

Hydraulic modeling of flow impact on bridge structures: a case study on Citarum bridge

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Abstract. Flood waves because of the rapid catchment response to high intense rainfall, breaches of flood defenses may induce huge impact forces on structures, causing structural damage or even failures. Overflowing stream that passes over the bridge, it means to discharge flood water level is smaller than the capacity of the river flow. In this study, the researches present the methodological approach of flood modeling on bridge structures. The amount of force that obtained because of the hydrostatic pressure received by the bridge at the time of the flood caused the bridge structure disrupted. This paper presents simulation of flow impact on bridge structures with some event flood conditions. Estimating the hydrostatic pressure developed new model components, to quantify the flow impact on structures. Flow parameters applied the model for analyzing, such as discharge, velocity, and water level or head that effect of bridge structures. The simulation will illustrate the capability of bridge structures with some event flood river and observe the behavior of the flow that occurred during the flood. Hydraulic flood modeling use HEC-RAS for simulation. This modeling will describe the impact on bridge structures. Based on the above modelling resulted, in 2008 has flood effect more than other years on the Citarum Bridge, because its flow overflow on the bridge.

1. Introduction

The flood as result of the rapid catchment response to intense rainfall, breaches of flood defenses, tsunamis or storm surges may induce huge impact forces on structures, causing structural damage or even failures. It may endanger and threaten human safety [1]. As part of the effort to return flows to historical levels, several changes to the existing water management infrastructure that implemented or are in the design phase. The percent probability of water levels exceeding baseline conditions was determined for the simulation period. This analysis showed that the length of time of inundation or the hydro period [2].

Current bridge design specifications deal with various extreme hazards independently, which may lead to less economic design and construction practices, and may underestimate failure probabilities [3]. Flood simulation present two representations of bridges. They include a novel and simple empirical formulation for total head loss caused by bridges, which covers all flow regimes: free water surface, partially submerged flow, and fully submerged flow [4]. The extension of the expected flood affected area and the increase in water surface elevation is highly dependent on the river morphology, bridge geometry, and flow and floodplain characteristics and may originate upstream flooding [5].



This study makes hydraulic modeling of the flow occurring that affects the bridge structure. To obtain such mapping impact, hydraulic modeling is central because it provides water depths and velocities everywhere and along the whole flood period [6].

There are several parameters become indicator of result of hydraulic flood modeling which influence bridge structure. They are flood discharge, velocity, and water level or head. Vehicle loads through the bridge and flood loads during extreme flooding influence Citarum Bridge structural resistance. The objective of this study is to investigate whether and to what extent bridges structures have an influence in flooding.

2. Study Area and Materials

2.1. Study Area

Citarum Bridge is located at upper Citarum watershed. It flows through the southern area of Bandung Regency up to Saguling Reservoir. Close to the Citarum Bridge, there is Dayeuh Kolot that is station off low discharge. In study area, there are seven tributaries in the upper Citarum up to the point of Dayeuh Kolot flow discharge station. Upper Citarum watershed is with a total area of watershed is 1.771 square kilometers.

