STUDY ON TSUNAMI DATABASE FOR TSUNAMI EARLY WARNING SYSTEM IN BANGLADESH

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ABSTRACT

In this study, numerical tsunami simulations along the Bangladesh coast were conducted in order to make tsunami database. The numerical model is based on the spatial grid system in Cartesian coordinate system using a non-linear tsunami theory. Two types of bathymetry grid interval were considered in this study such as (1) one arc minute, that is about 1850 m and (2) twenty arc seconds that is about 616.67 m. The source points have been set up near the Bangladesh coast and parallel to the trench. The coastal points, forecast points and one tide gauge station were set up near the coast. Ten source points were selected with four different magnitudes (M_w 6.5, 7.0, 7.5 and 8.0) and four different depths (0, 10, 20 and 30 km). Tsunami heights were checked graphically for all cases. The Green's Law was applied to obtain the reliable tsunami heights along the coast from the tsunami heights at forecast points. Results of both grid interval of bathymetry were compared with each other. The simulation results were stored in MySQL system for a tsunami database.

Keywords: Tsunami arrival time, Tsunami height, Tsunami database.

INTRODUCTION

Bangladesh is surrounded by the regions of high seismicity, which include the Himalayan Arc and Shillong plateau in the north, the Burmese Arc, Arakan Yoma anticlinorium in the east, and complex Naga-Disang-Jaflong thrust zones in the northeast (Hossain, 1989). The northeast side of the Indo-Australian plate forms a subducting boundary with the Eurasian plate on the border of the Indian Ocean from Bangladesh. The long seismic gap from Bangladesh coast to Andaman Islands of the bay of Bengal could produce a big tsunami in future. Southern part of Bangladesh is a coastal region. Millions of people are living in this coastal region. Considering the potential seismic source (Cummins, 2007), a tsunami in this region poses a very significant threat to a large coastal population. This study has been addressed a tsunami database for tsunami early warning system, which will prevent human lives and reduce damage from the tsunami.

METHOD OF ANALYSIS

Bathymetry Data

The bathymetry data were downloaded from the web site of GEBCO. Two types of grid interval of bathymetry data, one arc minute that is about 1850 m and twenty arc seconds that is about 616.67 m, were used in this study. GEBCO data have positive values on land grids and its grid format is NetCDF. It was needed to convert another format by using some GMT commands. The converted bathymetry grid data became negative values for land (-999) and positive values for sea depth.

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Magnitude and Depth

The four magnitudes and four depths have been set for the computation of tsunami simulation for each source point in order to make database. The magnitudes are M_w 6.5, 7.0, 7.5 and 8.0 with the interval of 0.5. The depths are 0, 10, 20 and 30 km with the interval of 10 km.

Output Points and Source Points

Twenty-two coastal points, twenty-two forecast points and one tide gauge station were considered as the output points that were set up near the coast. A minimum depth was fixed to 1 m for the coastal points and one tide gauge station. The forecast points were fixed at 10-minute ≈ 18.5 km away from the coast. The output points are shown in Figure 1 with contours of depth.

