity around the bridge pier in flood conditions with a return period of 2 years*

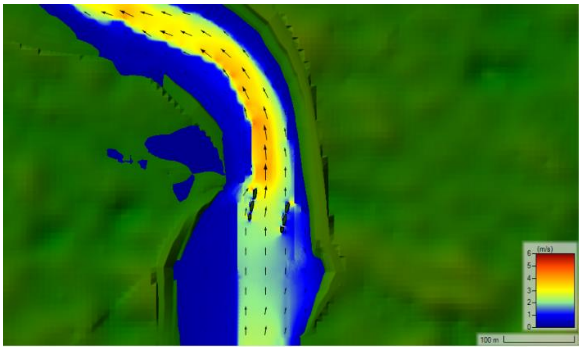

Fig. 15 *Pattern of current velocity around the bridge pier in flood conditions with a return period of 50 years*

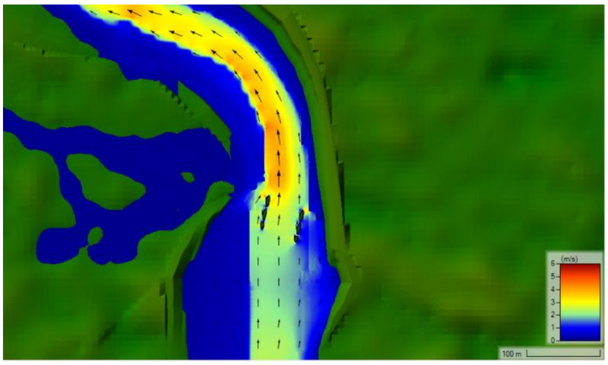

Fig. 16 *Pattern of current velocity around the bridge pier in flood conditions with a return period of 100 years*

Maximum velocity in each condition is presented in the following table:

Table 3. *Velocity value*

Condition	Velocity Maximum (m/s)		Average (m/s)
	Upstream	Downstream	
Return period 2 years	1.59	2.77	2.18
Return period 50 years	2.17	3.12	2.63
Return period 10 years	2.21	3.16	2.68
Discharge 80%	0.30	0.75	0.53
Discharge 90%	0.37	0.93	0.65

The velocity downstream of the bridge piers is higher than upstream. Due to the impact of the contraction of the bridge structure. In addition, the greater the discharge that occurs, the greater the resulting velocity.

The velocity distribution can be the basis for predicting whether the conditions around the bridge piers will experience erosion or sedimentation, using the Hjulstrom Diagram [27].

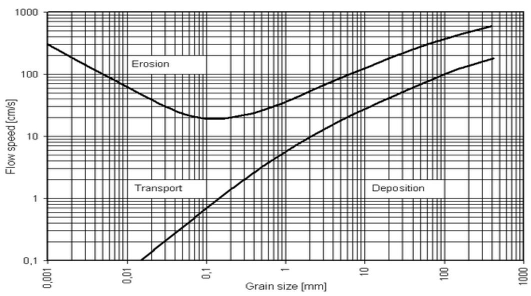

Fig. 17 *Hjulstorm Diagram for analysing condition around pier*

By using the Hjulstorm Diagram, bathymetry conditions are obtained by using the maximum velocity at each modeled discharge, and also using d50 bottom sediment grains. The results show as follows:

Table 4. *Velocity Average at Hjulstorm Diagram*

Condition	Velocity Average (cm/s)	Hjulstorm Diagram
Return period 2 years	218	Erosion
Return period 50 years	263	Erosion
Return period 10 years	268	Erosion
Discharge 80%	53	Erosion
Discharge 90%	65	Erosion

Based on the results of the plot on the Hjulstorm Diagram, for a sediment grain diameter of d50 (0.025 mm), with flow velocity in each return period, the bathymetric conditions around the pillars are eroded.

These two parameters, namely flow velocity and sediment grains, can be one of the perimeters in predicting the bathymetry conditions around the bridge piers.

