Survey and Numerical Simulation of Storm Surges Induced by Cyclone Nargis

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1. Introduction

Nargis, category 4 cyclone, made landfall into Myanmar on May 2nd of 2008, causing catastrophic destruction of about 10 billion US Dollar worth and about one hundred thousand fatalities along its way. It was the worst natural disaster in the history of Myanmar. It passed through the most populated portion of the country and very low land delta area, the Ayeyarwaddy Delta. The most of the fatalities in the affected area were made by the storm surges in low land coastal area.

After the cyclone hit, the inundations in the affected area could be known from satellite images comparing areas of wet land before and after the cyclone as shown in Fig. 1. However, only the locations of flood could be found by the images, not the inundation level of flooded water by the storm surge. Moreover, some locations shown in the satellite images were not clear if inundated or not, because the land level could not be measured accurately by the satellite images when the area was covered by dense canopies of forest.

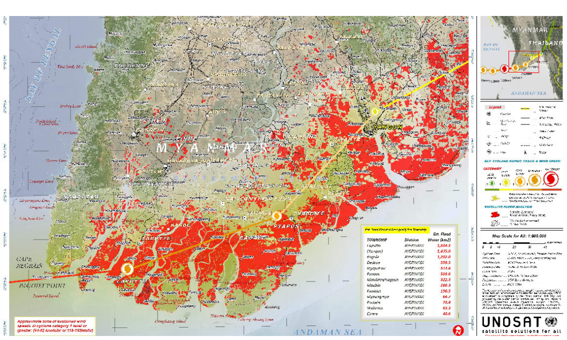

Fig. 1: Flood Analysis with MODIS Terra & Aqua Data recorded 5 May and 15 April 2008 (Figure prepared by UNOSAT)

2. Purpose and Scope of the study

The purpose of this study is to get the inundation level of flood over the affected area and understand more about the mechanism of the storm surges induced by the Cyclone Nargis in Ayeyarwaddy Delta through numerical simulation. The practical survey in the fields was carried out as the start of the study, for 5 days starting from 3rd July, 2008. A survey team including the author had been organized within the Tokyo University of Marine Science and Technology. It was dispatched to Myanmar and performed surveys for inundation level measurements in 5 regions in the delta area; the results of them are described in the next section.

Then, the numerical simulation was conducted by constructing the storm model with the pressure field and wind field estimated. After some trial processes, the constants such as the wind factor and rotation angle were adjusted. Later, this storm model was applied to a chosen domain. Finally, the output data were compared with the field survey data.

3. Field Survey

Five townships, namely; Kun-gyangon, Dadeye, Pyapon, Bogale and Laputta, which almost cover the whole affected area, were visited by the survey team to collect the flood data of cyclone. During the field survey, the local people were interviewed, and recorded the related information as much as possible.

3.1) Method of Survey

The water surface from nearby river or sea was used as the datum in the leveling to watermarks (Fig. 2). After that, these flood data were corrected with the tide data at that time and at the time of storm surge intruded, then calculated the surge heights by the cyclone.

Fig. 2: Measuring the flood heights in Dadeye; the dotted line indicate the watermark.

The estimation process of the storm surge in the survey area will be described with the aid of Fig. 3. In this figure, *Hm* means the height of the flood evidence from the nearby water level. *Hs* is the storm surge height, *Dm* and *Ds* are the predicted tidal level at the measured time and storm surge arrived time. The storm surge at the site was calculated with the relation: *Hs* = *Hm* + (*Dm* - *Ds*).

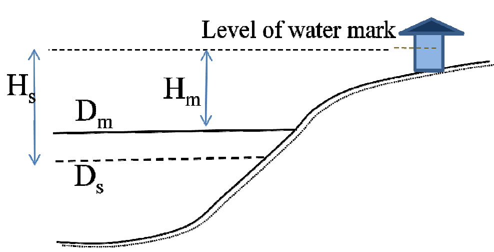

Fig. 3: Sketch showing the calculation process of storm surge.

3.2) Results of survey

The corrected surge heights (in meter) at the surveyed area are shown in the following Fig.4. The dotted line shows the track of cyclone passed. According to the results of survey, the higher storm surges up to 4.7 m were noted in the Laputta Township where is very close with the place of cyclone landfall. Not only the landfall area, but all of the low land area at the right side of the storm track also, suffered the significant flood because of the cyclone passage nearly parallel with the coast line.