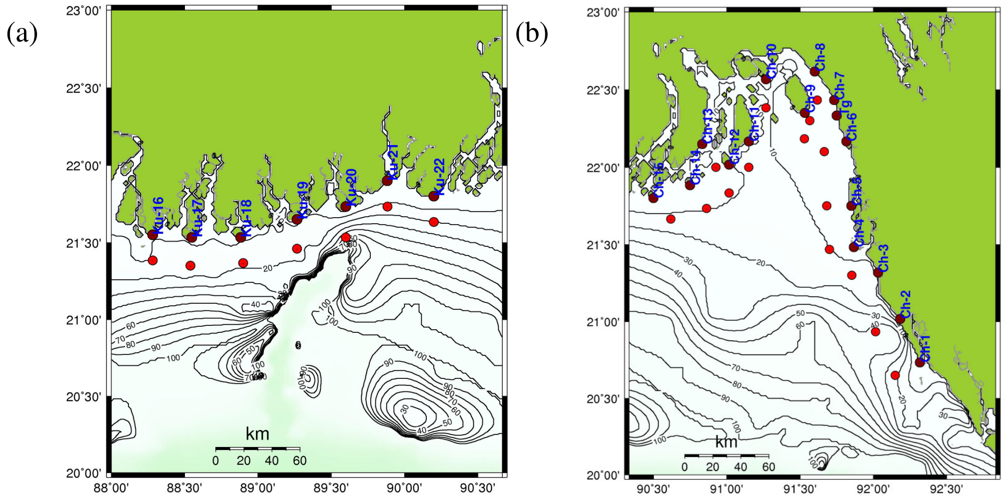


Figure 1. Bathymetry depth contour map near Bangladesh coast. Red circles and Maroon circles indicate forecast points and coastal points, respectively.

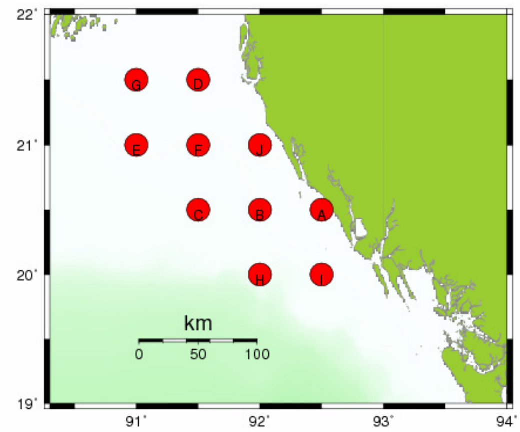


Figure 2. Location of source points.

The source points were set up near and parallel to the trench. It was fixed according to grid size (thirty-minute interval). Red circles in Figure 2 represent source points. The total number of source points is ten.

Fault Parameter and Seafloor Deformation

Fault parameters, length, width, and displacement were calculated by using scaling law (Tatehata, 1997) as a function of magnitude. The strike of 320º is set, which is parallel to the trench, considering that most of the earthquakes happen along the trench; the dip angle is 45º, slip angle is 90º and number of fault segment is one. The dip and slip angle are set at these values because it is the worst-case scenario of tsunami. The location of the hypocenter is assumed to be in the middle of the fault plane.

The depth of top left corner (TLC) of each fault was used as the input depth in order to compute tsunami simulation.

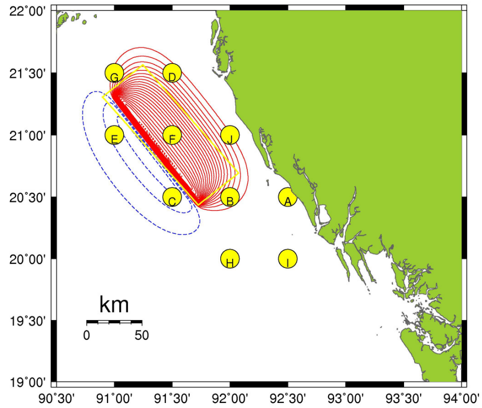


Figure 3. Vertical displacement of the seafloor.

The seafloor deformation due to fault was calculated by Okada's formulas (Okada, 1985), using the fault parameters. The vertical deformation of the sea bottom was used as the initial condition for the numerical tsunami simulation. The initial size of tsunami depends on the amount of vertical seafloor displacement. It is determined by the magnitude of earthquake, depth and fault plane mechanism. Figure 3 represents deformation area of source point F for magnitude of 8.0. The red contours denote uplift with the contour interval of 0.1 m, while the blue contours denote subsidence with the contour interval of 0.1 m.

