Assessment for the Design Elevation of the Calumpang Bridge in Batangas, Philippines at Different Rainfall Return Periods and the Typhoon Rammasun Flood Event with the Introduction of LiDAR Data

A.F. Gorospe, E.A. Barez, J.K. Coloso, J.C. Enzon, F. J. Tan, F.A.A Uy

Abstract: On July 2014, Typhoon Rammasun destroyed the Calumpang Bridge over the Calumpang River in Batangas, Philippines. While re-habilitation efforts for the bridge have finished, the validity of its elevation still needs to be studied. In order to create an elevation design that prevents flooding from reaching the bridge, a study was conducted using HEC-RAS, HEC-HMS, GIS software, and LiDAR data to model the hydraulic response and generate indundation maps of the Calumpang River during different rainfall return periods. It was found that: (1) only the downstream areas of the floodplain are significantly affected by flooding events from Typhoon Rammasun and at 15, 25, 50, and 100 year return periods, (2) water surface elevation only reached up to 4.45 meters during the typhoon, and (3) the 9-meter high deck of the rehabilitated Calumpang Bridge is safe from water reaching over the deck.

Index Terms: Bridge, Elevation, Hydrologic Modelling, Lidar, Inundation Maps,

I. INTRODUCTION

The Philippines is considered to be in the "Typhoon Alley" or "Typhoon Gateway" of the Pacific Northwest. An average of 20 tropical cyclones, mostly coming from the Pacific, passes through the Philippine Area of Responsibility (PAR) each year. In 2014, the country was hit by one of the strongest typhoons in its history, Typhoon Rammasun (local name: Glenda). According to the final report of the National Disaster Risk Reduction and Management Council (2014), the typhoon attained 150 kph sustained winds and 180 kph gustiness within the Philippine Area of Responsibility (PAR). In the aftermath, casualties numbered 106 dead, 1250 injured, and 5 missing. On the other hand, damages in infrastructure and agriculture amount to 38.6 billion PHP. Electricity was also shut down for the areas hit by the typhoon, hampering the efforts of disaster agencies to gain information about the aftermath. One of the more significant damages wrought by the typhoon is the collapse of the Calumpang Bridge over the Calumpang River in the Batangas province. The 100-meter long bridge was built in 1992, and it provides a direct con-nection between Batangas City and barangay Pallocan West. The bridge is an important part of the daily lives of residents in the area. When the bridge collapsed, several major sectors were badly affected, such as businesses, es-tablishments, power plant companies, and traffic schemes. Meanwhile, the Calumpang River (Filipino: Ilog Calumpang) is a perennial body of water with a catchment area of approximately 472 km2 (182.2 sq. mi). It is located to the east of Batangas City (Tagalog: Lungsod ng Batan-gas) and traverses the province of Batangas and drains to Batangas Bay (Fig. 1). After the typhoon had left the PAR, livelihoods of people living in the area were affected. According to Ba-tangas City officials, the collapse of the bridge was due to the water level rising high enough to reach the deck and destroy the foundation. However, the Department of Public Works and Highways (DPWH) report says otherwise; they claim it was more likely scouring and debris that caused the collapse of the bridge. At present, the bridge has been reconstructed by DPWH, and it still retains its former 9-meter elevation. Thus, there is a need to validate the appropriateness of the eleva-tion of the reconstructed bridge.

Figure 1. Location of the Calumpang River (in the red rectangle on the left) and the Calumpang Bridge (encir-cled on the right) in Google Maps.

Revised Manuscript Received on December 30,2018.

F. J. Tan, School of Civil, Environmental, & Geological Engineering, Mapúa University, Muralla St., Intramuros, Manila 1002, Philippines,

A.F. Gorospe, School of Civil, Environmental, & Geological Engineering, Mapúa University, Muralla St., Intramuros, Manila 1002, Philippines (co-first author).

E.A. Barez, School of Civil, Environmental, & Geological Engineering, Mapúa University, Muralla St., Intramuros, Manila 1002, Philippines (co-first author).

J.K. Coloso, School of Civil, Environmental, & Geological Engineering, Mapúa University, Muralla St., Intramuros, Manila 1002, Philippines (co-first author).

J.C. Enzon, School of Civil, Environmental, & Geological Engineering, Mapúa University, Muralla St., Intramuros, Manila 1002, Philippines (co-first author).

F.A.A Uy, School of Civil, Environmental, & Geological Engineering, Mapúa University, Muralla St., Intramuros, Manila 1002, Philippines (co-first author).

2. Causes of Bridge Failure

Floods often result in significant damage to bridges with piers embedded in riverbeds. While the torrents con-vince strong lateral loads on bridges, they also sabotage the integrity of bridges by removing the deposits from around bridge pier foundations [1].

