NEO-DETERMINISTIC STUDIES FOR SEISMIC HAZARD ASSESSMENT OF BANGLADESH

by

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Ishika Nawrin Chowdhury

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NOTATION

g	Acceleration due to gravity
M	Magnitude of earthquake
I	Intensity of earthquake
PGA	Peak Ground Acceleration
DGA	Design Ground Acceleration
v_{max}	Peak ground velocity
d_{max}	Peak ground displacement
v_s	Velocity of shear wave
v_p	Velocity of P-wave
Q_s	Quality Factor for shear wave
Q_p	Quality Factor for P-wave
ρ	Density of soil
R	Epicentral distance

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ABSTRACT

In this study, a seismic hazard map of Bangladesh has been prepared following neo-deterministic seismic hazard assessment (NDSHA) method. NDSHA is a deterministic approach based on the computation of synthetic seismograms. The input data consisted of structural models, seismogenic source zones, focal mechanisms and earthquake catalogues. There are many probabilistic hazard maps available for Bangladesh, including the seismic zoning map in Bangladesh National Building Code (BNBC). However this study focuses on preparing the seismic hazard map following neo-deterministic methods. With the knowledge of physical process of earthquake generation and wave propagation in anelastic media, realistic strong ground motion modeling was done. Synthetic seismograms at a frequency of 1 Hz were generated at a regular grid of 0.2°×0.2° by the modal summation technique. The ground motion parameters, expressed in terms of maximum displacement (d_{max}), maximum velocity (v_{max}), and peak ground acceleration (PGA), were extracted from the synthetic signals and mapped on a regular grid over the studied region. The NDSHA estimated values of PGA were compared with estimates of PGA values using different attenuation laws following both probabilistic (PSHA) and deterministic (DSHA) approach.

The NDSHA method in the present study estimated the PGA values of less seismically active zone of Bangladesh at south-west i.e. Khulna region, the central parts of the country including the capital city Dhaka, and the areas near the India –Bangladesh border region at north and north-east, and the values were found in the range of 0.01-0.1g, 0.1-0.2g and 0.2-0.63g respectively. The epicentral areas of the great Indian earthquake 1897 and Srimangal earthquake 1918 represented the maximum hazard with PGA values reaching 0.4–0.63g, exceeding the value of 0.36g as per updated BNBC. The peak displacement and velocity in the same region was estimated as 15–30 cm and 30–60 cms^{-1} respectively. Moreover, PGA values of the rupture areas of 1762 Arakan earthquake at Chittagong was found up to 0.3-0.4g surpassing the value of BNBC i.e. 0.28g.

Comparison of the results with probabilistic map having 2% probability of exceedence in 50 years (return period 2475 years) showed that, NDSHA estimated higher PGA values in seismically more active areas and lower values in areas with less ground shaking. As the NDSHA was found to estimate larger PGA values for south-east and north-east parts of the country exceeding the BNBC values by up to 1.43-1.75 times, to ensure public safety during a probable major earthquake hazard, the BNBC values for this region should be carefully revised again after critical evaluation.

CHAPTER 1

INTRODUCTION

1.1 General

Bengal basin containing the Ganga-Brahmaputra Delta is the largest river delta of the world and is vulnerable to natural hazards like earthquake. The collision of the Indian plate with the Eurasian plate is the cause of frequent earthquakes in the region comprising North-East India, Nepal, Bhutan, Myanmar and Bangladesh. The plates are converging mainly in two boundaries; the India-Eurasia plate boundary to the north and the India-Burma plate boundary to the east. So these subduction boundaries are surrounding Bangladesh on two sides i.e. north and north-east, thus raising the potential for high magnitude earthquakes. Historically Bangladesh has been affected by large earthquakes with magnitude 7.0 or greater; some of them had their epicenters within the country (e.g. 1885 Bengal earthquake, 1918 Srimangal earthquake). Absence of strong earthquakes affecting Bangladesh for more than 80 years has left the current generation unaware of the possibility of a strong earthquake. As a natural consequence, many buildings in the urban areas of Bangladesh are lacking earthquake resistant design. The effect may be further compounded by poor quality of materials and construction. Recurrence of similar earthquakes can therefore cause catastrophic consequences in densely populated urban areas of Bangladesh. Even moderate earthquakes close to the urban cities can cause great havoc. There is a general consensus among national and international experts about the possibility of a large magnitude earthquake occurring in the region any time, due to stress build up in fault systems caused by the northward movement of the Indian Plate. Therefore, assessment of seismic risk is a top priority for the country. Seismic hazard assessment is the first step for the risk assessment, and mitigation measures to be taken depending on the level of hazard estimated.

1.2 Background and Present State of the Problem

Standard seismic hazard assessment methods typically follow Probabilistic Seismic Hazard Assessment (PSHA) and Deterministic Seismic Hazard Assessment (DSHA) approaches. For Bangladesh most of the hazard assessment studies have been done following PSHA. Bangladesh National Building Code (BNBC), 1993 adopted a seismic zoning map dividing Bangladesh into three seismic zones (Ali and Choudhury 1994). Each zone is assigned with a seismic zone coefficient representing design peak ground acceleration (PGA) based on

Hattori's (1979) work. Since then there have been several studies on seismic hazard assessment of Bangladesh (GSHAP 1999; Ansary and Sharfuddin 2002; Noor et al. 2005; NDMA 2010; Al-Hussaini and Al-Noman 2010, Al-Hussaini et al. 2012). These studies followed the probabilistic seismic hazard assessment approach. The International Building Code (2009) has also used the probabilistic approach dependent on maps based on 2% probability of exceedence in 50 years. In its recent draft upgradation version of BNBC, it appears that different seismic design provisions including a new seismic zoning map has been proposed. However, similar probabilistic concept as before was used in determining the seismic design provisions.