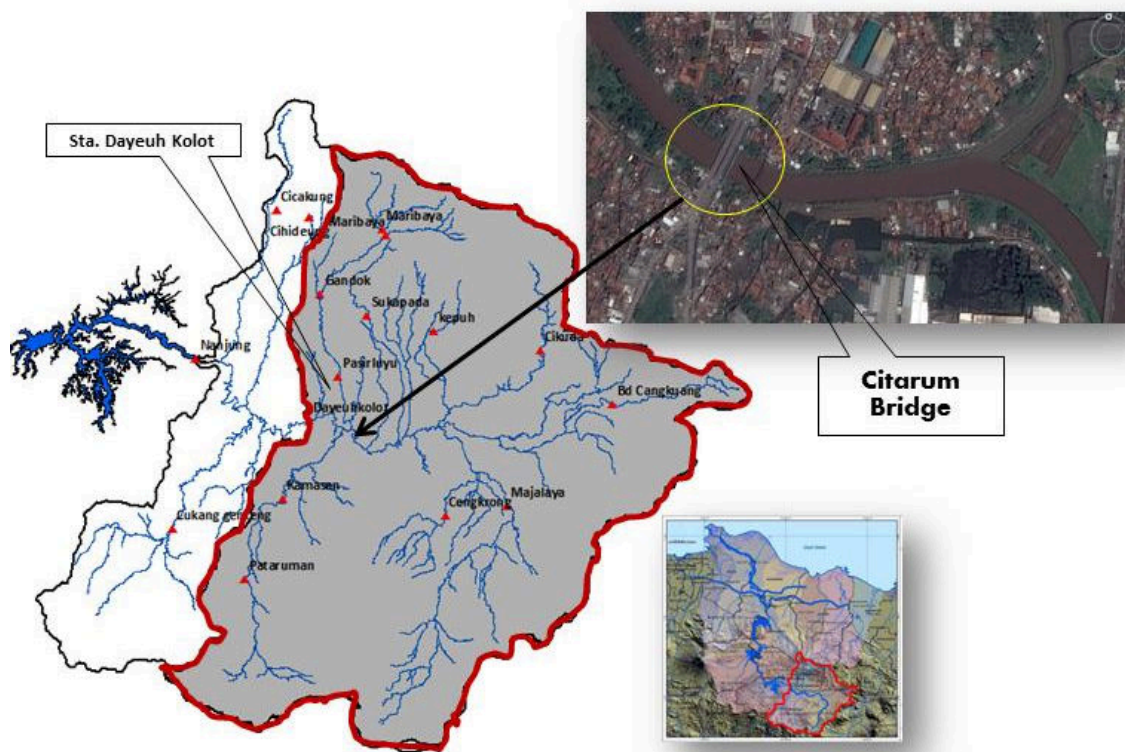


Figure 1. The location map of upper Citarum Watershed in West Java that shows the location of Citarum Bridge as a study area

The Figure 1 shows location map of upper Citarum Watershed that lies in Citarum Watershed in West Java, Indonesia. There is image of the Citarum Bridge obtained from Google Earth. Citarum Bridge called Rancamanyar Bridge because it is located on Rancamanyar Street, Baleendah, Bandung district, Indonesia. The bridge, which has a length about 80 meters and a width of 9 meters, is a link between the Rancamanyar Street and Sayuran Street.

2.2. Data Sources

In this study will make simulations for several flood events in 2007, 2008 and 2010. The three flood events based on the measurement data of flow discharge, that there is extreme flow discharge compared to other year. The data required in this model is the upper Citarum watershed data with output at the point of the Citarum Bridge. In analyzing simulation, the flow required the characteristics of upper Citarum watershed.

The data of the debit serves as the calibration and verification reference of the modeling created. The available record data is the measurement data of water level three times a day. Upper Citarum watershed utilizes remote sensing technology to provide information on land coverage by interpretation of objects in the image. Data sources on upper Citarum Watershed based on data from Major River Basin Organization of Citarum, which consists of several types of land cover.

3. Methods

3.1. HEC-RAS

The influence of the minor hydraulic modeling on flood dynamics, analyzed through a combined use of one-dimensional (1D) and two-dimensional (2D) hydraulic models. First, a number of detailed and simplified approaches to represent hydraulic structures in the computational grids analyzed by means of the HEC-RAS 1D model. 2D simulations of the flood event implemented and tested in several these approaches [7]. In this study, use HEC-RAS as hydraulic modeling software to help modeling analysis.

HEC-RAS employs 1d flood routing in both steady and unsteady flow conditions by applying an implicit-forward finite difference scheme between successive sections of flexible geometry. Unsteady flow is a physical process in the flow in a channel by adopting the concept of conservation of mass and momentum conservation. This physical process described by mathematical equations, known as the equation St. Venant [8]. The equations consist of continuity equation (mass conservation principle) and the momentum equation (the principle of conservation of momentum), which written in the form of partial differential equations as follows:

Continuity equation:

Momentum equation:

Where: A : area, Q : flow discharge, q_l : lateral discharge per unit width of channel, V : velocity, g = acceleration of gravity, x : distance measured in downstream flow direction, z : mean depth, t : time.

