TSUNAMI SIMULATION AND HAZARD ASSESSMENT ON THE BANGLADESH COAST

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ABSTRACT

The study was aimed to assess tsunami hazard on the Bangladesh coast, particularly to estimate tsunami heights as well as tsunami arrival times considering three tsunami source models. The 2004 Sumatra earthquake (M_w 9.1) source and several scenario earthquakes with M_w 8.0 and M_w 8.5 were considered along the pre-assumed trench. For Sumatra case fault parameters were used similarly to a very recent study. For scenario earthquakes with M_w 8.0 and M_w 8.5, 10 (Case1 – Case10) and 6 (Case01 – Case06) tsunami sources were considered, respectively, where tsunami source parameters for a rectangular fault model and slip amount were estimated for each case using scaling laws. It was found for the 2004 Sumatra case that tsunami arrived first after the earthquake within 2.2 hours with the maximum height of 31 cm at St. Martin Island. For scenario earthquakes, case9 and case05 where sources exist nearby the coast of Cox'sbazar were identified as the most severe cases with M_w 8.0 and M_w 8.5, respectively. Tsunami arrived within several tens of minutes after the earthquake with the maximum height of 110 cm and 184 cm for the case9 and case05, respectively, at the coast of Cox'sbazar. Case8-case10 of scenario earthquakes with M_w 8.0 and case05-case06 of scenario earthquakes with M_w 8.5 may appear as threat to local tsunami at Meghna estuarine-Chittagong-Cox'sbazar cost of Bangladesh in future.

Keywords: Tsunami Source Model, Tsunami Simulation, Tsunami Height, Travel Time

INTRODUCTION

Considering the potential seismic sources and high density of population (741/sqkm) with more than 70 percent vulnerable population, the coastal belt of Bangladesh can be identified as susceptible risk areas for tsunami. In fact, the coastal belts lacking all sorts of physical and non- physical measures to withstand the tsunami devastation, in case of future occurrence of tsunami in Indian Ocean, might create more devastation. It is well known that Bangladesh narrowly escaped from the 2004 Sumatra Tsunami. This escape was only for the some reasons, so far identified. Though the 2004 Sumatra Tsunami did not affect Bangladesh directly, it fits with nation's vision of comprehensive disaster management especially in tsunami hazard mitigation.

Objectives of the Study

Infrequent occurrence of tsunamis in the Bay of Bengal kept the geoscientists of this region almost unconcerned about the potentiality of tsunami hazard. There are some evidences of Paleo-Tsunamis and low height tsunamis (Aung et al., 2006). So far evidences of devastating tsunamis are not available but threats of tsunamis in the coastal belt of the country cannot be ruled out. The study addressed tsunami hazard assessment with the following objectives:

- Compute tsunami propagation numerically to obtain tsunami wave forms, and travel time;
- Analyse tsunami waveforms in terms of tsunami heights and tsunami arrival times to investigate the tsunami threats at Bangladesh coast.

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METHODOLOGY OF THE STUDY

Data Source and Collection

Tide Gage Stations and Bathymetry data

Tsunami propagation was calculated at 39 tide gauge stations as outpoints along the Bangladesh coast (Figure 1). Out of 39 stations 33 are assumed at front face of sea using Google Earth and GMT (Generic Mapping Tools) and 6 are operated by Bangladesh Inland Water Transport Authority (BIWTA). The stations operated by BIWTA demanded very minor correction of locations due to bathymetry grid resolution during preparation of location data on bathymetry grid using GMT. GEBCO bathymetry data which is available in the internet (www.ngdc.noaa.gov/mgg/gebco) is used in this study. This is 1 arc-minute grid size data digitized from contour map.

