Research Paper

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Inundation Risk Analysis of The Storm Surge and Flood in The Coastal Area of The Ariake Sea Using Gis and 2-D Flooding Simulation

Engineering

KEYWORDS : Inundation risk, storm surge, flood, GIS.

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ABSTRACT

Inundations in the coastal area occur due to not only storm surge but also flood. If the storm surge and flood occur at the same time, causes significant inundation in the coastal communities and results into huge water disaster. In this study, 2-D numerical simulation of flooding and GIS are utilized to consider the inundation risk of these disasters in the coastal area of the Ariake Sea. Inundation risk in this area is high risk, buildings or houses and public facilities be affected.

1. INTRODUCTION

Storm surge is a phenomenon in which ocean water surface elevations rise as a result of high winds and decreases in atmospheric pressure during tropical storm and typhoon. Storm surge by typhoon is the one of the frequent disasters in Japan. Every year Japan territory is crossed by typhoon with variety of categories, ranging from wind speed categories from the smallest to the largest which can cause significant inundation in the coastal areas. Lives and properties located in the coastal area of typhoon-prone regions are at great risk during large storm events. Storm surge has the potential of vast area inundation.

Many of the risks are given by the storm surge along the coastal areas including residential areas, industries, agriculture, etc., with exposure to inundation from the combination of storm surge and river flooding. However, storm surge combined with flood in the coastal area is not well studied. Understanding of these risks of inundation as a result of storm surge and river flooding is quite necessary especially for the coastal communities. River flooding by high discharge is another disaster that causes inundation in the coastal area.

This study aims to get an overview of inundation when the two disasters, storm surge and river flood simultaneously occur in the coastal area of Ariake Sea and Saga lowland. This study also considers of inundation risk affected in the coastal communities especially on the buildings or houses and public facilities for evaluation of the future disaster management based on the simulation's results.

2. STUDY AREA AND SUPPOSED DISASTERS

The Ariake Sea, which is surrounded by Fukuoka, Saga, Nagasaki and Kumamoto Prefectures, is the biggest bay in Kyushu island in Japan (Figure 1). This is an inner bay, where a lot of rivers flowing in, such as Chikugo River, Kase River, Rokkaku River, Yabe River, etc. This bay includes wide muddy tidal flats. The Ariake Sea's tidal range is the largest in Japan, and maximum tidal range is as much as 5 to 6 m at the innermost part. Coastal areas of this bay are mainly lowland with an unusually small slope, so once sea water enters into these areas, they will be immediately inundated.

If the typhoon track coincides with the Ariake Sea's longitudinal axis, it can cause a large storm surge. The large rivers such as Chikugo River, Kase River and Rokkaku River empty into this bay. There are settlements, airport, agricultural land, industrial area and office buildings and other public facilities in this coastal area. The Japanese government has built coastal dyke along the shoreline and river within this areas with the maximum elevation of 7.5 m based on the analysis of Isewan Typhoon in 1959.

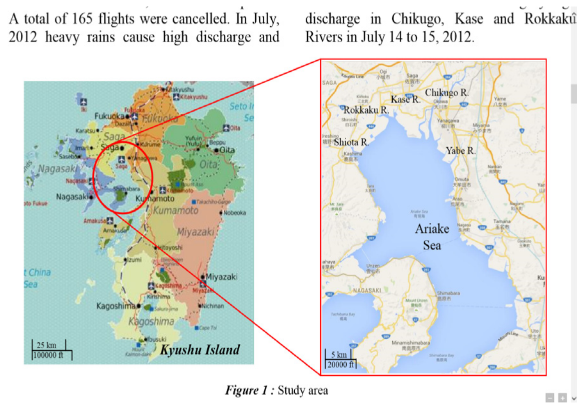

Figure 1 : Study are

In 1985, the typhoon Pat hit a track in this area. With highest winds of 80 mph (36 m/s), this typhoon caused storm surge in the region of Kyushu island giving 79 people injured, 38 houses demolished, 110 damaged, and over 2,000 were flooded. More than 160,000 homes lost power. A total of 165 flights were cancelled. In July, 2012 heavy rains cause high discharge and widespread flooding in this area, causing at least 10 deaths and around 50,000 evacuations. Supposed disasters are storm surge and flood that have occurred in this area. The first disaster is storm surge by Typhoon Pat that occurred in August, 31 to September, 1, 1985. The second disaster is River flooding by high discharge in Chikugo, Kase and Rokkaku Rivers in July 14 to 15, 2012.

