Influence of the constriction areas causes overflow and damage of river embankment during floods

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1. Introduction

Typhoon Hagibis that occurred in the beginning of October 2019 was one of a largest and powerful tropical cyclone and was considered to be the most devastating typhoon to hit Japan in recorded history. Extreme wind together with heavy rainfall caused massive impacts to Japan. Landslides and flooding have occurred in many places from Kanto region to Tohoku region of Japan. One of the problems cause the extension of flood areas is because of the damages of river embankment due to overflow at the constriction areas. As observed in Marumori area during this extreme event, most of the complete breaching locations happened mainly in the constriction and narrow areas (Fig. 1). In this study, a detail analysis of this phenomenon is conducted for the case of the Marumori Town located in the upstream of Abukuma River in Miyagi Prefecture of Japan.

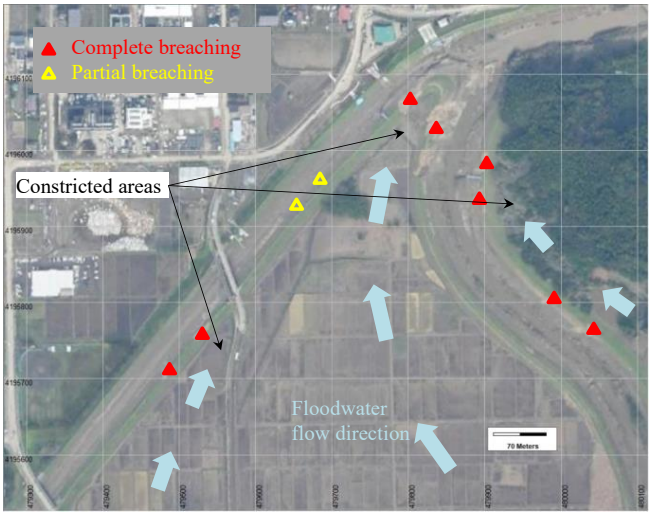

Figure 1. Compete and partial breaching locations of river embankment in Marumori area, Miyagi

2. Materials and method

2.1. Data collection

Marumori area is located in the upstream of the Abukuma River which consists of tree tributaries named Uchi, Gofukuya, and Shin rivers.

In order to achieve the objectives, detail data sets such as the bathymetry, inflow discharges from tributaries, water level and rainfall are required. In this study, a 5m resolution topography from the Geospatial Information Authority of Japan (GIS) together with the river transect measurement data from the local government were collected. The measure rainfall data and water level variations during the Typhoon Habigis were acquired from the Hipo Meteorology station and Uchikawa station, respectively.

The river tributaries flows for the flood simulation in Marumori area were simulated by using the 2D Rainfall-Runoff-Inundation (RRI) model with the hydrological data and maps based on Shuttle Elevation Derivatives at 90m resolution [1]. The model domain and the location of the extracting points for each river tributaries are shown in Fig. 2. The maximum flow discharge of 700 m^3/s was obtained in Uchi River, whereas Gofukuya River and Shin River have smaller discharges.

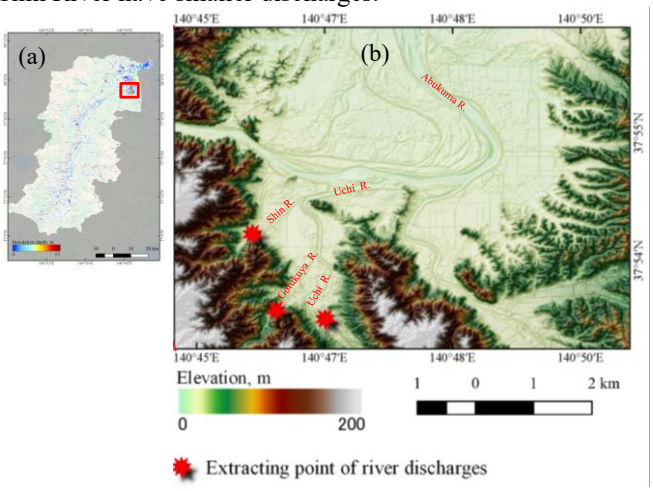

Figure 2. (a) RRI model domain and (b) extracting points of river discharges for each tributaries

2.2. Flood model development

The Environmental Fluid Dynamics Code (EFDC) [2] is an open-source code model. The Dynamic Solutions International [3] has made further improvements on the code and calls as the Environmental Fluid Dynamics Code Plus (EFDC+) model. The latest EFDC+ code can be downloaded freely from the Github website [4]. In this study, the Environmental Fluid Dynamics Code Plus 8.5 (EFDC+ 8.5) was used to develop the flood simulation model for Marumori area.

A very fine model grid resolution was designed to represent the actual topography and river dike system for this study area with the minimum grid cell of 2.5m. A bit coarse grid cells was for the paddy field flooding area to optimize the model simulation time. All above collected data sets are used to set the initial conditions and boundary conditions for the Marumori flooding model.

2.3. Model calibration

The measuring data of water level at Uchi River station was used to calibrate the model simulation results. Although the station was damaged during the peak of flood, but it is so valuable data set for the model calibration purposes. A good agreement between the model simulation results and measured data with the Root Mean Square Error (RMSE) of 0.686m is obtained. Especially, the maximum simulated water level is a very much comparable to the measured water level data which indicates the calibrated model has a high accuracy and can be applied for the further model result analysis.