3.2. Boundary Conditions

In all the above models, two boundary conditions are required, which are usually set at the upstream end of the channel through an imposed inflow as well as the assumption of uniform water depths at the upstream and downstream end (kinematic wave condition). Although an imposed depth would result in more stable solutions than the condition of uniform flow, we choose the latter since, in practice, it is rare to know the temporal evolution of the water depth at a specific location. The models compute the appropriate time step based on the Courant number stability criteria.

3.3. Calibration and Verification

If compared to the model implemented on the basis of in-situ data only the hydraulic model parameterized on the basis of satellite and in-situ hydrometric data provides a better reproduction of average flow conditions, and it also results in the most accurate representation of the maximum water profile observed during a major flood occurred [9]. The Root Mean Squared Error (RMSE) criterion and its related normalization, the Nash–Sutcliffe efficiency (NI) are the two criteria most widely used for calibration and evaluation of hydrological models with observed data. The performance indicators are Nash–Sutcliffe Index (NI) [10].

4. Results and Discussions

4.1. Flood Modeling

Based on input data in flood modeling use HEC-RAS with 1D (one-dimensional) and 2D(two-dimensional) with hydrograph peak flood discharge: 259.94 m³/s in 2007; 223.55 m³/s in 2008, and 298.22 m³/s in 2010. In those years, the flood modeling on bridge will be analyze

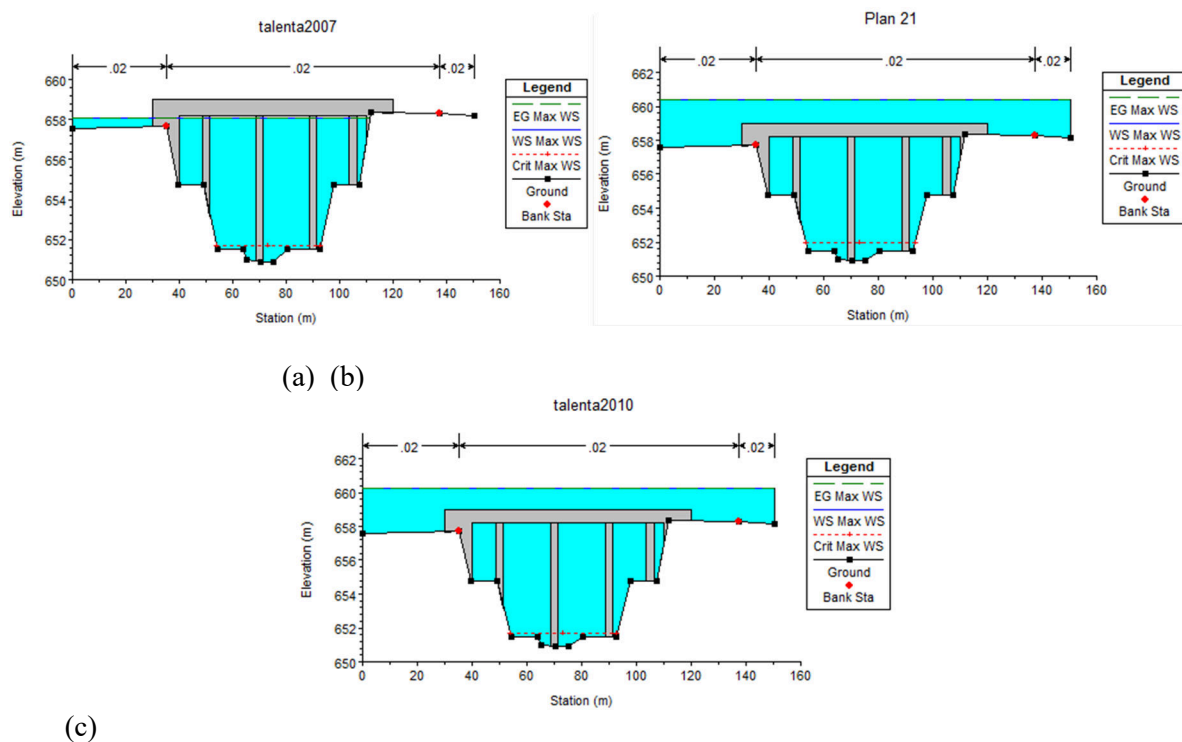


Figure 2. Citarum Bridge in upper Citarum flood conditions in years (a) 2007; (b) 2008, and (c) 2010