3. METHODOLOGY

This study utilizes a two dimensional hydrodynamic model, MIKE 21 FM HD developed by DHI (Danish Hydraulic Institute). This software is used to create simulation of several typhoons that ever crossed Ariake Sea and high discharge condition simultaneously occurred at the same time to determine the areas with water level higher than the height of the existing dyke that could cause inundation. In this study, 11 measurement lines are considered as transects to investigate the inundation in the coastal area, i.e. 1) Shiroishi, 2) Rokkaku Estuary, 3) Kase Estuary, 4) Higashiyoka, 5) Saga Airport, 6) Chikugo Estuary, 7) Ohama, 8) Rokkaku River, 9) Kase River, 10) Chikugo River_1 and 11) Chikugo River_2 shown in the Figure 2.

Figure 2 : **Measurement lines**

In the numerical simulations, the following data are taken as input data; bathymetrical data, topographical data, wind data (speed and direction), some of the water level at stations, discharge data and time step of simulation. Bathymetrical data are obtained from the Ariake Project of Saga University. Topographic data are obtained from 50 m DEM of Japan supplied by Geospatial Information Authority of Japan. Wind data in the form of wind speed and wind direction provided by Meteorological Agency taken at the same time with water level and tide from August 31 to September 1, 1985 in some stations. The discharge data are provided by MLIT that took these data from July 14 to July 15, 2012 at some stations of Chikugo, Kase and Rokkaku Rivers. The hydrograph data of tide and discharge can be shown in figure 3 to figure 4.

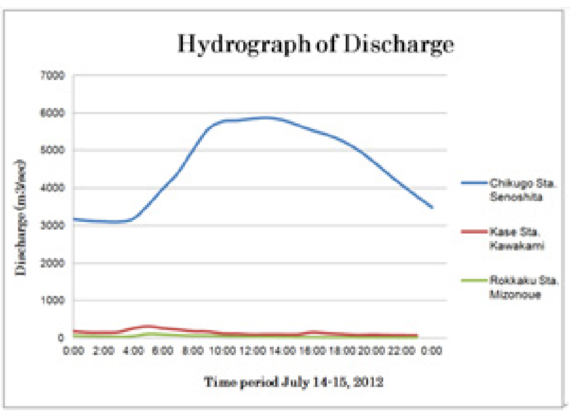

Figure 3 : **Hydrograph of discharge**

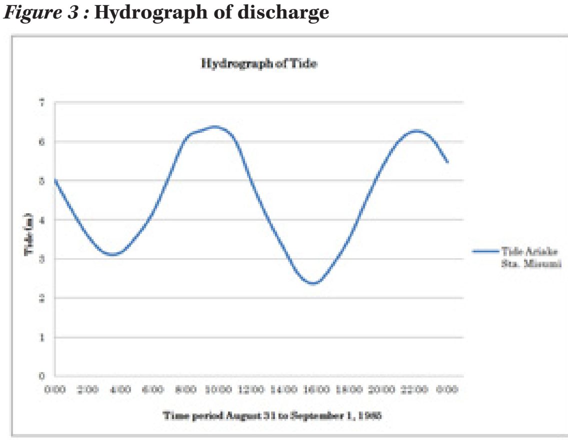

Figure 4 : **Hydrograph of tide**

The simulation was implemented from August 31 to September 1, 1985 when the Typhoon Pat passed through the Ariake Sea area. The model calculation was established by the computational mesh with open boundary to input time series data of tide and discharge at Ariake Sea and at the Chikugo, Kase and Rokkaku Rivers in the Saga Lowland as shown in the Figure 5 and Figure 6.