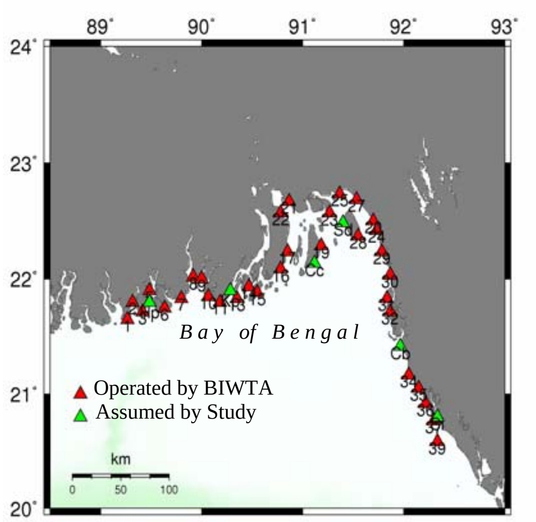

Figure 1 Tide Gauge Stations as Outpoints at Bangladesh Coast.

Data Processing and Analysis

Tsunami Source Model

The extent, geometry and slip distribution of a fault rupture and other parameters of a fault play important roles in tsunami generation. It is envisaged that a tsunamigenic earthquake would be of magnitudes 8.0 and greater, however, local tsunami may occur with magnitudes 7.0-8.0 provided necessary conditions are fulfilled (Khan, 2005). A recent study also predicts that a major earthquake of M_w 8.5 may occur every century on this segment of the subduction (Socquet et al., 2006).

Due to lack of historical data and previous study of the area, in this study, the 2004 Sumatra earthquake source and several scenario earthquakes (Figure 2, 3) sources are considered from Bangladesh coast to north Andaman Island along the pre-assumed Arakan trench alignment (Socquet et al., 2006; Nielsen et al., 2004) to estimate the extent of tsunami source and slip distribution. For Sumatra case, the geometry of each subfault, slip amount and other fault parameters are used similarly to the study by Fujii and Satake (2007) where tsunami source is divided into 22 subfaults covering the aftershock area for a day after the mainshock. For scenario earthquakes with M_w 8.0 and M_w 8.5, 10 and 6 tsunami sources were considered respectively. Tsunami source parameters for a rectangular fault model (Okada, 1985) and slip amount (Table 1, 2) were estimated for each case using scaling laws based on the Okal's (2006) equations. The depths and dip angles are assumed to be 3 km and 10° respectively, for all the cases. Strike angles are based on pre-assumed trench alignment (Socquet et al., 2006) and rake angles (slip) are based on the averaged compressional axis direction.

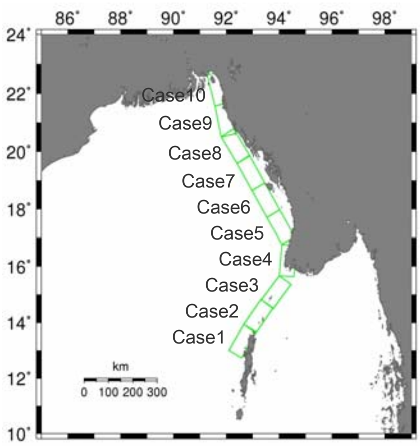

Figure 2 Tsunami Source Models (M_w 8.0).

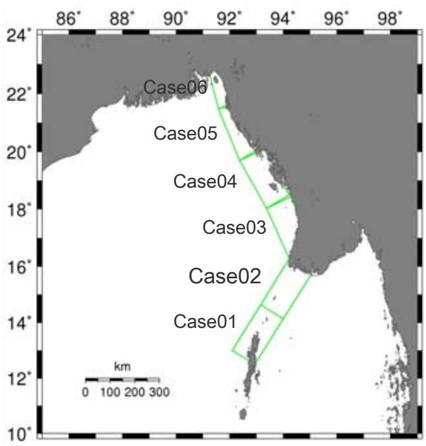

Figure 3 Tsunami Source Models (M_w 8.5).