The Figure 2 shows flow parameter that impact on Citarum Bridge. There are three parameters: flow discharge, velocity and water level in years 2007, 2008 and 2010. The figure (a) showed that in 2007, when the flood happened, the flow was not overflow on the Citarum Bridge. The figure (b) showed that in 2008, when the flood happened, the flow was not overflow on the Citarum Bridge. It seems more save than in 2007. In other condition, in 2010, the figure (c) showed that in that year when the flood happened, it was overflowing on Citarum Bridge. It was about a meter above the bridge. It means the area around the bridge will be inundation.

The Figure 3 shows flow parameter that impact on Citarum Bridge. There are three parameters: flow discharge, velocity and water level in years 2007, 2008 and 2010. The figures (a) show the flow discharge in 2010 higher than in 2007 and 2008. The discharge can analyze to other flood condition. The figure (b) shows that velocity in 2010 higher than 2007 and 2008. Based on theory, the speed is directly proportional to the flow discharge for the same cross section and long section. The figure (c) shows that water level in 2010 is higher than in 2007 and 2008. It seems in Figure 2 that the flow are overflowing the bridge.

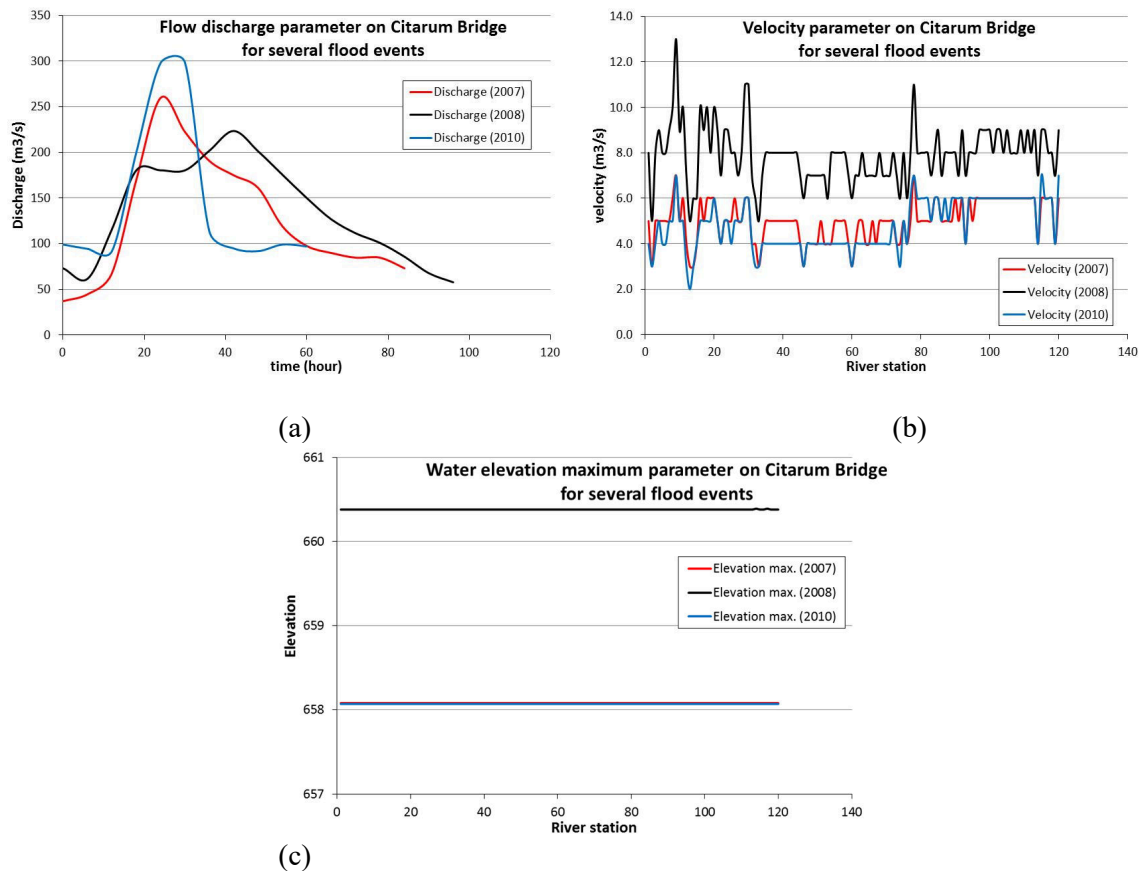


Figure 3. Flow parameter on Citarum Bridge: (a) flow discharge, (b) velocity, and (c) water level in years 2007, 2008 and 2010 for several flood events

4.2. Flow validation

The flow determined the strength in predicting the modeling by Nash-Sutcliffe model efficiency coefficient (E). Based on the validation of Nash Index method (Index E) obtained the result in years 2007 with index 0.76, 2008 with index 0.74 and 2010 with index 0.76. The index values show that the flow modeling is close to one, that means the modeling is acceptable.

5. Conclusions

Based on this study, it introduced a new methodology for prediction of the design flood discharge. The role of hydraulic modeling in the design of the bridge across the river is on the aspect bridge safety against the flood stream in the river. The bridge over structure should be sufficient High so that pier and deck protected from flood. The base, the pillar, and the foundation of the bridge should be safe against the risk of scouring. This risk increases great if the riverbed decreases (degradation). Hydraulic modeling that analyzed in this study shows the different about three flood conditions in years 2007, 2008 and 2010. Based on the above modeling resulted, in 2008 has flood effect more than other years on the Citarum Bridge, because its flow overflow on the bridge.