Conclusion

The conclusions that can be drawn from the research on the hydrodynamic model of flood flow around the bridge in Ciujung River that has been carried out are as follows:

1. The simulation results of the flow pattern of the Ciujung river obtained the value of the flow velocity under normal conditions and flood conditions. The average velocity under normal conditions when discharge is 80% and 90% is 0.53 m/s and 0.65 m/s. While the flow velocity in flood conditions during the 2 years return period is 2.18 m/s, the 50 years return period is 2.63 m/s, and the 100 years return period is 0.65 m/s.
2. The flow velocity on the upstream of the bridge piers is lower than the flow velocity on the downstream of the bridge piers. The contraction due to changes in cross-section results in faster downstream velocity.
3. Flow velocity and sediment grain diameter data can be used to determine the bathymetry conditions around the bridge piers using the hjulstorm diagram. The results show that for each modeled discharge condition, it causes erosion around the bridge piers.
4. With the prediction of erosion, further research can be carried out regarding the study of local erosion or scour that occurs around the bridge pillars.

References

P.N. Mustain, A. Mardjono, I.R. Moe, E. Agustia, T.M. Aribawa, A. Prana and B. Yanbing, “Flood observation map in Banten Province Using Radar Images, Case Study: Cidanau, Ciujung, Cidurian River Basin,” IOP Conf. Series: Earth and Environmental Science, 794, 012067, 2020.

R. Wigati, Soedarsono, and Y. Ananda, “Analisis Banjir Menggunakan Software Hec-Ras 4.1 (Studi Kasus sub DAS Ciujung Hulu HM 0+00 sampai dengan HM 45+00),” Jurnal Fondasi, vol. 7, no. 1, 2018.

S. Afidah, S. Anggoro, S. Sudarno, "Pengembangan Strategi Pengelolaan Sungai Ciujung, Provinsi Banten Menggunakan Metode AHP," Prosiding Seminar Nasional Lahan Suboptimal ke-8, October 2020.

Sulaeman, D., Hidayat, Y., Rachman, L.M., Tarigan, S.D., Kajian Dampak Perubahan Penggunaan Lahan Terhadap Debit Aliran DAS Ciujung, Infrastruktur Vol. 4 No.2 Desember 2014: 78-85.

Kusuma, M. S. B., Hutasoit, L. M., Kombaitan, B., Syafila, M., Setiadi, T., Aryantha, I., Piliang, Y. A., "Strategi pengelolaan terpadu penyelesaian permasalahan DAS Citarum," 2018, Forum Guru Besar ITB.

Abfertiawan MS, Gautama RS, Kusuma SB, Notosiswoyo S. Hydrology simulation of Ukud River in Lati Coal Mine. Journal of Novel Carbon Resource Sciences and Green Asia Strategy 2016;3(1):21-31

Rizaldi, A., Kusuma, M.S.B., Kuntoro, A.A., Kardhana, H., Trend Analysis of Rainfall, Land Cover, and Flow Discharge in the Citarum Hulu–Majalaya Basin, International Journal on Advanced Science, Engineering and Information Technology, 2022, 12(4), pp. 1469–1477

Kuntoro A.A., Putro A W, Kusuma M S B, Natasaputra S 2017 The effect of land use change to maximum and minimum discharge in Cikapundung river basin the 3rd International Conference on Construction and Building Engineering (ICONBUILD) 1903 p 100011-1,100011-7, DOI: https://doi.org/10.1063/1.5011621

Chalid, A., Suhirna, U., Siregar, C.A., Analisis Pengaruh Erosi Lahan Pada Daerah Aliran Sungai Ciujung Kabupaten Lebak. Jurnal Talenta Sipil, Volume 5 Nomor 1, Februari 2022, 144-152.

Indonesian National Board for Disaster Management—BNPB. Disaster Events in 2020 Kejadian Bencana Tahun 2020; BNPB: Jakarta, Indonesia, 2021.

Gunawan, T.A., Kusuma, M.S.B., Cahyono, M., and Nugroho, J., The Application of Backpropagation Neural Network Method to Estimate the Sediment Loads. MATEC Web of Conferences 101, 2017, 05016.

