THE COUNTERMEASURES FOR FLOOD MITIGATION EVALUATED BY 1D AND 2D COUPLED MODELS

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The development of numerical models to simulate the real time situations is important to find possible solutions for natural disasters. Numerical models can also evaluate the effectiveness of the possible solutions by analyzing various scenarios. Coupled 1D and 2D hydraulic models play a significant role in analyzing flooding problems. Kubokawa, Japan had undergone flooding in 2014. We developed a detailed flood inundation model incorporating the available pumps, flood gates and other components in order to analyze possible countermeasures for mitigation of floods in the future. The model includes rainfall runoff models, a 1D river model and a 2D river basin model. The developed model was verified using field observation data of high water levels in the river and the inundations of the area. The results from the numerical model and field survey data indicate that the main causes for the flooding are the bathymetry of the area (i.e., the low lying areas in the surrounding high elevations) and the flow from the surrounding mountain. It was also found that the river has not overflowed. In this study, several countermeasures were identified to potentially mitigate future flooding. They include constructions of two retention ponds and a bypass channel for the inflow from surrounding mountain area. This paper summarizes the development of numerical model and the analysis performed to evaluate the effectiveness of such flood mitigation measures.

1 INTRODUCTION

Flooding is a very common natural disaster to many parts of the world. Coastal and inland flooding happens due to number of different reasons such as heavy rainfalls, storm surges, tsunami, river bank failures etc. Numerical modeling of flood inundation plays a key role in analyzing different aspects of floods and analyzing countermeasures. From the past several kinds of numerical models including 1D and 2D hydrodynamic models have been used for analyzing different effects of floods. However, since each type alone has some drawbacks, coupled 1D and 2D models has been used as an advanced method for flood analysis for complex flood plains given currently available technology (Tayefi et al. [1]).

Kubokawa is a small town in Kochi prefecture, Japan that underwent flooding in the strong typhoon season in 2014(Nakano [2]). The prefectural government aims to mitigate flooding with some countermeasures. The current paper summarizes the analysis of the flood and several countermeasures with numerical models. The meandered Yoshimi River, a tributary of Shimanto River, flows through the Kubokawa. The Shimanto River is one of the largest rivers in Shikoku island Japan (Pawitan et al. [3]) and its catchment receives the highest rainfall in Japan with an average annual precipitation of 2600 mm. During the flood event in August 8-11, 2014, precipitation was 676.5 mm and maximum precipitation intensity was 53.5 mm/hr. During the flood, houses inundated above floor level were 165 and below floor level were 117 (Nakano [4]). Here above and below floor level is defined according to the Japanese houses which have an increased floor than the ground level, to prevent dust coming to the houses. The flooded area presented several drainages with flood gates and pumps. Further, the mountainous area nearby is believed to have contributed to the flooding. Given that the many components influencing the study area and its complex topography, a coupled 1D and 2D model was selected for carrying out the flood inundation simulation. Particularly, MIKE FLOOD coupled model with MIKE 11 1D model and MIKE 21 2D model were used for this study.

2 METHODOLOGY

ARCGIS, MIKE 11, MIKE 21 and MIKE FLOOD were used as the tools for the numerical analysis. In the coupled model, MIKE 11 was used as the 1D river model, MIKE 21 was used as the 2D basin model and MIKE FLOOD was used to link the 1D model and 2D models together and generate inundations. The terrain was processed using a Digital Elevation Model (DEM) with spatial resolution 10 m and 5 m available in Geospatial Information Authority of Japan using ARC GIS. Inflow from the upstream watersheds and the mountain areas were obtained from MIKE 11 RR models (i.e. URBAN A and B models). Figure 1 is an illustration of components of the model. Runoff obtained from the RR models are connected to MIKE 11 1D model as inflow boundaries. Runoff obtained from the mountain watersheds were inserted to MIKE 21 2D model as inflow sources. Two drainages with flood gates and pumps were available in the site and they were included to the MIKE 21 model. Discharges through the flood gates were given as the links in MIKE FLOOD. Drainages were inserted to the MIKE 21 model as culverts.