According to Wyss et al. (2012), the Probabilistic Seismic Hazard Assessment (PSHA) has some shortcomings, most of which can be handled by the Deterministic Seismic Hazard Assessment (DSHA) especially where earthquake catalogue completeness is poor and strong earthquakes are expected. PSHA extrapolates the probability of maximum considered earthquake (MCE) from the annual frequency of small earthquake. But it may lead to underestimation of the seismic hazard risk in areas capable of large earthquakes. The DHSA is based on determining the ground motion at a particular site for an earthquake of fixed magnitude at a known fault. Neo-deterministic Seismic Hazard Assessment (NDSHA) has similar objectives as DSHA; however it is based on the physics of seismic wave propagation and employs numerical techniques to solve the wave propagation problem (Panza et al. 2001). Realistic synthetic seismograms can be constructed by the modal summation technique (Florsch et al. 1991) using the specialized computational program made available by the seismology group of Department of Mathematics and Geosciences, University of Trieste, Italy. From these synthetic signals engineering parameters can be extracted in order to assessing the seismic hazard. Maximum displacement, maximum velocity and peak ground acceleration for maximum credible earthquake (MCE) can be mapped over the region of the study. The Neo-Deterministic Seismic Hazard Assessment (NDSHA) has proved its efficiency in many parts of the world (Panza et al. 1999, 2002; Aoudia et al. 2000; Bus et al. 2000; Markusic et al. 2000, Zivcic et al. 2000, El-Sayed et al. 2001, Parvez et al. 2003; Zuccolo et al. 2011). Thus conducting earthquake hazard studies using NDSHA approach may yield useful information in assessing seismic hazards in the context of Bangladesh geology.

1.3 Objective of the Research

The present study principally constitutes seismic hazard assessment for Bangladesh using the concept of neo-deterministic study, and numerical techniques developed and made available by the seismology group of Department of Mathematics and Geosciences, University of Trieste, Italy. The main objectives of this study are:

i) Preparing an updated earthquake catalogue (up to 2015).

ii) Identification of the probable seismic source zones and the seismic activity parameters to each corresponding zone by extensive bibliographic study.

iii) Generating realistic synthetic seismograms using advanced computational techniques following Neo-Deterministic Seismic Hazard Assessment (NDSHA) method.

iv) Studying the effects of repeat scenario of historical earthquakes in selected major cities of Bangladesh using both NDSHA method and Deterministic Seismic Hazard Assessment (DSHA) method based on attenuation equations.

v) Preparing a national scale earthquake hazard map for Bangladesh adopting NDSHA procedures.

vi) Comparison of the NDSHA results with PSHA results and proposed seismic zoning map (updated BNBC) for Bangladesh.

1.4 Organization of the Thesis

The thesis includes five chapters. Introduction is presented in Chapter 1 that includes the background of the problem and objective of this study along with the thesis organization. Chapter 2 consists of literature review including the present and past state of seismic hazard assessment for Bangladesh. Chapter 3 introduces the methodology of neo-deterministic seismic hazard assessment. It also presents repeat scenario of some of the historical major earthquakes in and around Bangladesh and the results are compared with DSHA results. Chapter 4 describes in detail the preparation of a national scale seismic hazard map following NDSHA. The results are then compared with probabilistic maps for Bangladesh. The conclusions drawn from the seismic hazard analysis by this study are presented in Chapter 5, along with the recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The present study is mainly concerned with seismic hazard assessment for Bangladesh using the concept of neo-deterministic study. With a brief introduction to the earthquakes occurring in the region, this chapter reports the outcomes from different seismic hazard studies for Bangladesh done by other researchers, some of them done at local level while some done on a global scale. Systematic studies for seismic hazard and risk assessment specifically for Bangladesh have been conducted at a limited scale since early 1990's. This chapter also presents the results of some recent researches on active faults in and surrounding the country. Results from neo-deterministic seismic hazard studies conducted in recent years for different countries are also presented.

2.2 Earthquakes in Bangladesh

2.2.1 Historical Earthquakes

Historically Bangladesh has been affected by five earthquakes of large magnitude (M) greater than 7.0 (Richter scale) during the 61 year period from 1869 to 1930 (Table 2.1). Among them, the 8.1 magnitude 1897 Great Indian earthquake in Shillong, Assam had an epicentral distance of about 230 km from Dhaka. That powerful earthquake caused extensive damages to masonry buildings in many parts of Bangladesh including Dhaka. The 1885 Bengal earthquake (M 7.0, 170 km from Dhaka) and 1918 Srimangal earthquake (M 7.6, 150 km from Dhaka) had their epicenters within Bangladesh, they caused considerable damage locally. The 1762 Arakan earthquake, estimated magnitude M 8.5 (estimates vary depending on sources), although not well documented, is reported to have caused major land mass changes in the coastline from Myanmar to Chittagong. The epicenter is not well-constrained and likely locations vary from the Arakan coast to near Chittagong. Large earthquakes in this region have not been occurring for quite a long time (85 years) and significant stress buildup in the faults can lead to a major earthquake taking place.