Numerical Tsunami Simulation

TUNAMI-N2 code is applicable in order to compute a tsunami propagation. The simulation program (e.g. Fujii, 2008a) is carried out considering the bottom friction and using the non-linear term. The area of computation is determined by considering the source points and coastal points. The area is 15º N to 23ºN and 85ºE to 95ºE. The number of grid points is 601 and 481 in x and y direction, respectively. The calculation time is set to12 hours for the area. The time step is set to 3 s. Number of time steps for snapshots is 200 (10 min). Tsunami heights at the coast are calculated by using Green's law from tsunami heights at the forecast points.

Inverse Refraction Diagram

Refraction diagrams were used to calculate the tsunami travel times by using TTT (e.g. Fujii, 2008b). TTT originally developed by Paul Wessel, Geoware and modified by UNESCO (TTT Software Package).

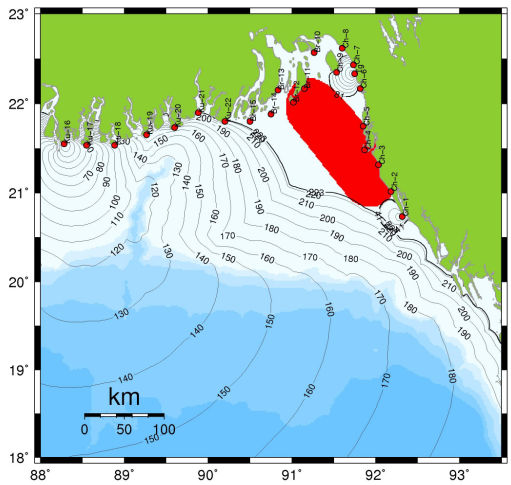


Figure 4. Inverse refraction diagram.

Refraction diagram can be drawn backwards from the coast. Such a diagram is called inverse refraction diagram and is sometimes used to estimate the tsunami source area. It is prepared to calculate inverse travel times of tsunami from the coastal points to the source. The grid points that have absolute values greater than 0.04 m are considered as the source points inside the seafloor deformation area. The red color of Figure 4 indicates the grid points. Light black curves are the travel time arcs computed for three-output points. Red area indicates assumed tsunami source. The contour interval is ten minutes. The difference between any two contour lines of inverse refraction diagram indicates that tsunami wave velocity is dependent on water depth.

RESULT AND DISCUSSION

The results of tsunami simulation (tsunami heights and tsunami travel times at the output points) are stored first into Excel sheets in order to make a database.

Tsunami Heights

The simulation results are represented in Figure 5 for checking. One is tsunami height versus magnitude with constant depth and another one is tsunami height versus depth with fixed magnitude.

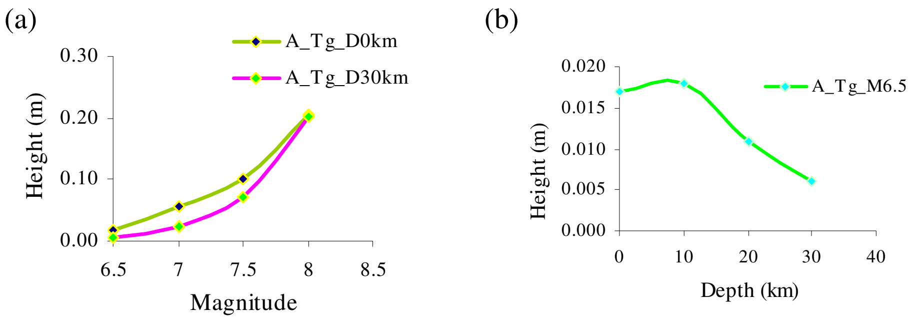
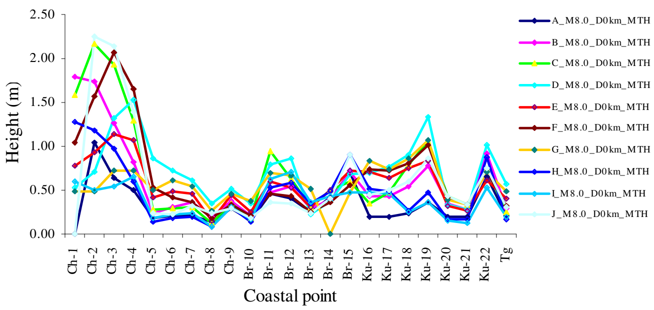


Figure 5. (a) Magnitude versus tsunami height with constant depth.
(b) Depth of fault center versus tsunami height with fixed magnitude.
A: source point, Tg: tide gauge station, D: depth, and M: magnitude.