Table 1 Tsunami Source Parameters for Scenario Earthquakes (M_w 8.0)

Case No.	Length (km)	Width (km)	Depth (km)	Strike (°)	Dip (°)	Rake (°)	Longitude (°)	Latitude (°)	Slip (m)
Case1	120.22	60.11	3	30	10	160	92.100	13.000	3.48
Case2	120.22	60.11	3	36	10	166	92.664	13.941	3.48
Case3	120.22	60.11	3	37	10	167	93.328	14.820	3.48
Case4	120.22	60.11	3	5	10	154	94.007	15.688	3.48
Case5	120.22	60.11	3	330	10	120	94.105	16.770	3.48
Case6	120.22	60.11	3	330	10	120	93.539	17.710	3.48
Case7	120.22	60.11	3	330	10	120	92.973	18.650	3.48
Case8	120.22	60.11	3	328	10	118	92.407	19.590	3.48
Case9	120.22	60.11	3	348	10	130	91.808	20.511	3.48
Case10	120.22	60.11	3	345	10	127	91.572	21.573	3.48

Table 2 Tsunami Source Parameters for Scenario Earthquakes (M_w 8.5)

Case No.	Length (km)	Width (km)	Depth (km)	Strike (°)	Dip (°)	Rake (°)	Longitude (°)	Latitude (°)	Slip (m)
Case01	213.79	106.89	3	32	10	160	92.100	13.000	6.19
Case02	213.79	106.89	3	32	10	160	93.164	14.639	6.19
Case03	213.79	106.89	3	335	10	120	94.228	16.278	6.19
Case04	213.79	106.89	3	330	10	115	93.377	18.028	6.19
Case05	213.79	106.89	3	337	10	125	92.371	19.700	6.19
Case06	213.79	106.89	3	345	10	127	91.584	21.478	6.19

Latitudes, Longitudes and Depths indicate the left bottom corner of each fault of scenario case.

Computational Domain

The 1min grid spacing computational domain is derived from the 1min GEBCO bathymetry extending from 0° - 24° North in latitude and 82° - 100° East in longitude for the Sumatra case and from 10° - 24° North in latitude and 85° - 99° East in longitude for the scenario earthquakes in all cases (Figure 2, 3). There are 1441×1081 and 841×841 grid points for Sumatra case and scenario cases (M_w 8.0 and 8.5) along the latitude and longitude directions respectively. A time step of 0.5 sec is used to satisfy the stability condition. Total number of time steps is 72,000 for computation (10 hours).

Tsunami Simulation

Tsunami propagations were simulated with a view to obtain tsunami waveforms and tsunami travel times at coast for all the cases. To calculate tsunami propagation initiated at each case, the nonlinear shallow water long wave equations were numerically solved by the TUNAMI code (TUNAMI-N2) developed by Disaster Control Research Center of Tohoku University, Japan. For the initial condition, static deformation of the sea floor is calculated using the three source models' parameters for all the cases (Figure 4).

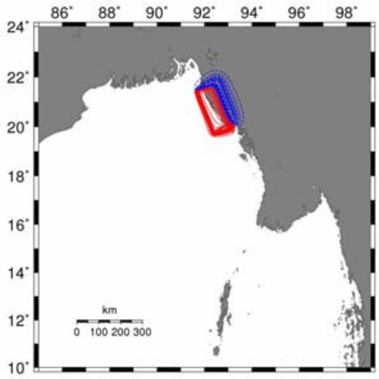

Figure 4 Sea Floor Deformation for Case05 of Scenario EQs (M_w 8.5).

Travel Time Calculation

Tsunami travel time was calculated both from waveforms for the most severe cases of scenario earthquakes including Sumatra case and by TTT for all the cases of scenario earthquakes. In order to calculate tsunami travel times using TTT software developed by Geoware, inverse refraction diagram was prepared for each outpoints. The grid points which have absolute value of greater than 0.1 m are considered as the source points inside the seafloor deformation area. Then using the source points, tsunami travel times are extracted from inverse refraction diagram for each outpoint. Finally, the minimum values are taken as the tsunami travel times for each outpoint.