Table 2.1 List of major historical earthquakes affecting Bangladesh

Date	Earthquake Name	Magnitude (Richter)	Epicentral distance from Dhaka (km)	Epicentral distance from Sylhet (km)	Epicentral distance from Chittagong (km)
2 April, 1762	Arakan	7.5-8.5*	-	-	**
10 Jan., 1869	Cachar	7.5	250	70	280
14 July, 1885	Bengal	7.0	170	220	350
12 June, 1897	Great Indian	8.1-8.35*	230	80	340
8 July, 1918	Srimangal	7.6	150	60	200
2 July, 1930	Dhubri	7.1	250	275	415

* Value varies depending on source

** Uncertain; close to south of Chittagong

2.2.2 Recent Earthquakes

During the last two decades, the occurrence and damage caused by a number of earthquakes (magnitude between 4 and 6) inside the country or near the country's border, more recently the occurrence of large earthquakes in Sikkim and Nepal has raised the awareness among the general people and the government. The damage has been mainly restricted to rural areas or towns near the epicenter, but there have been some instances of damage in urban areas 50 to 100 km away. An under-construction reinforced concrete frame building collapsed killing several people in the port city of Chittagong due to the November 21, 1997 magnitude 6.0 earthquake at Bangladesh-Myanmar border. This is a typical example of faulty design and construction, collapse occurring at a very low level of shaking, about 100 km from the epicenter of the earthquake. The July 22, 1999 magnitude 5.1 earthquake with its epicenter very near the island of Moheshkhali, caused extensive damage and collapse of rural mud-walled houses. Concrete column of a cyclone shelter was severely damaged. People reported hearing a loud noise (bang) immediately preceding the earthquake which is possible at locations close to the epicenter. Severe cracking damage to brick masonry buildings and severe damage to mud-walled houses were observed in Kolabunia, Barkal Upazilla due to July 27, 2003 magnitude 5.6 Barkal-Rangamati earthquake. Large crack developed for a long distance along the river, indicative of soil movement toward the river. In Chittagong city, about 90 km away from the epicenter, the earthquake caused ground settlement and cracks in the Public Library building and also damaged an electric transformer. The high frequency of earthquakes occurring in the Chittagong area has caused a good deal of anxiety among the people there.

Dhaka city, located in the central region of Bangladesh can be affected by large magnitude earthquakes occurring at a distance in the major fault zones. Another point of major concern is that there are active faults near the city also. This was realized during the December 19, 2001 magnitude 4.5 Dhaka earthquake that caused panic among many city residents. The epicenter was very close to Dhaka city. Frightened people in several high rise buildings rushed down the stairs, as they felt considerable shaking in the upper floors. In September 10, 2010 M 5.1 earthquake hit near Matlab which is about 60 km away from Dhaka city. The location and magnitude of a probable earthquake near Dhaka needs to be investigated. In recent large magnitude earthquakes have taken place several hundred kilometers from Dhaka, namely the 2011 M 6.9 Sikkim earthquake, 2015 M 7.8 Nepal earthquake, 2016 M 7.2 Myanmar earthquake. These earthquakes have caused long duration shaking in the capital city and created panic.

2.3 Active Faults

There have been numerous studies on the active faults in the north-east Indian region. This region is seismically active and has caused many major earthquakes (e.g. 1869 Cachar earthquake, 1897 Great Indian earthquake, 1950 Assam earthquake, 2011 Sikkim earthquake). The major faults in this region are identified in some publications. The Indian Plate is moving towards the north with slip rate of around 5 to 6 cm/year, and subducting under the Eurasian Plate. Large earthquakes were generated along the plate boundary under the compressive condition (Figure 2.1). The subduction fault on the eastern edge of the Indian Plate is partitioned into two fault system, the northern extension of the subduction fault and the Sagaing Fault System for a right-lateral fault, from off Sumatra. However, the historical earthquake along the northern extension of the subduction fault is inferred to be only the 1762 event and the recurrence period is about 900 years. The recurrence period is too long for subduction fault. Most of the strain along the plate boundary on the north of Sumatra may be consumed along the Sagaing Fault. Shillong Plateau is located in the north of Bangladesh and the E-W trending Dauki Fault goes through on the southern fringe of Shillong Plateau. The Dauki Fault may cross to the northern extension of the subduction fault in Sylhet.

Bangladesh has several seismic networks such as network of Geological Survey of Bangladesh (GSB), Dhaka University (DU), Bangladesh Meteorological Department (BMD), Bangladesh University of Engineering and Technology (BUET) etc. But their history is short. Some Bangladeshi researchers have summarized seismicity data using the data of India and world observatory. Recently under the Comprehensive Disaster Management Project (CDMP 2013), the active faults that are threatening for Bangladesh have been identified. They have used GPS data also from their recently installed network. Along with the main plate boundaries the following faults are also identified which are described below in accordance with the CDMP report 2013.