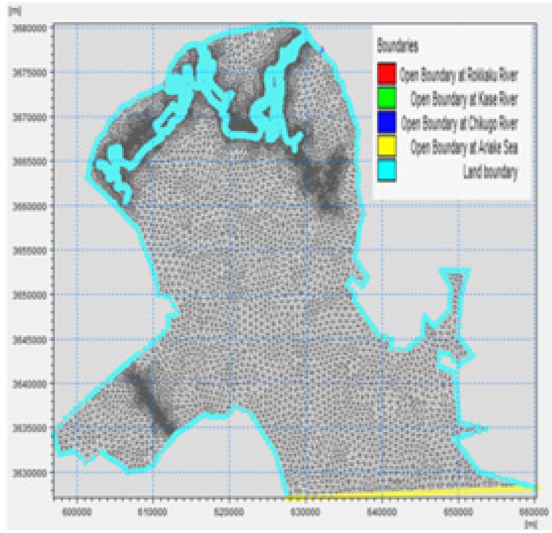

Figure 5 : **Many kinds of computational boundary**

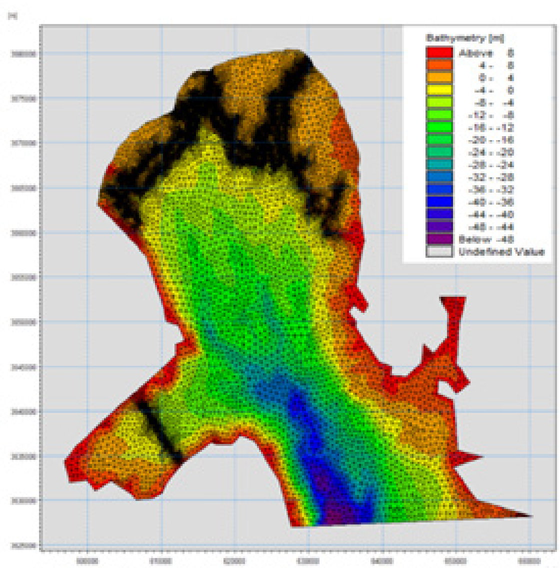

Figure 6 : **Computational mesh and bathymetry**

Table 1 : Mesh information

Item	Amount
Number of elements	86008
Number of faces	129302
Number of nodes	43295
Number of sections	5
Min x-coordinate (m)	596901
Max x-coordinate (m)	660343
Min y-coordinate (m)	3627039
Max y-coordinate (m)	3680416
Min z-coordinate (m)	-52.35
Max z-coordinate (m)	9.93

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As the computational conditions, time step interval of 0.9 s and number of time step, 96000 are used. The mesh information can be shown in Table 1.

2-D Hydrodynamic models

Complex interaction of channel and floodplain flow fields make two-dimensional simulation codes move desirable than one-dimensional codes in many modeling situations (Horritt and Bates 2002). Continuous improvements in computational resources and affordability have also increased implementation of two-dimensional modeling. Most widely used two-dimensional codes utilize depth-averaged Navier-Stokes equations, commonly called the Saint-Venant shallow water equations, shown in equation (1), (2) and (3) as follows.

$$\frac{\partial h}{\partial t}+\frac{\partial (hU)}{\partial x}+\frac{\partial (hV)}{\partial y}=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{\partial (hU)}{\partial t}+\frac{\partial (hUU)}{\partial x}+\frac{\partial (VU)}{\partial y}=\frac{\partial (hT_{xx})}{\partial x}+\frac{\partial (hT_{xy})}{\partial y} - gh\frac{\partial z}{\partial x}-\frac{\tau_{bx}}{\rho} \quad \ldots\ldots (2)$$

$$\frac{\partial (hV)}{\partial t}+\frac{\partial (hUV)}{\partial x}+\frac{\partial (VV)}{\partial y}=\frac{\partial (hT_{xy})}{\partial x}+\frac{\partial (hT_{yy})}{\partial y} - gh\frac{\partial z}{\partial y}-\frac{\tau_{by}}{\rho} \quad \ldots\ldots (3)$$

where h is flow depth, U and V are velocities in the x and y directions, T_{xx}, T_{xy} and T_{yy} are depth-averaged turbulent stresses, z is the water surface elevation, g = acceleration due to gravity, and τ_{bx}, τ_{by} are bed shear stresses.

4. RESULTS AND DISCUSSIONS

Table 2 : Maximum water level at each line

No	Lines Name	Maximum Water level (m)
1	Shiroishi	6.67 m
2	Rokkaku Estuary	6.7 m
3	Kase Estuary	6.7 m
4	Higashiyoka	6.54 m
5	Saga Airport	6.52 m
6	Chikugo Estuary	6.68 m
7	Ohamma	6.51 m
8	Rokkaku river	6.71 m
9	Kase river	6.85 m
10	Chikugo river1	> 7.5 m
11	Chikugo river2	> 7.5 m

Table 2 shows the maximum water levels at each measurement line. The simulation's results on the 11 specified location indicates that the maximum water levels exceed 6.5 m. In some locations near shoreline, the water level does not exceed the height of the existing coastal dykes of 7.5 m high. In the measurement location on the Chikugo River, the water levels exceed 7.5 m level, so that the water overflowed on both sides causing inundation of the surrounding area, as shown in Table 2 and Figure 7 to 10.