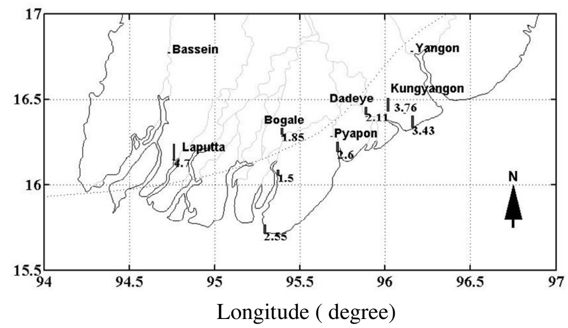

Fig. 4: Survey results of tide-corrected storm surges in 5 Townships at Ayeyarwaddy Delta.

4. Method of Numerical Simulation

4.1) Basic equations and related parameters

The method of numerical simulation utilized in this study is the two-dimensional equations of motion and continuity which are expressed as;

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} = \frac{-D}{\rho}\frac{\partial P}{\partial x} + fN + \frac{1}{\rho}(\tau_{sx} - \tau_{bx}) \quad \ldots\ldots\ldots \quad (1)$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial x}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} = \frac{-D}{\rho}\frac{\partial P}{\partial y} - fM + \frac{1}{\rho}(\tau_{sy} - \tau_{by}) \quad \ldots\ldots\ldots \quad (2)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \quad (3)$$

where *x* is the longitudinal axis, *y* the latitudinal axis, *z* the vertical axis with the origin taking the equilibrium level of the sea surface. And *u* and *v* are defined as the *x* and *y* components of velocity and, *M* and *N* are the *x* and *y* components of flow flux given by $M = \int_D^0 u dz$, $N = \int_D^0 v dz$, respectively. η is the sea surface displacement and D is the total water depth.

The right parts of the equations of motion, Eqs. (1) and (2), are the external force factors affecting to the storm surges. P is the pressure, and f is the Coriolis parameter. τ_{sx} is the x component of wind stress over the sea surface and τ_{bx} is the bottom shear stress.

4.2) Storm model

The pressure field of the storm model was defined by the Myer formula (Exponential Law). Wind in the storm is calculated by the Miyazaki *et al.* formula written in the form:

$$\boldsymbol{W} = C_1 \boldsymbol{G}' + C_2 \boldsymbol{W_s} \, exp\left(\frac{-r}{r_e}\right) \qquad (4),$$

where $\boldsymbol{G}'$ is a wind vector, $\boldsymbol{W_s}$ the velocity vector of the storm moving . $\boldsymbol{G}'$ has the same magnitude as the gradient wind vector $\boldsymbol{G}$ and the direction of $\boldsymbol{G}'$ is turned inward of the storm at a certain angle from $\boldsymbol{G}$ to take the effect of the friction between the atmosphere and the Earth's surface into account. The magnitude of $\boldsymbol{G}$ is calculated by the parabolic equation.

For determining Rp, C_1 and C_2 in Eq. (4) it may be appropriate to use the data observed at meteorological stations; however, such data are often influenced by the surrounding topographic conditions. In the present study, the data observed at Yangon were used to determine Rp .

To determine the maximum wind speed and the radius of maximum wind Rp , a two-step process was used to generate wind fields for use from the storm data. Firstly, roughly estimated Rp was used for a trial and, then calculated to get the maximum wind along the track of cyclone. By using the calculated maximum wind, Rp values were taken from a Nomograph that incorporates the maximum wind speed and atmospheric pressure anomaly.

There is a suggested relation between latitude of the particular location and the inflow angle between $\boldsymbol{G}$ and $\boldsymbol{G}'$. But, the larger values than these are used for the practical simulations (T. Konishi and Y. Tsuji, 1994) by adjusting with the observed data. The magnitude of 0.9 was selected for C_1 and 6/7 for C_2. The inflow angle between $\boldsymbol{G}'$ and $\boldsymbol{G}$ is taken as 30°, for this study.

5. Simulation Results

After various trials to calculate the storm surge around the Ayeyarwaddy delta, the suitable size of the domain was determined to consider between latitude 12 to 18 degree for latitudinal direction, and longitude 92 to 98 degree for longitudinal direction as shown in Fig. 5.