RESULTS AND DISCUSSIONS

Maximum Tsunami Heights

2004 Sumatra Earthquake (M_w 9.1)

Figure 5 shows that for this devastating event, maximum tsunami height was limited only in the south-east and western part of the coast of Bangladesh. Tsunami height rose over 20 cm only at 6 outpoints where maximum tsunami height was 31 cm. Because of lack of the observation data, it is quite difficult to compare the results obtained for this study. However, this result is very similar to the eyewitness which was 25-30 cm as published in the media and mentioned in the several national dialogues.

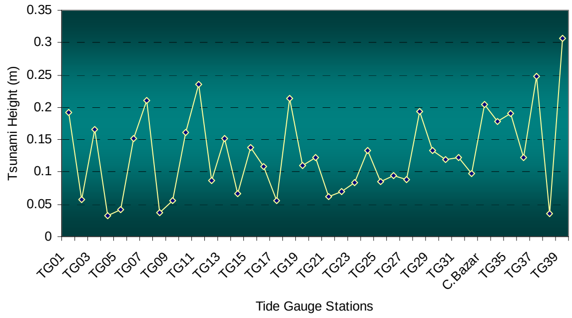

Figure 5 Maximum Tsunami Height at 39 Outpoints for Sumatra Earthquake (M_w 9.1).

Scenario Earthquakes (M_w 8.0)

Figure 6 shows the tsunami height at 39 outpoints for 10 cases of scenario earthquakes with M_w 8.0. Case9 is the most severe case for which maximum tsunami height rose 1.1 m according to the waveform data. Tsunami height rose bellow than 20 cm in the Meghna Estuarine Coastal Belt (TG20-27) for all the cases except case10 (Figure 6). For case10 tsunami height rose over 80 cm. Tsunami height varied at some adjacent outpoints in the western part of the coast probably due to location far from the coast. Only 4 sources (case7-10) may appear as threat to local tsunami at Bangladesh coast for which tsunami height has risen over 50 cm at maximum.

Scenario Earthquakes (M_w 8.5)

Figure 7 shows the tsunami height at 39 outpoints for 6 cases of scenario earthquakes with M_w 8.5. Case05 is the most severe case for which maximum tsunami height rose 1.84 m according to the waveforms. Tsunami height rose bellow 40 cm in the Meghna Estuarine and Chittagong Coastal Belt (TG20-31) for all the cases except case06 (over 130cm). Out of 6 sources 4 sources (case03-06) may appear as threat to local tsunami at Bangladesh coast for which tsunami height has risen maximum over 50 cm.

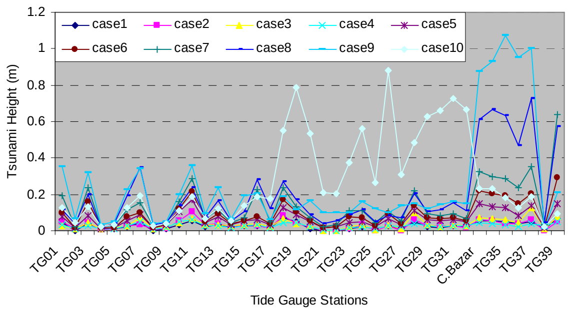

Figure 6 Maximum Tsunami Heights at 39 Outpoints for 10 cases of Scenario Earthquakes (M_w 8.0).

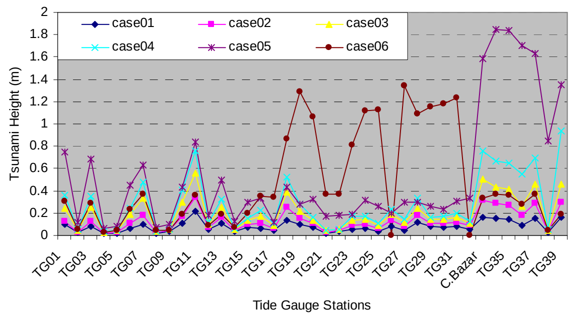

Figure 7 Maximum Tsunami Heights at 39 Outpoints for 6 cases of Scenario Earthquakes (M_w 8.5).