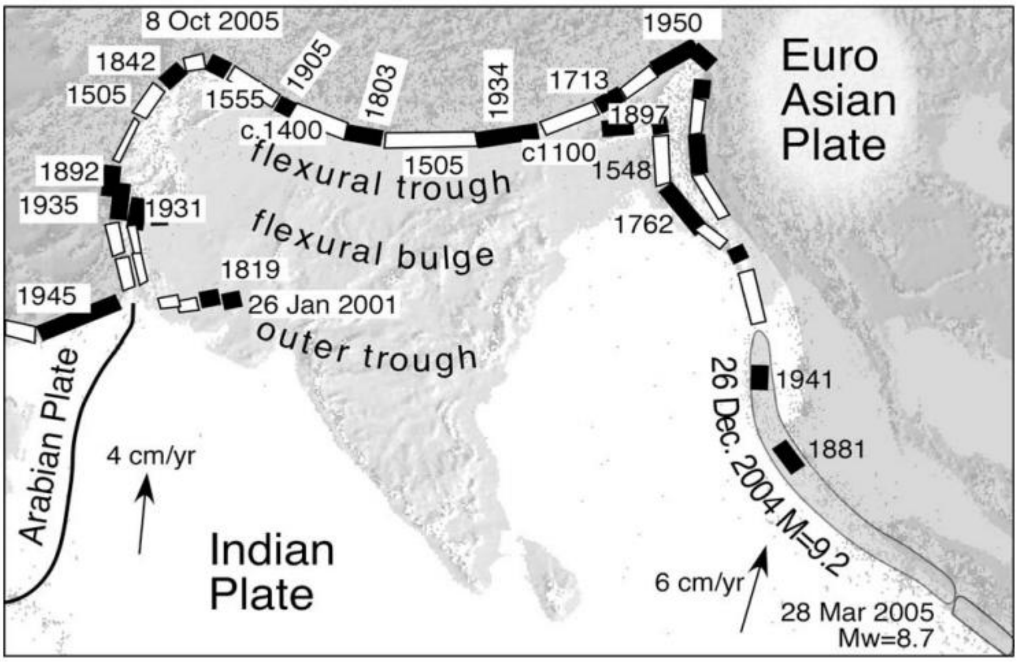


Figure 2.1 Historical Earthquakes along Indian and Eurasian Plate Boundary
(Bilham and Hough, 2006)

The Himalayan Front Fault as a mega-thrust is developed on the collision boundary between the Indian and Eurasian plates. The Shillong Plateau stands on the south of the Himalayan Front Fault, and the Dauki fault, which is a north-dipping reverse fault, passes on the southern margin of the Shillong Plateau. The Shillong Plateau is composed of bedrocks of the Indian shield, which was uplifted by the activity of the Dauki fault. The Dauki fault is thought to be an active fault related to the collision boundary. Its strike is parallel to the Himalayan Front Fault and it is an intra-plate active fault.

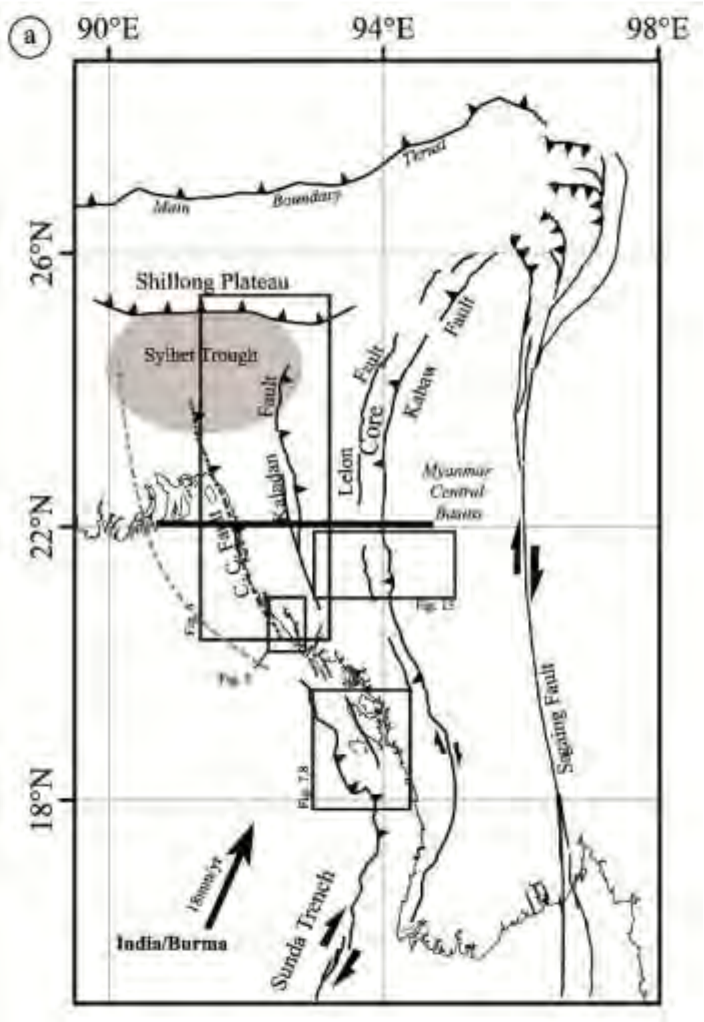


Figure 2.2 Fault map after Maurin and Rangin (2009)

The slip partitioning is inferred on the eastern margin of the Indian plate due to its oblique convergence to the Eurasian plate. The mega-thrust along the subduction zone and the Sagaing fault as a right lateral fault are developed on both the western and eastern sides of accretionary prisms, respectively. The N-S long region between these faults behaves as a micro plate and is called the Burman plate as a part of the Eurasian plate. The fold belt with the N-S axis is characteristic of the Burman plate. The western part of the accretionary prisms is younger and called Chittagong-Tripura Fold Belt (CTFB). The plate boundary fault from off Myanmar to off Chittagong is the northern extension of the rupture area which has caused the 2004 M 9.2 off Sumatra earthquake. The 1762 earthquake has occurred in this region (Steckler et al. 2008). It is thought that the plate boundary extends to the north of off Chittagong and it comprises a different segment from that of off Myanmar to off Chittagong, since this segment has not ruptured in 1762. The Tripura segment has a different faulting history and recurrence interval from the Arakan segment. The detailed location of the plate boundary fault in and around Bangladesh is in debate. Steckler et al. (2008) suggest that the Comilla Tract is an uplifted terrace, and the buried front of a mega-thrust reaches to the mouth of Padma River. Furthermore, the Madhupur blind fault is estimated to be the northwestern extension of the Tripura segment. Maurin and Rangin (2009) suggested that the Chittagong Coastal Fault is considered to be the plate boundary fault, which is a thick-skinned right lateral fault, on the western margin of the Chittagong-Tripura Fold Belt (CTFB), and the deformation front is inferred on the west of the Comilla Tract (Figure 2.2).