Figures 7 to 10 show, inundation processes caused by high discharge and high tide by the storm surge in the coastal area of Ariake Sea. In the case that two disasters, the high discharge by torrential rain and the storm surge occur at the same time, instantaneous inundation maps are seen in the case of only high discharge disaster. However, the water level does not reach to a normal level soon and continues to fluctuate for a long time like the typhoon.

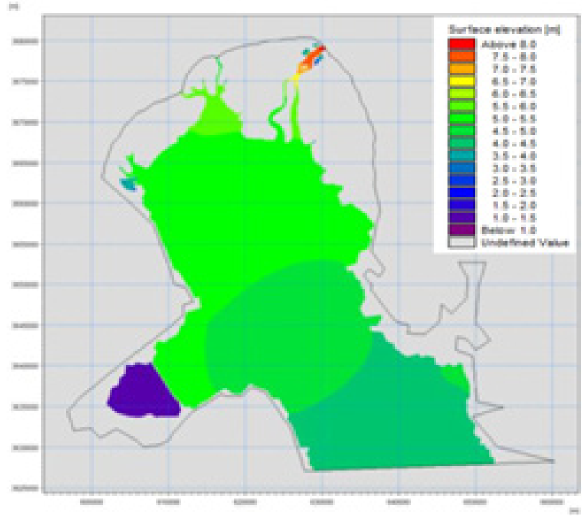

Figure 7 : Inundation processes at time 2:00 on August, 31, 1985

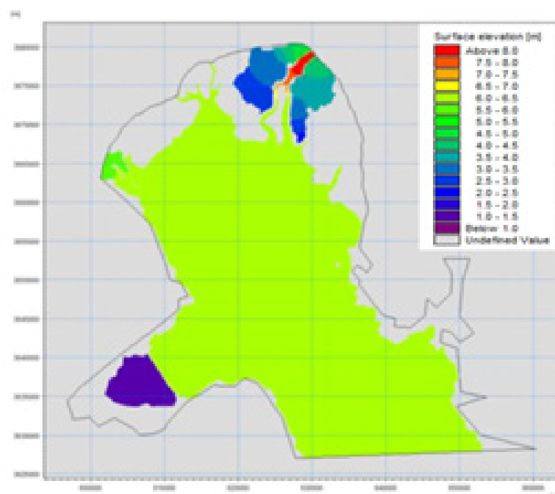

***Figure 8 :* Inundation processes at time 12:00 on August, 31, 1985**

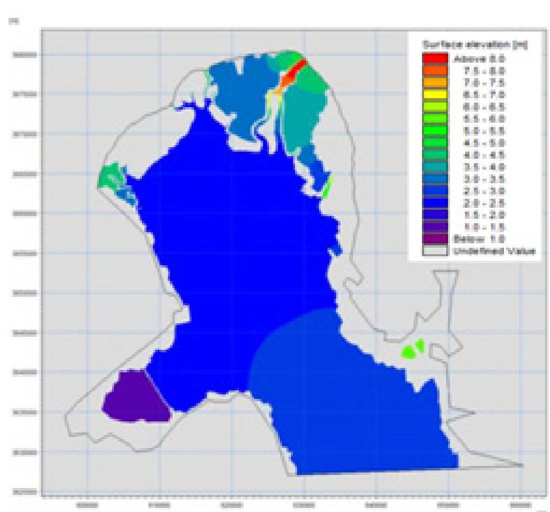

Figure 9 : **Inundation processes at time 18:00 on August. 31, 1985**

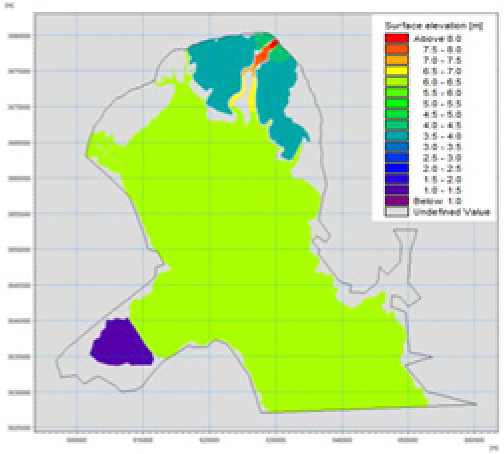

Figure 10 : **Inundation processes at time 00:00 on September, 1, 1985**

Based on the simulation's result by 2-D numerical model, the areas near the mouth of Chikugo River are at high risk of inundation due to the storm surge and flood. There are settlements, road and other public facilities in these areas. In the simulation model, existence of houses and buildings are not considered except the river and coastal dyke. In GIS analysis, the data of houses or buildings and public facilities existence are required.