According to Lee and Sternberg [2], in a flood, the speed of the flow of water increases as the level of the water around the bridge rises. Trees and other debris are also carried downstream. In general, the primary cause of bridge failure is not sloppy maintenance or deviation from design standards, but extreme events. A bridge designed to current standards and properly maintained can still fail through objects and debris carried by the river, water speed, or water level.

To narrow down the cause of the failure of the bridge, the water level of the river during Typhoon Rammasun must be known. Thus, the purpose of this study is to use HEC-RAS and HEC-HMS, with the aid of LiDAR data and GIS software, to model the hydraulic response of the Calumpang River during Typhoon Rammasun and at different rainfall return periods. As a result, the elevation of the river during the typhoon may be determined, and the appropriateness of the new elevation of the rehabilitated bridge will be validated

II. Methodology

The study will be a case study about the effects of flooding and rainfall return periods of the Calumpang River on the Calumpang Bridge through the use of HEC-RAS. Selected rainfall return periods (15, 25, 50, and 100) will be used in analysis, in reference to an extreme event (Typhoon Rammmasun). The data generated will be used to validate the elevation proposed in the rehabilitation of the bridge.

3.1 Use of LiDAR Data

LiDAR, which stands for "Light Detection and Ranging," is capable of providing high-resolution spatial data needed to set up advanced flood simulation models and provide digital topographic maps [3]. To obtain LiDAR data, an airborne laser is pointed at a targeted area on the ground, and the beam of light is reflected by the surface it encounters. A sensor records this reflected light to measure a range, which are then combined with position and orientation data generated from integrated GPS and Inertial Measurement Unit systems, scan angles, and calibration data. The result is a dense, detail-rich group of elevation points, called a "point cloud." Each point in the point cloud has three-dimensional spatial coordinates (latitude, longitude, and height) that correspond to a particular point on the Earth's surface from which a laser pulse was reflected [4].

One product from LiDAR that is used in this study is the Digital Terrain Model (DTM). It is the boundary surface between the solid ground and the air, which is also the surface of superficial water run-off. This is the surface needed to model the geometry of the watershed and the floodplain [5].

The LiDAR data used for this study comes from the Mapúa Phil-LIDAR 1 project. Airborne missions used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Pegasus and Gemini systems. The Calumpang DTM has a 1-meter resolution, with 20-cm vertical accuracy and 50-cm horizontal accuracy.

3.2 Procedure

In order to accomplish this, rainfall events from Typhoon Rammasun and return periods will first be obtained from the Philippine Atmospheric Geophysical and Astronomic Services Administration (PAGASA). The cross-sectional area and the digital terrain model (DTM) of the Calumpang River will be obtained from the Mapúa Phil-LiDAR 1 project. Other data will also be gathered from the DPWH Bureau of Design (Bridge Section) regarding the Calumpang Bridge itself. The hydrological and hydraulic models to be used are HEC-HMS and HEC-RAS to simulate the flooding during Typhoon Rammasun.

The model for the river basin of the Calumpang River was provided by the Mapúa Phil-LiDAR 1 project, which used HEC-HMS. HEC-RAS will then be run on designated rainfall return periods to show the extent of flooding along the floodplain. Rainfall Intensity Duration Frequency (RIDF) data was used for 15, 25, 50, and 100 year rainfall return periods for Ambulong, Batangas, a municipality traversed by the river, as seen in Figure 2. Precipitation data from Typhoon Rammasun (Table 1) was also chosen for the model.

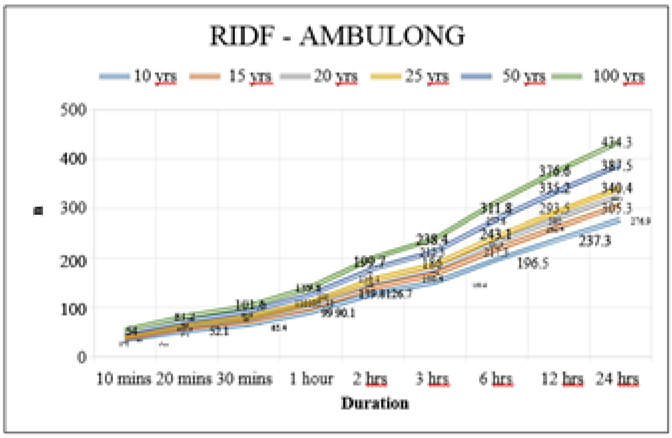

Figure 2. Rainfall Intensity Duration Frequency (RIDF) Data up to 100 years

Table 1. Rainfall Data of Typhoon Rammasun at Ambulong, Batangas

Time (in hours)	Rainfall (in mm)
006	25.3
012	16.8
018	118.2
024	198.7
Daily Total (Sum)	359