Figure 5(a) shows that as the magnitude increases the tsunami height also increases. Figure 5(b) shows that as the depth increases the tsunami height decreases. Simulation results are checked for all cases and all coastal points. Then we found that big magnitude together with shallow earthquake produces large tsunami.

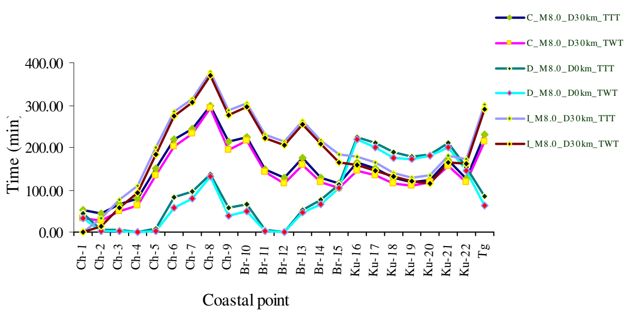


According to the simulation results, tsunami amplitudes become the maximum at the coastal points that are closer to the source and tsunami amplitudes become the minimum at the coastal points, which are far from the source. Depending upon magnitude, depth and location of source, Figure 6 shows that the tsunami heights along the coast are different.

Figure 6. Tsunami heights against the coastal points for different tsunami sources with the same magnitude and depth.

Comparison between Tsunami Travel Times from Tsunami Waveforms and TTT

Depending upon different source points with the same magnitude M_w 8.0 and depths (0 and 30 km), Figure 7 shows the comparison between tsunami travel times from tsunami waveform's times and tsunami travel times calculated by using TTT software.



The tsunami travel times are almost similar for the same case. Tsunami travel times are difficult to detect from the first small change of waveforms at the coastal points.

Figure 7. Comparison between tsunami travel times using waveforms and TTT against 22 coastal points and one tide gauge station.

Tsunami Heights with Green's Law

GEBCO, one arc minute data, is not good enough to calculate accurate tsunami heights along the coast. The Green's Law, energy conservation law along the ray (Satake, 2008), is needed to obtain the reliable tsunami heights along the coast from the forecast points at the sea. Tsunami heights at the coast (H_1) are calculated by tsunami amplitudes at the forecast points (H) multiplied by the fourth root of the sea depth ratios at the forecast points (h) and at the coastal points (h_1). The sea depth at the coast (h_1) is assumed 1 m. Hence, tsunami heights along the coast becomes,

$$H_1 = \sqrt[4]{h}\,H \qquad (1)$$

Depending upon different source points with the same magnitude and depth, the tsunami heights calculated by applying Green's Law are shown in Figure 8.

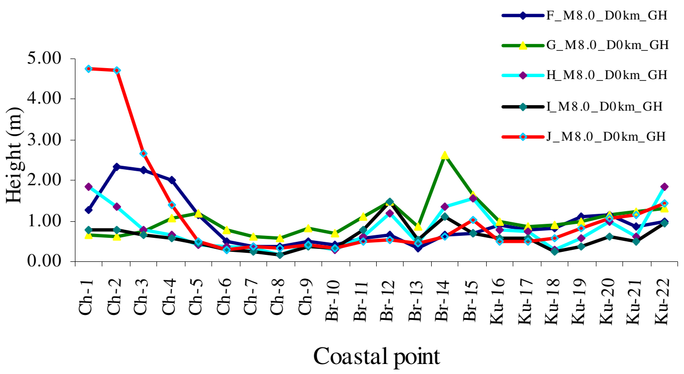


Figure 8. Tsunami heights with Green's Law for different tsunami sources with the same magnitude and depth.