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References

- [1] Liang Q, Chen K, Hour J, Xing Y, Wang G and Qing J 2016 Hydrodynamic Modeling of Flow Impact on Structures under Extreme Flow Conditions *Elsevier* **28** 267-274
- [2] Long S A, Cook A M, Fennema R, Tachiev G I, Villamizar V, Kotun K, Wilhelm F M 2016 Analysis of Bridge Construction as a Restoration Technique for Everglades National Park, FL, USA, Using Hydrological Numerical Modeling *Journal of Hydraulic Engineering ASCE* **142**.
- [3] Wang Z, Patgett J E and Osorio L D 2014 Risk-Consistent Calibration of Load Factors for the Design Of Reinforced Concrete Bridges Under The Combined Effects Of Earthquake And Scour Hazards *Elsevier* **79** 86-95
- [4] Heilemariam F M, Brandimarte L, Dottori F 2013 Investigating The Influence of Minor Hydraulic Structures on Modeling Flood Events in Lowland Areas *Hydrological Processes* **28** 1742-1755
- [5] Shen D, Wang J, Cheng X, Rui Y and Ye S 2015 Integration of 2-D Hydraulic Model and High-Resolution Lidar-Derived DEM for Floodplain Flow *ModelingHydrology and Earth System Sciences* **19** 8
- [6] Paquier A, Mignot E, Bazin P H 2015 From Hydraulic Modeling to Urban Flood Risk *Elsevier* **115** 37-44
- [7] Brandimarte L, Woldeyes M K 2013 Uncertainty in the Estimation of Backwater Effects at Bridge Crossings *Hydrological Processes* **27** 1292-1300
- [8] Dimitriadis P, Tegos A, Oikonomou A, Pagana V, Koukouvinos A, Mamassis N, Koutsoyiannis D and Efstratiadis A 2016 Comparative evaluation of 1D and quasi-2D hydraulic models based on benchmark and real-world applications for uncertainty assessment in flood mapping *Elsevier* **534** 478-492
- [9] Domenneghetti A, Tarpanelli A, Brocca L, Barbetta S, Moramarco T, Casstellarin A and Brath A 2014 The Use of Remote Sensing-Derived Water Surface Data for Hydraulic Model Calibration *Elsevier* **149** 130-141
- [10] Yucel I, Onen A, Yilmas K K, Gochis D J 2015 Calibration and evaluation of a flood forecasting system: Utility of numerical weather prediction model, data assimilation and satellite-based rainfall *Elsevier* **523** 49-66