During this process, additional parameters (flood severity, depth, velocity, rate of rise and duration) gained from data from PAGASA and coefficients will also be added. The resulting output, along with preliminarily gathered data and output from GIS software, will be used as input for the HEC-RAS model. Aside from the output from the HEC-HMS model, these inputs are the DTM, stream lines, flow path, cross section, and crossings of the river. Stream lines and flow paths were manually digitized on a LiDAR DTM in GIS software, while the cross section was overlaid, as seen in Figure 3. On the other hand, crossings were manually entered into the HEC-RAS geometry.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

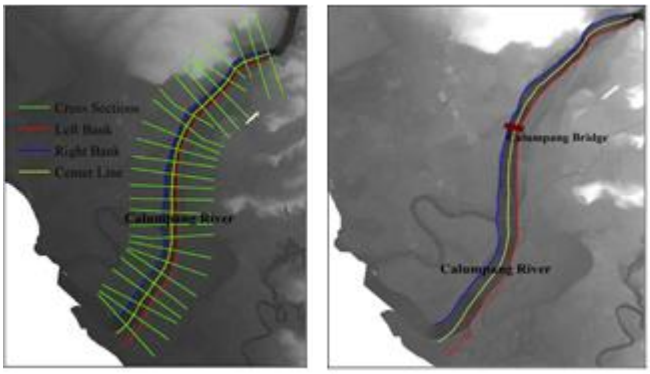

Figure 3. Stream lines, flow paths, and cross section of the Calumpang River on a LiDAR DTM of Calumpang (left); geometry schematic of the Calumpang Bridge (right).

III. Results and Discussion

4.1 Flood Inundation Maps

Precipitation is the major factor considered in the simulation run of different rainfall return period and certain flood events of two different typhoons. Discharge outputs of the river (m3/s) for every 10 minutes based on RIDF data for 15, 25, 50, and 100-year rainfall return periods was computed.

The hydrology of the Calumpang River Basin, ac-quired from the simulation of HEC-HMS, can be entered into the HEC-RAS model, along with the geometry of the model in Fig. 3, the discharge data from RIDF, and data from Table 1. The resulting data was used to produce dif-ferent flood inundation maps for every return period and Typhoon Rammasun (Figure 4).

According to the generated inundation maps, flooding mostly occurs downstream and is minimal upstream. The water surface elevation on the upstream path in the areas of Kumintang Ibaba, Pallocan Kanluran and other nearby barangays range are shown in Table 2. Meanwhile, in the downstream path, the flood extends to most of the areas of Wawa, Libjo, Malitam and Cuta. Water surface elevations there are also shown in Table 2.

Table 2. Downstream and Upstream Water Surface Elevation (WSE) per Rainfall Event

Rainfall Event	Upstream WSE (in meters)	Downstream WSE (in meters)
15-year RP	3.52 – 5.77	2.50 – 3.50
25-year RP	4.20 – 6.22	2.70 – 4.10
50-year RP	4.30 – 6.30	2.90 – 4.20
100-year RP	4.70 – 7.03	3.10 – 4.60
Rammasun	4.00 – 6.11	2.50 – 4.00

4.1 Comparing Water Elevation between Different Rainfall Events

Comparing the water elevation from different rainfall events, Typhoon Rammasun can be compared to a 25-year return period. The bed of the bridge has an elevation of approximately 7 meters from the mean sea level [6]. The highest water elevation among the chosen rainfall events is 4.98 meters, from the 100-year rainfall event. Typhoon Rammasun's (local name Rammasun, as desig-nated in the model) water elevation was 4.45 meters (Figure 5).

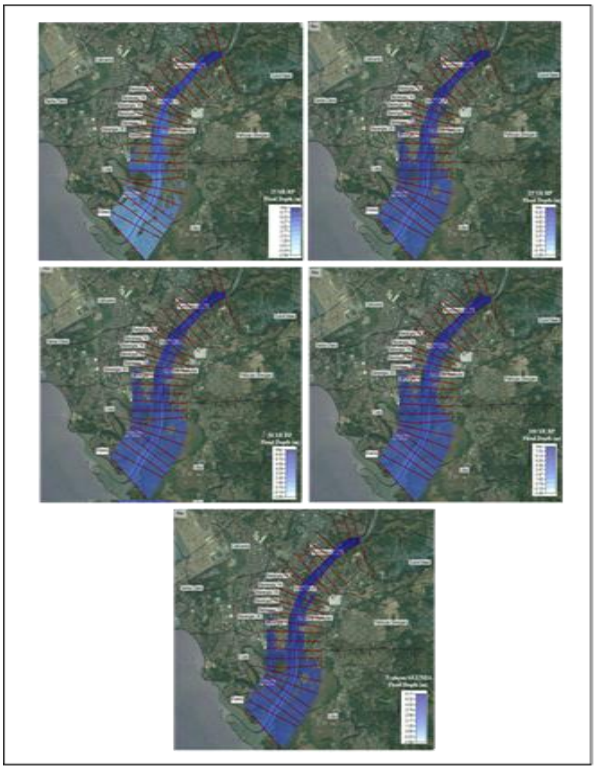

Figure 4. Flood inundation maps of 15- (top left), 25- (top right), 50-(middle left), and 100-year (middle right) return periods and Typhoon Rammasun (locally known as Glenda; bottom).