3. Results and discussion

3.1 Overflow at Uchi River and Gofukuya River

Numerical simulation results show that, under a

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breaking-recorded of rainfall during the Typhoon Hagibis, the river water level rose very quick and caused the water overflow the river dike system which happened starting from the river upstream to the downstream area. In addition, at the constriction area such as the river confluence area, where a large amount of flow is concentrated, the river is unable to drain water resulting in rising of water level, overflow from river to other flood plain areas. Fig. 4 is a snapshot from the model results at the moment when overflow started to happen. It is noted here that these overflow locations are in agreement with the actual breaching locations in this area.

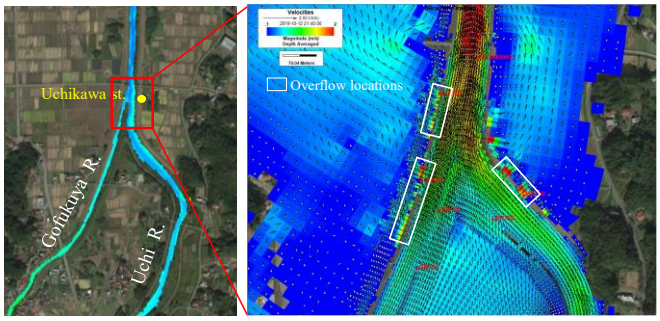

Figure 3. Overflow at the confluence location of the Uchi River and the Gofukuya River

3.2 Complete breaching of river dike at the constriction area along Shin River

In order to investigate the extension of the massive floodwater in the Marumori paddy fields causing by a serious breaching in the Gofukuya River, an artifitical removal of the river dike with the width as same as the actual measurement was conducted. The simulation model result shows that the floodwater was extended to the entire paddy field area and concentrated the constricted areas causing overflow as shown in Fig. 4. It is noted that the dye concentration indicates the river floodwater and zero concentration is the rainfall water in Fig. 4 This phenonmenon is one of reasons to cause the complete breaching at the narrowed area along the Shin River and Uchi River.

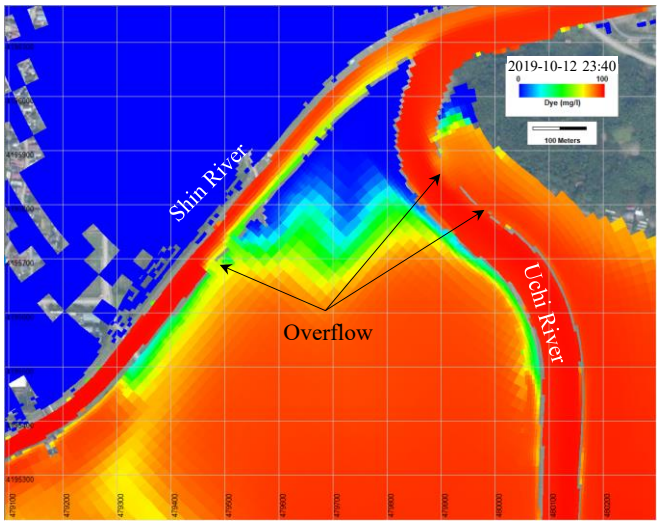

Figure 4. Extension of the Gofukuya River floodwater after breaching occurrence

Flow velocity roses at the middle of paddy field (L1), inside of constricted area (L2) and near to the location of partial breaching (L3) are plotted and shown in Fig. 5. From this result,it is obviously seen that the flow velocity is larger in side of the constricted area. In addition, the dominant flow direction is from the paddy field to the Shin River, whereas at other two locations, the dominant flow direction is to the downstream and relatively small velocity.

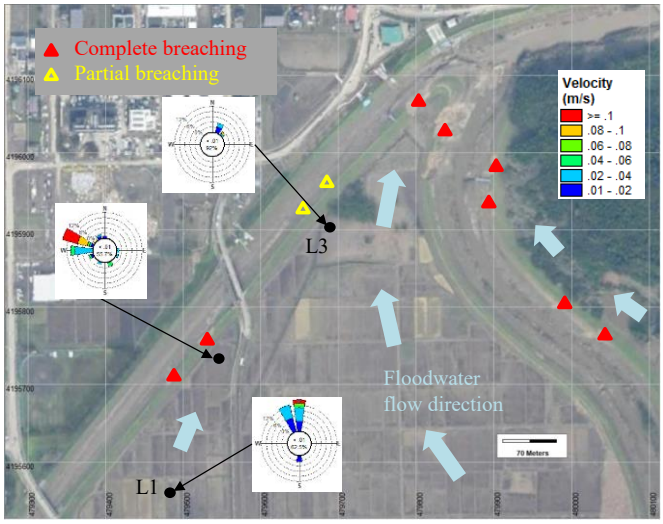

Figure 5. Flow velocity and direction

4. Conclusions

A detail numerical flood model has developed for the Marumori flood area. The model was calbrated well with the observed data in the Uchikawa station.

Base on the model simulation result analysis, water overflows and river dike breaches are mainly happended at the constriction areas such as at the river branches confluence point or at the narrowed areas.

Abukuma River is a class A river that managed by the central government, thus areas along the Abukuma main stream is quite rare to be flooded. The upper tributaries of the Abukuma River are managed by the prefectural and municipal goverments. It is recommended that the local goverments should pay more attention to those constricted areas to avoid the river dike breaches due to water level rise and extension of flooding issues during the extreme rainfall events as similar to the Typhoon Hagibis conditions.

Acknowledgments

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