Kardhana, H.; Valerian, J.R.; Rohmat, F.I.W.; Kusuma, M.S.B. Improving Jakarta's Katulampa Barrage Extreme Water Level Prediction Using Satellite-Based Long Short-Term Memory (LSTM) Neural Networks. Water Issue 14, 2022, 1469

Kusuma, M.S.B., Rahayu, R.A., and Cahyono, Development Study of Turbulent κ-ε Model for Recirculation Flow III: Two Dimension Recirculation Flow in a Reservoir. ITB Journal of Engineering Science, Vol. 41, Issue B(1), 2009, pp. 1-16

Kusuma, M.S.B., Setiawati, T., and Farid, M., Experimental Model of Dam Break Flow around several Blockages Configurations. International Journal of GEOMATE, Vol. 16, Issue 58, 2019, pp. 26-32.

Magdalena, I., Hariz, A.A.A., Farid, M., Kusuma, M.S.B., Numerical studies using staggered finite volume for dambreak flow with an obstacle through different geometries, Results in Applied Mathematics, 2021, 12, 100193

Farid, M., Marlina, A., Kusuma, M.S.B., Flood Hazard Mapping of Palembang City by using 2D Model. Proceedings of the 3rd International Conference on Construction and Building Engineering (ICONBUILD)2017, AIP Publishing, 978-0-7354-1591-1.

Formánek, A., Silasari, R., Kusuma, M.S.B., Kardhana, H., Two-dimensional Model of Ciliwung River Flood in Jakarta DKI for Development of the Regional Flood Index Map. Journal of Engineering and Technological Sciences, Vol. 45, Issue 3, 2013, pp. 307-325

Kusuma, M.S.B., Farid, M., Habibi, S.A., Yasin, D.M., Johan, E., The influence of the new LRT pier to the sedimentation pattern around Ampera Bridge in Musi river, South Sumatera, Indonesia, International Journal of GEOMATE, 2020, 18(69), pp. 159–167

Chinnayakanahalli, K., Kroeber, C., Hill, R., Tarboton, D.G., Olson, J., Hawkins, C.,"The Multi-Watershed Delineation Tool: GIS Software in Support of Regional Watershed Analyses", Utah State University, 2006.

Ahmad, I., Verma, V., and Verma, M.K., "Application of Curve Number Method for Estimation of Runoff Potential in GIS Environment", IPCBEE, vol. 80.4, 2015.

Standar Nasional Indonesia no. 2415 "Tata Cara Perhitungan Debit Banjir Rencana", Badan Standardisasi Nasional. 2016

Modul 1 "Analisis Curah Hujan", Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2022.

Modul 2 "Analisis Debit Banjir", Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2022.

Chow, V.T., "Hidraulika Saluran Terbuka", Jakarta: Erlangga, 1989.

Ongdas, N., Akiyanova, F., Karakulov, Y., Muratbayeva, A., and Zinabdin, N., "Application of HEC-RAS (2D) for Flood Hazard Maps Generation for Yesil (Ishim) River in Kazakhstan", Water, 12, 2672, 2020.

Destiany, A., Fauzi, Manyuk., Handayani, Y.L., "Analisis Debit Andalan Sungai Batang Lubuh Pos Duga Air Pasir Pengaraian", Jurnal Teknik, Vol. 13, No. 2, pp 9-16, October 2019.

Abedini, M., Azlin, M., Said, M., and Ahmad, F., "Effectiveness of Check Dam to Control Soil Erosion in a Tropical Catchment (The Ulu Kinta Basin)", Catena 97, 63-70, 2012.

The undergraduate program of Civil Engineering Diponogoro University in 2017. Work in the Ministry of Public Works and Housing. Currently completing her thesis to get a Master's degree at the Bandung Institute of Technology.

Publication:

Mochamad Agung Wibowo, Naniek Utami Handayani, Asri Nurdiana, Moh. Nur Sholeh, and Gita Silvia Pamungkas. (2018). Mapping of Information and Identification of Construction Waste at Project Life Cycle. AIP Conference Proceedings 1941, 020049.