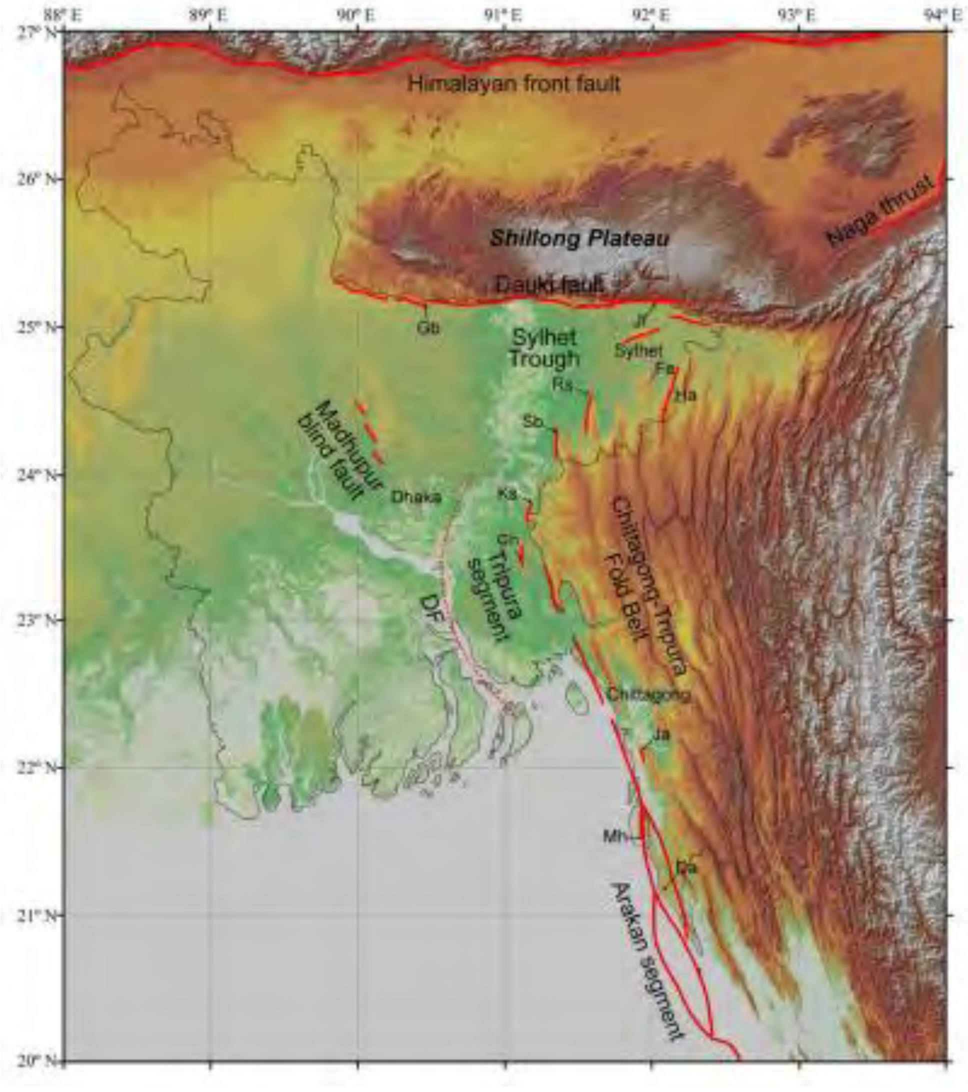


Figure 2.3 Active faults in and around Bangladesh: Gb: Gabrakhari, Jf: Jaflong, Fe: Fenchunganj, Ha: Hararganj. Rs: Rashidpur, Sb: Shahzibazar, Ks: Kasba, Ch: Comilla hill, Ja: Jaldi, Mh: Maheshkhali, Da: Dakshin Nila. The dashed line represents a deformation front (DF). (CDMP 2013)

Based on the tectonic-geomorphic investigation, it is suggested that the Tripura segment passes along the western margin of the CTFB, and the deformation front is located around the mouth of Padma River , since the deep seismic reflection survey is indicative of the deformation front more west (Maurin and Rangin 2009). The fault traces of the Tripura segment were suggested from the tectonic-geomorphic investigation. The fault traces of the Arakan segment was extracted from the Chittagong Coastal Fault after Maurin and Rangin (2009). The Comilla uplifted terrace is an interesting suggestion.

Figure 2.3 shows the active faults in and near Bangladesh presented in the CDMP report 2013. Most of active faults within Chittagong-Tripura Fold Belt (CTFB) is thought to be secondary faults and deformations related to the rupture of the Tripura segment. However, a part of these faults towards north may generate large earthquakes separately from the plate boundary fault like the 1918 Srimangal earthquake. However, it is difficult to separate active structures from the secondary structures.

2.4 Seismic Hazard Assessment Methods

Probabilistic seismic hazard assessment (PSHA) method determines the probability of exceeding various levels of ground motion over a specified period of time. PSHA steps start with the definition of earthquake sources. Sources might be fault sources or area sources within which earthquakes are assumed equally likely to occur at any location. Then the seismicity recurrence characteristics (e.g. seismicity rates) for each source are defined, assuming that earthquakes act independently. A recurrence relationship, or equivalently an earthquake probability distribution, indicates the chance of an earthquake of a given size to occur anywhere inside the source during a specified period of time, usually one year. A maximum magnitude is chosen for each source that represents the maximum event to be considered. After that comes the estimation, through the attenuation relationships, of the earthquake effects produced by earthquakes of different size occurring at different locations in each seismic source. Finally the hazard at a site is determined. The effects of all the earthquakes of different sizes occurring at different locations in different earthquake sources at different probabilities of occurrence are integrated into one curve that shows the probability of exceeding different levels of ground motion at the site during a specified period of time (Zuccolo 2009).