Tsunami Travel Times at Coast

Tsunami travel times were obtained at 39 outpoints along the Bangladesh coast for the 2004 Sumatra earthquake with M_w 9.1 and scenario earthquakes with M_w 8.0 (10 cases) and M_w 8.5 (6 cases). In order to calculate travel time it was compared with the result calculated by TTT and those obtained from waveforms at first for the most severe cases. It is found that travel times are almost the same between the both methods. Sometimes, it is also quite confusing and time consuming to obtain travel time using waveforms. Therefore, tsunami travel times were calculated by TTT for all the cases of scenario earthquakes with M_w 8.0 and M_w 8.5 except Sumatra case. For Sumatra case, travel time is obtained from tsunami waveforms.

2004 Sumatra Earthquake (M_w 9.1)

Tsunami arrived first at St. Martin Island (TG39) southernmost part of Bangladesh coast within 2.2 hours after the occurrence of earthquake. In the southern part of the coast- near cox'sbazar (TG33-37) tsunami arrived approximately within 2.5 hours and in the western part of the coast- near Sundarban (TG01, TG03) tsunami reached within 3.0 hours after the Sumatra earthquake (Figure 8). Tsunami arrived earlier in the southern and western part than the Meghna estuarine coast line (TG21-30) of the coast of Bangladesh. In the Meghna estuarine coast line tsunami arrived more than 6 hours after the earthquake.

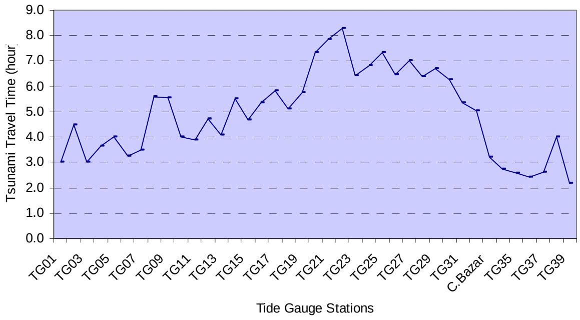

Figure 8 Tsunami Travel Times at 39 Outpoints along the Bangladesh Coast for Sumatra Earthquake (M_w 9.1).

Scenario Earthquakes (M_w 8.0)

Tsunami arrives spending no time at Bangladesh coast for 3 sources (Case8-10) specifically in the eastern part of Meghna estuarine and Chittagong coast line (TG20, TG23-32) for Case10, and in the Cox'sbazar-Teknaf coast line (TG32-39) for Case7 and Case8 (Figure 9). In general tsunami reaches earlier in the western part of coast- near Sundarban (TG01-07) and in the south-eastern part of coast- along cox'sbazar coast line (TG34-37, TG39) approximately 2.0-3.5 hours and 1.5-3.0 hours respectively than Meghna estuarine and Chittagong coastline (TG20-30) after the earthquake. In the Meghna estuarine and Chittagong coast line tsunami arrived 5.0-7.5 hours after the earthquake.

Scenario Earthquakes (M_w 8.5)

Tsunami arrives spending no time at Bangladesh coast for 2 sources (Case05-06) specifically in the eastern part of Meghna estuarine and Chittagong-Cox'sbazar coast line (TG20, TG23-34) for Case06, and in the Cox'sbazar-Teknaf coast line (TG30-39) for Case05 (Figure 10). In general, tsunami reaches earlier the western part of coast- near Sundarban (TG01-08) and the south-eastern part of coast- along cox'sbazar coast line (TG34-37, TG39) approximately 2.0-3.5 hours and 1.0-3.0 hours respectively than Meghna estuarine and Chittagong coastline (TG19-32) after the earthquake. In the Meghna estuarine and Chittagong coast line tsunami arrived approximately 4.0-7.0 hours after the earthquake except case05 and case06.