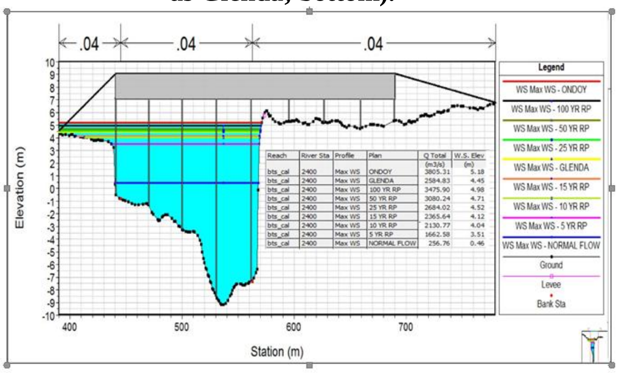

Figure 5. Water elevation from different rainfall events.

IV. Conclusions

The study aimed to model a hydraulic response of the Calumpang River during Typhoon Rammasun and at dif-ferent rainfall return periods. The destructive force of Ty-phoon Rammasun triggered a flood event that made the Calumpang Bridge fail. There were several theories from different agencies and witnesses, ranging from the water reaching the deck of the bridge to the piling up of debris. Therefore, to determine the cause, the assumption was made that the water reached the deck. The hydraulic re-sponse of the river was modeled through HEC-HMS, HEC-RAS, LiDAR data and GIS software. Based on the results of the map in HEC-RAS, the nearby residential areas in Wawa, Malitam and Libjo in the Calumpang River experienced flood elevations, based on the 15, 25, 50, 100 return periods and Typhoon Rammasun rainfall on the inundation map. However, only the downstream part of the river was flooded.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The up-stream part had a high water surface elevation of 4050 meters, so the nearby areas were not flooded.

The maximum water surface also did not reach the deck of the Calumpang Bridge. Based on the cross section run in HEC-RAS, the water surface elevation from Typhoon Rammasun was at most 4.45 meters, while the height of the deck was approximately 9 meters. Thus, it can be as-sumed that another reason besides water reaching the deck the piers collapsed due to scouring and debris that may be the cause of the collapse of the bridge.

The elevation of the newly rehabilitated bridge is still 9 meters. From the results above and from the different rain-fall return periods, the elevation of the rehabilitated Calumpang Bridge was found to be appropriate. The bridge will still be safe from water reaching over its deck.

Through this study, other past flood events may be as-sessed, and the knowledge gained may also be used for future reference. In particular, it can be used for flood risk management, mitigation and planning, damage assess-ments, and environmental and ecological assessments. The communities around the Calumpang Bridge will also bene-fit from this study, and the bridge will also be protected against future flood events. For extensions of this study, the cross-sectional area can be further expanded to see the full extent of the downstream flooding of the river at dif-ferent rainfall return events. Construction procedures and other factors relating to bridge failure may also be used to further enrich analysis of the flooding events discussed in this study and even other past flooding events of the Phil-ippines.

V. ACKNOWLEDGEMENT

The authors would like to thank the Mapua Phil-LiDAR 1 Project, funded by the Department of Science and Technology – Philippine Council for Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD) for the data and models.

REFERENCES

1. C. Hung and and W. Yau. “Behavior of scoured bridge piers subjected to flood-induced loads,” Engineering Structures, vol. 80, pp. 241-250, December 2014.
2. G. Lee and E. Sternberg. “A new system for preventing bridge collapses,” Issues in Science and Technology, vol. 24, no. 3, pp. 31-36, June 2008.
3. V. Meesuk, Z. Vojinovic, A. Mynett, and A. Abdullah. “Urban flood modelling combining top-view LiDAR data with ground-view SfM observations,” Advanced in Water Resources, vol. 75, pp. 105-117, January 2015.
4. The Mapúa Phil-LiDAR 1 Project, Mapúa Institute of Technology, Manila, Philippines, 2014.
5. Introduction to LiDAR DEM, UP Disaster Risk and Expo-sure Assessment for Mitigation, Quezon City, Philippines, 2014.
6. Department of Public Works and Highways, Philippines.