Another widely used method for seismic hazard assessment is the deterministic seismic hazard assessment (DSHA) method. A basic DSHA is a simple process and useful especially where tectonic features are active and well defined. Determining the maximum credible earthquake (MCE) motion at the site is the main focus of DSHA. The steps start with identifying nearby seismic source zones which can be specific faults or distributed sources. Distance to site for each source is then identified along with magnitude and other characteristics (i.e. fault length, recurrence interval) for each source. Then response parameter of interest is established for each source as a function of magnitude, distance, soil conditions, etc., using either the envelope or the average of several ground motion attenuation relationships. Values from each source are tabulated and the largest value is used. The DSHA tends to be conservative since the maximum earthquake the fault is capable of generating is assumed to occur at the location on the fault closest to the site. DSHA is frequently used in California due to the knowledge of faults and the region's high seismicity. When a distributed source is considered in the analysis, a distance must be determined. However, the DSHA does not account for the probability of an earthquake occurring on a fault.

Neo-deterministic method is a type of deterministic method but uses physics of wave propagation instead of attenuation relationships. The procedure for the neo-deterministic seismic zoning is based on the calculation of synthetic seismograms (earthquake scenarios). Starting from the available information on Earth structure, seismic sources, and the level of seismicity of the investigated area, it is possible to compute complete synthetic seismograms and the related estimates on peak ground acceleration (PGA), velocity and displacement. The detail steps of this method are presented in Chapter 4.

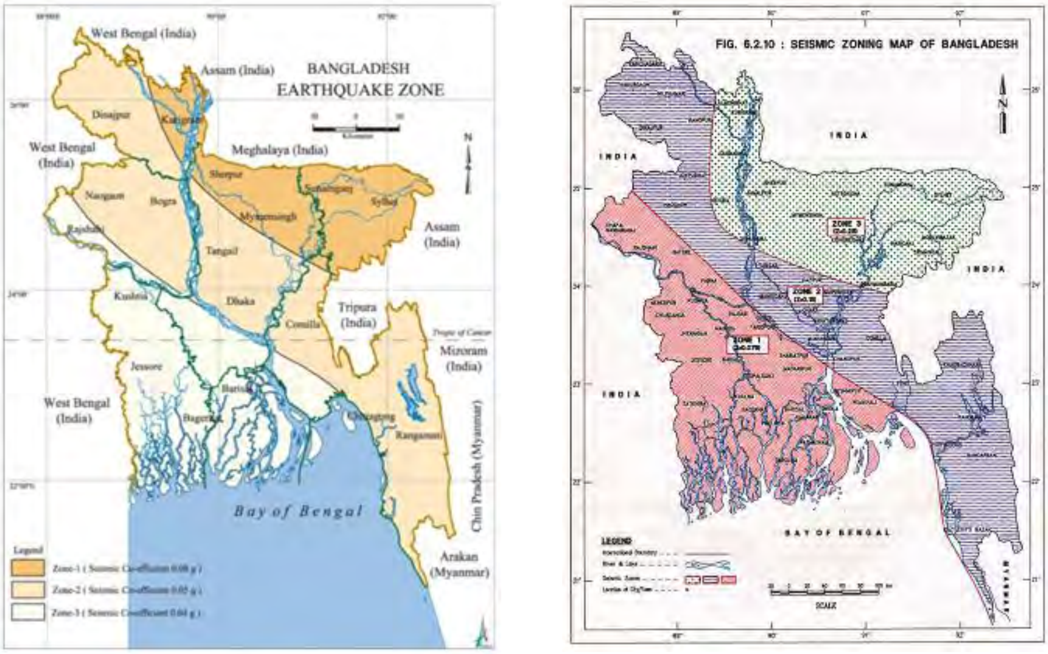
The basic differences between these three methods of seismic hazard assessment are summarized in Table 2.2.

Table 2.2 Difference between seismic hazard assessment methods
(source: Panza et al. 2008)

Procedure	**Probabilistic Method PSHA**	**Deterministic Method DSHA**	**Neo-Deterministic Method NDSHA**
Step 1	Seismic sources Identification of Seismogenic Zones and Capable Faults, Epicenters and Focal mechanism		
Step 2	Recurrence Rate	Fixed Magnitude Fixed Distance Choice of the Controlling Earthquake	Scenario Earthquakes – Fixed Magnitudes, Distances and specific Seismic Source properties. Choice of the Controlling Earthquake
Step 3	Attenuation Relations		Synthetic ground motions No need of Attenuation Relations
Step 4	Seismic hazard assessment in terms of *Probability of exceedance of a given ground motion measure*	Seismic hazard assessment in terms of *Fixed Ground Motion Measure*	Seismic hazard assessment in terms of *Envelopes of PGA or other Ground Motion Measure*