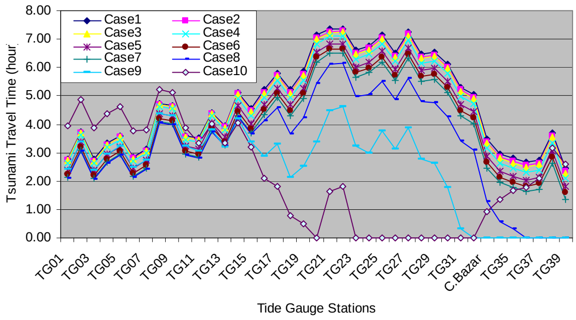

Figure 9 Tsunami Travel Times at 39 Outpoints for 10 Cases of Scenario EQs (M_w 8.0).

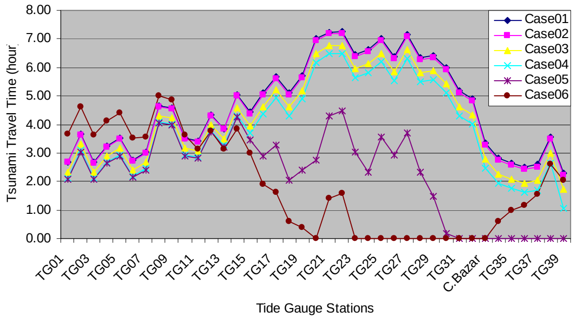

Figure 10 Tsunami Travel Times at 39 Outpoints along the Bangladesh Coast for 6 Cases of Scenario EQs (M_w 8.5).

CONCLUSION

In this study three source models were considered, mainly, the 2004 Sumatra tsunami source, scenario earthquakes with M_w 8.0 sources (10 cases) and M_w 8.5 sources (6 cases) from Bangladesh coast to Andaman Island along the assumed trench axis to assess the tsunami hazard on Bangladesh coast.

Tsunami height rose highest 0.31 m for Sumatra case, 1.1 m for case9 and 1.84 m for case05 of scenario earthquakes with M_w 8.0 and M_w 8.5, respectively. The maximum tsunami height rose over 50 cm for case7-10 and case03-06 of scenario earthquakes with M_w 8.0 and M_w 8.5, respectively. The area with the maximum tsunami height of over 50 cm was limited along the Cox'sbazar-Chittagong, the Meghna estuarine, and in the western part of the coast. It can be mentioned here that the limitations were due to existence of tsunami source nearby the area and the direction of principal tsunami from the source.

Tsunami first arrived within 2.2 hours after the earthquake at St. Martin Island for Sumatra case, spending no time for 3 sources (Case8-9) and 2 sources (Case05-06) of scenario earthquakes with M_w 8.0 and M_w 8.5 respectively. In general tsunami arrived earlier in the south and south-eastern part of the coast than western and Meghna estuarine part of the coast for most of the cases except case10 and case06 of scenario earthquakes with M_w 8.0 and 8.5, respectively. For those 2 cases tsunami arrived earlier spending no time at Meghna estuarine part than other part of the coast. It can be assumed that if earthquake takes place in future with M_w 8.0 or M_w 8.5 at the sources described before tsunami will not take time to reach Meghna estuarine, Chittagong and Cox'sbazar cost of Bangladesh.

Finally, considering the existence of Arakan trench, seismic gap and results of tsunami simulation it can be assumed that those sources (case8-9 and case05-06 of scenario earthquakes with M_w 8.0 and M_w 8.5, respectively) may appear as threat to local tsunami at Bangladesh coast in future. The residents of these coastal areas will not get enough time to take shelter and escape from the devastation of the first wave of local tsunami.

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