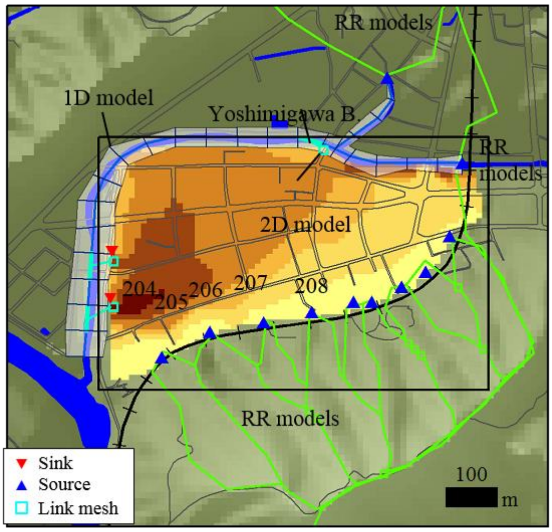

Figure 1: Components of the flood inundation model

MIKE 11 river model consisted of 1 km river reach, 2 upstream boundaries and one downstream boundary (water level in the Shimanto River). Grid size in the longitudinal direction (Δx) was about 50 m. Time interval (Δt) was 1 sec. MIKE 21 mesh was created using only the inundated area on the left bank as shown in the Figure 1. Grid sizes in x and y directions were 10 m. Time interval was 1 sec. Inflow from the mountain watershed was inserted to the model as source terms. Two pumps were installed as sink terms. At present there are two pumping stations and during the flood on 8-11 August 2014, the site has operated total of 59 m^3/min capacity. The simulation started from 2014/08/08 00:00 AM to 2014/08/11 00:00 AM. The simulation was conducted in three stages using the outputs of one stage as inputs to the next stage given that the flood gates were operated in three different times. Simulations were done for 2014/08/08 00:00 AM to 2014/08/10 00:00 AM (With flood gates open), 2014/08/10 00:00 AM to 2014/08/10 8:30 (with flood gates closed) and 2014/08/10 8:30 to 2014/8/11 00:00 AM (with flood gates open). Pumping rates were given as time series data from 2014/08/08 to 2014/08/11 and when no pump was in operation, time series data had a value of zero.

3 RESULTS AND DISCUSSION

3.1 The causes of flooding

The model was validated using the field observations of the flood occurred in 10-11 August 2014. The results of the maximum water levels along the river and maximum inundation depth were compared with the field observations of the flood. The numerical and observed data were found to be consistent [5]. The results of several analyses indicated that the bathymetry was the main cause of flooding as a low elevation area was covered from high elevation areas making the area a retention pond. A water budget calculation of the area confirms that the total inflow to the area from precipitation and inflow from the mountain area was larger than the outflow form the drainages and pumps. The results indicated that the rainfall contributed 74% of the flood as the topographical conditions prevented it being flown to the river. Further, results indicated that, 25 % of the flood was due to the inflow from the surrounding mountain area. In contrast to the general guess, it was found that only around 0.5% was though the opening near the gate at the Yoshimigawa Bridge.

3.2 Analysis of the countermeasures

After careful consideration of the causes of the flooding, and the estimated costs, from 5 potential countermeasures suggested by the city office [5], two potential countermeasures as given in the Table 1, were selected for further analysis. Figure 2 shows schematic views of two countermeasures. The numerical results have found that a considerable amount of inflow generated from the mountain. Therefore, countermeasure 2 was selected to simulate with the model. Figure 2 shows schematic views of two countermeasures.

Table 1. Potential countermeasures selected for the analysis

Counter measure	Components	Estimated Cost (billion Yen)	Advantages	Disadvantages
1	Pump with 1.3m^3/s capacity and two retention ponds of 4000 m^3 and 11000 m^3 capacity	3.4	Easy to implement	Maintenance cost of running two pumps, no direct reduction of the inflow from the mountain
2	Bypass channel and two retention ponds of 10000 m^3 and 3000 m^3 capacity	3.4	Can reduce the total inflow from the mountain, can reduce the flooding in low land area	Need to select the location carefully not to have housing acquisitions

Since the mountain area is located at higher elevations, the channel was proposed with a higher elevation so that flood gates are not required and thereby no pumping is required. The channel dimensions and the layout of the channel are shown in Figure 2. Retention ponds are proposed as 3000m^3 and 10000 m^3 capacity each with areas of 1500 m^2 and 5000 m^2. These two retention ponds are proposed to have in two abandoned lands and the ground elevation of the area is relatively lower than the surroundings. Figure 3 shows the flood storage volumes under different scenarios. From the figure, it is clearly visible that all the countermeasures reduce the maximum flood storage volume considerably. Combination of bypass channel and retention ponds has reduced the maximum flood storage volume by 20000 m^3 which is a 38% reduction with the case without any measures. This is the best possible approach in terms of reducing the maximum flood volume. With the bypass channel alone has reduced the maximum flood storage volume by 13000 m^3 and it is a 27% reduction compared to the case without any measures. Two retention ponds alone has reduced the maximum flood storage volume by 6500 m^3 and it is a 13 % reduction compared to without any measures scenario.

Figure 4 shows the inundation maps with different countermeasures. According to the figures, it is clearly visible that all countermeasures has reduced the inundation areas. The area inundated by water depth more than 0.5 m is 25100 m^2 for the case with bypass channel and two retention ponds. It is a 26% reduction compared to the case without any measures. The area inundated by water depth more than 0.5 m is 24400 m^2 with the bypass channel. It is a 29 % reduction compared to the case without any measures. The area inundated by water depth more than 0.5 m is 30400 m^2 with the retention ponds alone. It is a 10 % reduction compared to the case without any measures.