2.5 Probabilistic Seismic Hazard Assessment Studies for Bangladesh

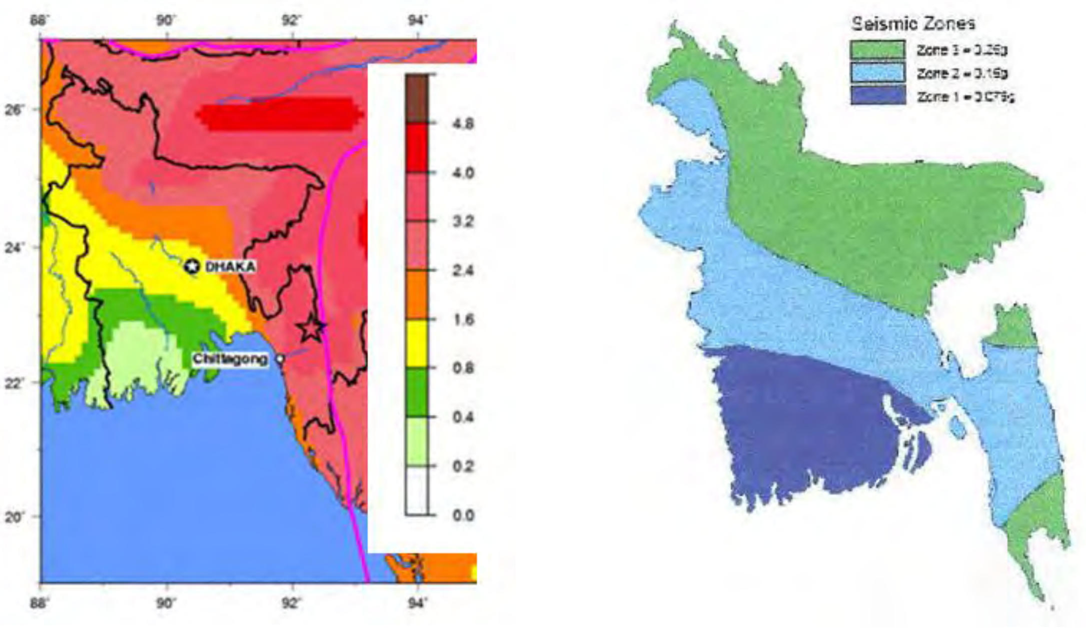
A chronological brief literature survey on published seismic hazard assessment studies conducted by other researchers at local and global level is presented here. The first official seismic hazard-zoning map in the country was published in 1979 for the Geological Survey of Bangladesh (GSB) prepared by a Committee of Experts on Earthquake Hazard Minimization. As shown in Figure 2.4a, it divides the country into three seismic zones with seismic co-efficients of $0.04g$, $0.05g$ and $0.08g$ (g is acceleration due to gravity), the north-east zone having the highest coefficient. In the process of development of the country's first building code (DDC 1993a), Kundu (1992) prepared an earthquake catalogue, based on data from Indian Society of Earthquake Technology (ISET) and US National Oceanic and Atmospheric Administration (NOAA). This catalogue was included in the supplementary report (DDC 1993b) to the 1993 Bangladesh National Building Code (BNBC). The Building Code adopted a revised seismic zoning map (Figure 2.4b) with three seismic zones (Ali and Choudhury 1994) with zone coefficients representing design peak ground acceleration (PGA) and seismic design procedures following Uniform Building Code ICBO 1991.



(a) (b)

Figure 2.4 (a) 1979 Seismic zoning map of Bangladesh, (b) Seismic zoning map in 1993 Bangladesh building code

These zoning coefficients are based on PGA values predicted by Hattori (1979) for a return period of 200 years. This work was done as part of global seismic hazard assessment for different regions by him. Zone 3 lies in the central north and north-east of the country (includes Sylhet, Mymensingh, Jamalpur, Bogra, Kurigram) representing a PGA of 0.25 g (Z=0.25). Next to Zone 3 is Zone 2 (which includes the major cities of Dhaka and Chittagong as well as Comilla, Rangpur, Dinajpur, Naogaon) and has a Z value of 0.15. Zone 1 in the southwestern part has a Z value of 0.075. Z represents design basis earthquake (DBE). Global Seismic Hazard Assessment Program (GSHAP) launched in 1992 by the international Lithosphere Program (ILP) performed standard probabilistic seismic hazard assessment works all over the world till 1999. Their predictions for PGA values for a return period of 475 years (10% probability of exceedance in 50 years) are shown in Figure 2.5a (USGS). Dhaka appears to have a PGA value of 0.13 g, Chittagong 0.24 g and Sylhet 0.34 g. Ansary and Sharfuddin (2002) formed an earthquake catalogue for the period 1865 to 1995 and used the data for seismic hazard assessment of Bangladesh. They proposed a modified seismic zoning map (Figure 2.5b) with significantly larger areas for Zone 3 and Zone 2, i.e., increased seismic hazard, based on results for return period of 200 years. Their seismic hazard estimation methodology was based on the assumption that the PGA at a site maintains a recurrence frequency relationship similar to the Gutenberg-Richter magnitude frequency relationship.