The maximum tsunami height with Green's Law against the coastal point (ch-1) is estimated 4.8 m. This coastal point shows the highest tsunami height with Green's Law as it is closest to the tsunami source.

Finer Grid Computation

Twenty arc second grid intervals (~ 616.67 m) of bathymetry data are applicable to compute the tsunami simulation for the same area. The twenty arc second grid intervals of bathymetry data are re-sampled from GEBCO one arc minute grid data. The number of grid points is 1801 and 1441 in x and y direction, respectively. The time step is set to 2 s. Number of time steps for snapshots is 300 (10 min). Figure 9 shows that tsunami heights for the twenty arc second grid interval are little higher than those for the one arc minute grid interval, because the grid size is smaller. Finer grid computation can express shorter wavelength of tsunami than coarser one. The black curve denotes tsunami heights against coastal points for the twenty arc second grid interval; the green curve denotes tsunami heights against coastal points for the one arc minute grid interval.

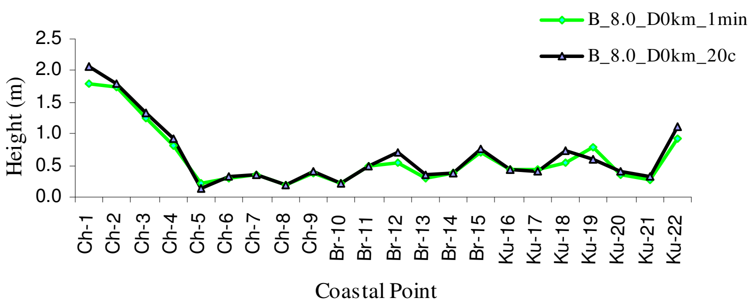


Figure 9. Comparison of tsunami heights for twenty arc second grid interval and one arc minute grid interval.

The simulation time required for the twenty arc second grid interval is four hours for each case. Meanwhile the simulation time required for the one arc minute grid interval is twenty-one minutes for each case. The computation with the one arc minute grid interval of bathymetry data and Green's Law were useful to save time of about 474 hours.

DATABASE

MySQL Database

Simulations data is put into a MySQL database by using some MySQL commands. The simulation result is divided into two tables under the name of "BMD_tsunami" main table, that is, "Hyp_Ruhul" table and "Simudata". "Hyp_Ruhul" table contains all information regarding hypocenter parameters as latitude (º), longitude (º), depth (km), magnitude, slip (cm), length (km), width (km), strike (º), dip (º), rake (º) and vertical displacement (m). Output points together with simulation results are stored at the "Simudata" table. "Simudata" table contains the number of output points, name of output points, longitude (º), latitude (º), depth (m), tsunami travel time (min), travel time of maximum tsunami heights, maximum tsunami heights (m), Green's heights (m), FILE_NAME.

The method of database system used in this study is important in order to issue tsunami warning. The numerical simulation takes a long time, if we ran the simulation after the occurrence of an earthquake, tsunami would arrive at the coasts before tsunami warning is announced.

CONCLUSION

In this study, a prototype tsunami database in Bangladesh is created. Simulation results are stored into the MySQL database. When an earthquake occurs, the tsunami heights and tsunami travel times along the coastal area will be obtained by interpolation of the data using the location of epicenter, magnitude and depth from the database for the information of tsunami warning.

According to the analysis of simulation results, it is found that big magnitude together with shallow earthquake produces large tsunami. The coastal points, which are more far in distance from the source, have the smallest tsunami heights and take the longest tsunami travel times. On the other hand, the tsunami sources nearest to the coastal area cause higher tsunami heights. Tsunami heights computed for the finer grids (20 arc second grid) are slightly higher than that for the one arc minute grids against the same coastal points because the grid size is smaller. Finer grid computation can express shorter wavelength of tsunami than coarser one.

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