A Comparison of countermeasure 1 and 2 suggests that the countermeasure 2 is more appropriate as it directly cuts the inflow from the mountain area. Referring to the inflow patterns of the area as shown in figure 2, and inundation map (d) in Figure 4, we can conclude that, when only the two retention ponds were used with pumps, the flooding due to mountain inflow will not be reduced in the areas which are far away from the retention ponds.

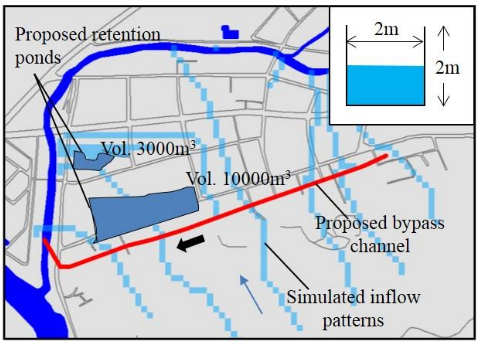

Figure 2: Proposed bypass channel for mountain flow as a countermeasure for flood and the proposed retention ponds

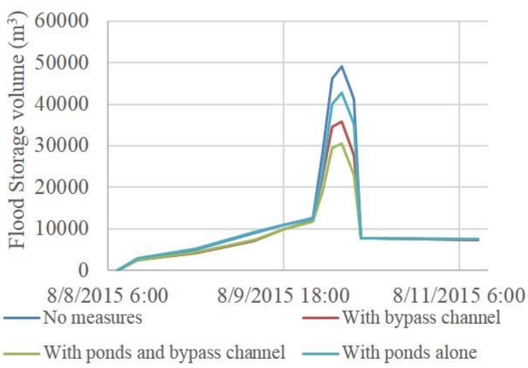

Figure 3: Flood storage volumes under different scenarios

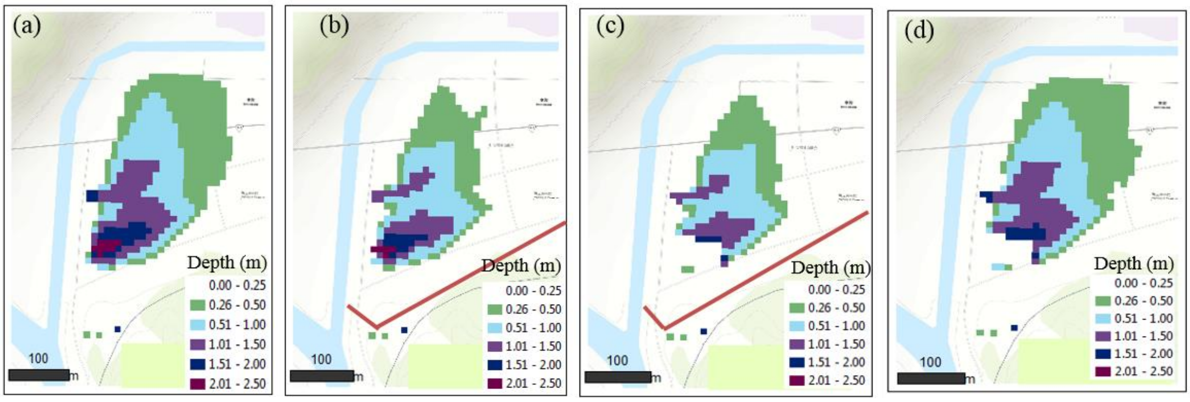

Figure 4: Inundation maps under different scenarios (a) no countermeasures, (b) bypass channel, (c) bypass channel and retention ponds and (d) retention ponds only

Further, even though both countermeasures are under same construction cost, since the countermeasure 1 has a maintenance cost of running two pumps, it is more expensive than countermeasure 2. However, construction of the bypass channel has to be carefully designed such that it doesn't affect the environment conditions. To have a higher elevation so that no pumping is required and to have no acquisition of housing is required, it has to be created in the belt of a forest area. To have minimum damage to the ecosystem, and the surrounding forest, bypass channel may be needed to construct with rubble or soil.

4 CONCLUSIONS

Countermeasures to reduce flooding in Kubokawa area, Japan were proposed and evaluated using numerical models. Initially, a detailed flood inundation model including all the components was prepared and validated with the field observations of a flood occurred during a flood in 8 - 11 August 2014. Causes of the flood and their contributions were identified. Several countermeasures against the flooding were proposed. They include construction of a bypass channel, and retention ponds, retention ponds with pumps and increasing the capacity of the pumps. The effectiveness of the countermeasures was analyzed with the numerical model. The results indicate that the construction of the bypass channel with two retention ponds can reduce the maximum inundation volume by 38% and the inundated area greater than 0.5 m depth by 26 %.

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