GIS Analysis

GIS model analysis are conducted to obtain the inundation risk based on the simulation result of 2D inundation numerical modeling. The data of 2D simulation result are converted to shape file. Furthermore, inputted data of buildings or houses and public facilities are also converted to the shape files. According to the level of the inundation risk, the amount of buildings or houses and public facilities inundated is obtained. Figure 11 and Figure 12 show the inundation risk of buildings and public facilities in the coastal area of Ariake Sea in the case that storm surge and flood simultaneously occur in this area. More than 107,000 buildings or houses and 270 public facilities are inundated.

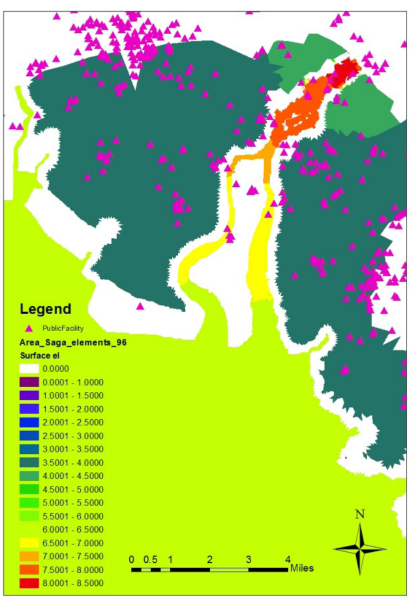

Figure 11 : **Inundation of the public facilities**

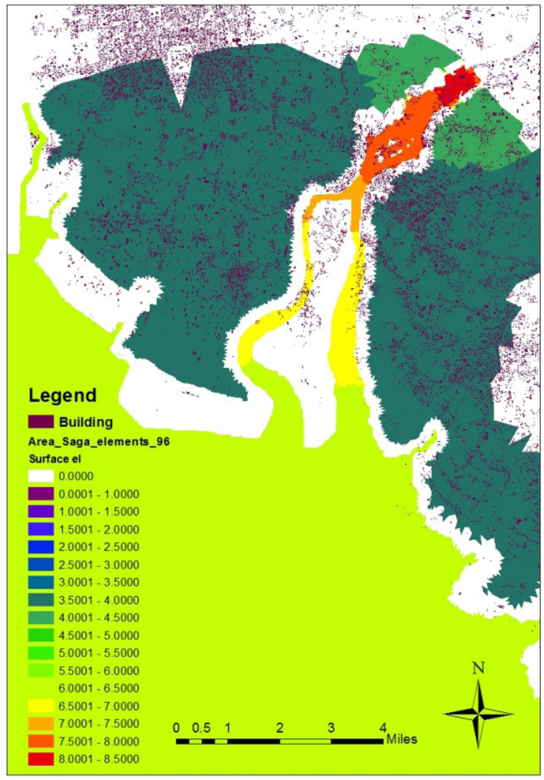

Figure 12 : **Inundation of the buildings**

5. CONCLUSIONS

(1) Based on the 2D inundation numerical modeling, the storm surge and the flood by torrential rain at the same time can cause inundation disaster near the river mouth.

(2) The inundation risk in the coastal area is high. The buildings or houses, and public facilities are supposed to have serious damage.

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Chikugo R.

REFERENCE

A.K.T. Dundu (2012), A Study on Impact of Storm Surge by Typhoon in Saga Lowland and Surroundings using Hydrodynamic Numerical Modeling, International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol: 12 No: 01. | DHI (2006), MIKE 21, Short introduction and tutorial, Danish Hydraulic Institute, Denmark. | DHI (2009), MIKE 21 Flow Model: Hydrodynamic Module Scientific Documentation, Danish Hydraulic Institute, Denmark. | DHI (2011), MIKE 21 FLOW MODEL FM, Hydrodynamic module, user guide, Danish Hydraulic Institute, Denmark. | Daniel Giles and Matthew Moore (2010), Review of Hydraulic Flood Modeling Software used in Belgium, The Netherlands, and The United Kingdom, Hydroscience & Engineering University of Iowa, College of Engineering, p5-6. | Horritt, M.S., and P.D. Bates (2002), Evaluation of 1D and 2D numerical models for predicting river flood inundation, Journal of Hydrology, p87-99. | X., Wang, et. al. (2008), Simulation of flood inundation of Guiyang City using remote sensing, GIS and hydrologic model, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B8. Beijing | Xihua Yang and Bengt Rystedt (2002), Predicting Flood Inundation and Risk Using GIS and Hydrodynamic, Indian Cartographer. | | |