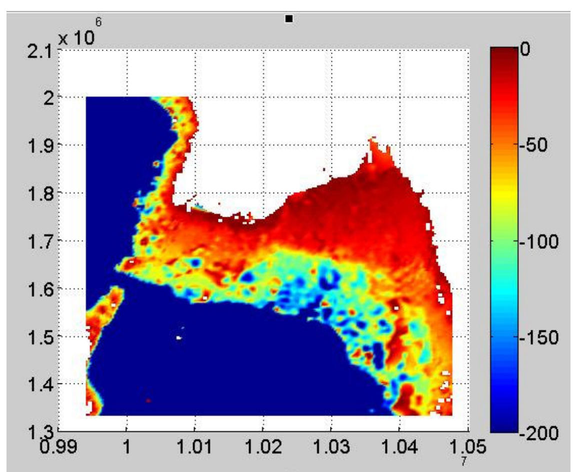

Fig. 5: Bathymetry of the area of interest

The vertical and horizontal units in the figure are the converted length in meters units from Lat-Lon units for the numerical calculation. The bathymetry in meters of the basin is also shaded up to 200 m below the water surface.

The 3 km space grids and the time steps of 10 s are used in the simulation. Initial conditions are set as η = 0 and ***M, N*** = 0 and only the storm surge is computed. On the coastal line boundary (closed), the conditions of zero normal velocity are applied. As an open boundary condition, the modified radiation condition is used for the southern, western and northern boundary of the domain.

Figures 6 and 7 show the water surface elevation at the instant of the storm just after land fall to the Ayeyarwaddy Delta. The spot ✧ represents the location of the center of storm and the arrows give directions of storm wind.

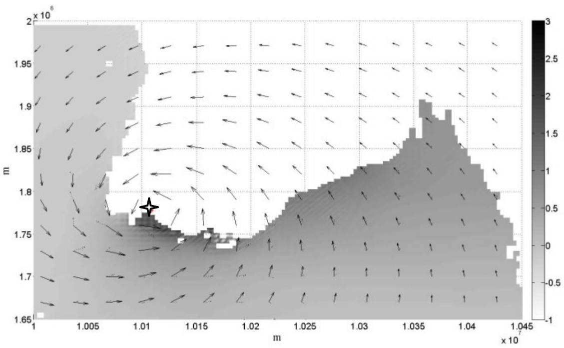

Fig. 6: Water level elevation and wind at the moment of cyclone landfall to delta area

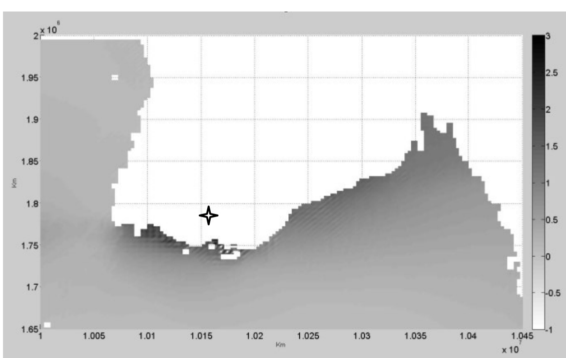

Fig. 7: the maximum storm surge heights (in meter)

In this case, the simulation started from 2 days before landfall because of the less effect from the deep sea area phenomenon. The highest storm surge in that moment is 2.6 m at the right side coast of the storm center.

In Fig. 7, the contour of the maximum heights of water throughout the stimulation from the starting point to the spot is shown. The largest water depth in this case is 3.1 m.

6. Conclusions

A field survey of storm surge inundation caused by Cyclone Nargis was conducted at five townships, Kun-gyangon, Dadeye, Pyapon, Bogale and Laputta. Inundation depth after tide correction up to 4.7 m was measured in the Laputta Township.

Numerical simulation for water surface elevation by the cyclone was performed. The surge heights in the inner parts of the delta area could not be estimated in this study. In this simulation, only the storm surge induced by the cyclone was considered, which means that the tidal effect was not included. Therefore, these results could be compared directly with the tide-corrected data of the field survey. The maximum floods obtained from the simulation were close to the field results at the coast line area of the delta area.

References

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