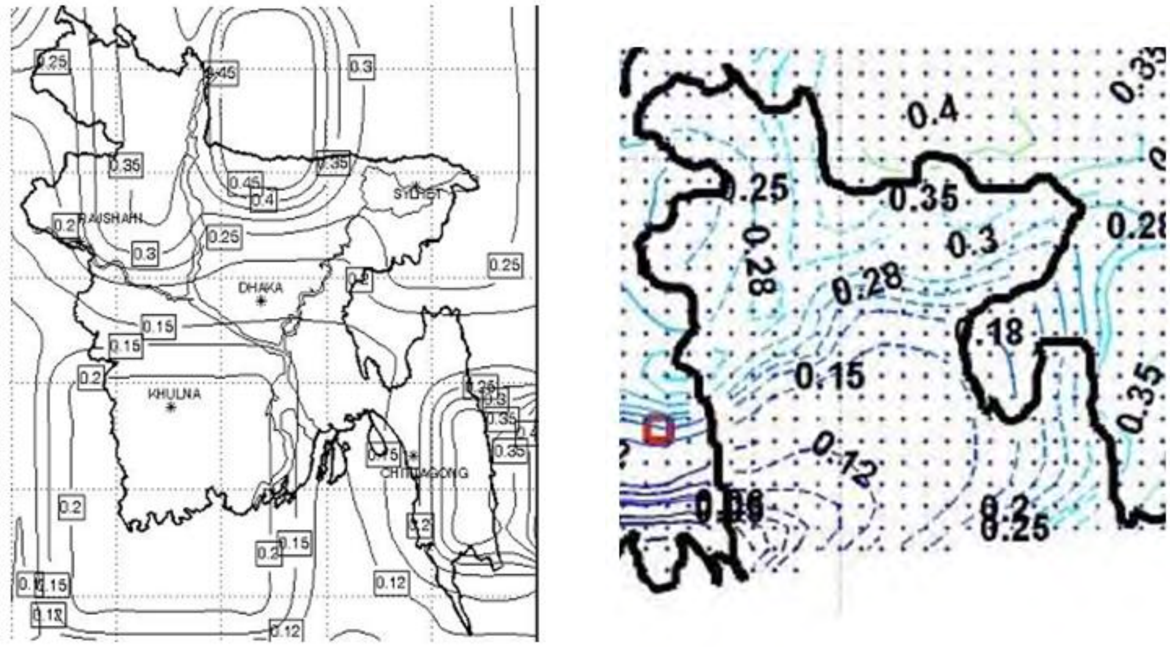
(a) (b)

Figure 2.5 (a) GSHAP Predicted PGA (m/s2) for return period of 475 years, (b) Proposed seismic zoning map (Ansary and Sharfuddin 2002) based on results for return period of 200 years

Noor et al. (2005) presented PSHA results considering rectangular NS oriented seismic sources. Figure 2.6a presents PGA values for a return period of 475 years. PGA value for Dhaka is around $0.17g$, Chittagong $0.2g$, Sylhet $0.27g$, Mymensingh $0.4g$. More recent standard PSHA studies at regional level has been conducted by the National Disaster Management Authority (NDMA), Govt. of India. Figure 2.6b present NDMA (2010) predicted PGA (in g) for return period of 2475 years. Comparison will be made later with more recent studies which has led to a revised seismic zoning map (Al-Hussaini et al. 2012) based on Maximum Considered Earthquake (MCE) and new seismic design criteria for Bangladesh.

More recently, standard probabilistic seismic hazard assessment method using multiple source zones has been applied (Al-Hussaini et al. 2012) for determining the PGA values for various return periods ranging from 475 years to 2475 years. The earthquake catalogue has been formed (Al-Hussaini and Al-Noman 2010) using various sources and including historical earthquakes. Information from ADPC work (2009) for Comprehensive Disaster

Management Program Phase-I of Bangladesh were used. A total of seven seismic source zones have been designated. Four seismic source zone models consisting of seven seismic sources boundaries were used. They used the computer program CRISIS (UNAM 1999) to perform probabilistic seismic hazard assessment (PSHA) studies for Bangladesh. In the absence of reliable attenuation laws for Bangladesh, recent well-established attenuation relations developed by various researchers for different regions (Western USA, Eastern USA, Iran, Europe and India) of the world were used in the study. In addition a new attenuation relationship for Bangladesh originally developed by Islam et al. (2010), and later corrected for site effect, was used. This local attenuation law is based on intensity based isoseismals of historical and recent earthquakes, and therefore employs intensity-PGA (peak ground acceleration) relationship as well. This law is found to be close to the attenuation law for Western USA developed by Abrahamson and Silva (1997). Bolt (1987) also mentioned that the attenuation in Bangladesh is expected to be similar to that in the Western USA.



(a) (b)

Figure 2.6 (a) Predicted PGA (g) for return period of 475 years (Noor et al. 2005), (b) Predicted PGA (g) for return period of 2475 years (NDMA 2010)

Recent codes are considering larger return periods to account for large earthquakes with long recurrence periods. The International Building code (ICC 2000) considers the Maximum Credible Earthquake to correspond to a return period of 2475 years which is equivalent to 2% probability of exceedance in 50 years. The Indian Code (BIS 2005) is using concept of Maximum Considered Earthquake (MCE) motion in its seismic zoning map.

Figure 2.7 shows results of PSHA studies (Al-Hussaini et al. 2012) for a return period of 2475 years for a preferred seismic source zone model using the attenuation law of Abrahamson and Silva (1997). The maximum PGA value is $0.38\ g$ in the north and north-east of Bangladesh, the PGA value in Chittagong city is $0.28\ g$, the PGA value in Dhaka city is around $0.18\ g$. They proposed new seismic design provisions including a new seismic zoning map for the updated Bangladesh national building code (updated BNBC). Their proposed seismic zoning map (Figure 2.8) for Bangladesh, was based on the following: (i) PSHA results for return period of 2475 years (ii) limited NDSHA results (iii) effects of large historical earthquakes (iv) previous seismic zoning map of BNBC-1993 (v) new seismic zoning map of neighbouring India and (vi) work of other researchers. They divided the country into four (instead of three) seismic zones with zone coefficient Z equal to 0.12 (Zone 1), 0.2 (Zone 2), 0.28 (Zone 3) and 0.36 (Zone 4). The zone coefficient represents the PGA value for MCE on rock or very stiff soil site. Site effect is not included.

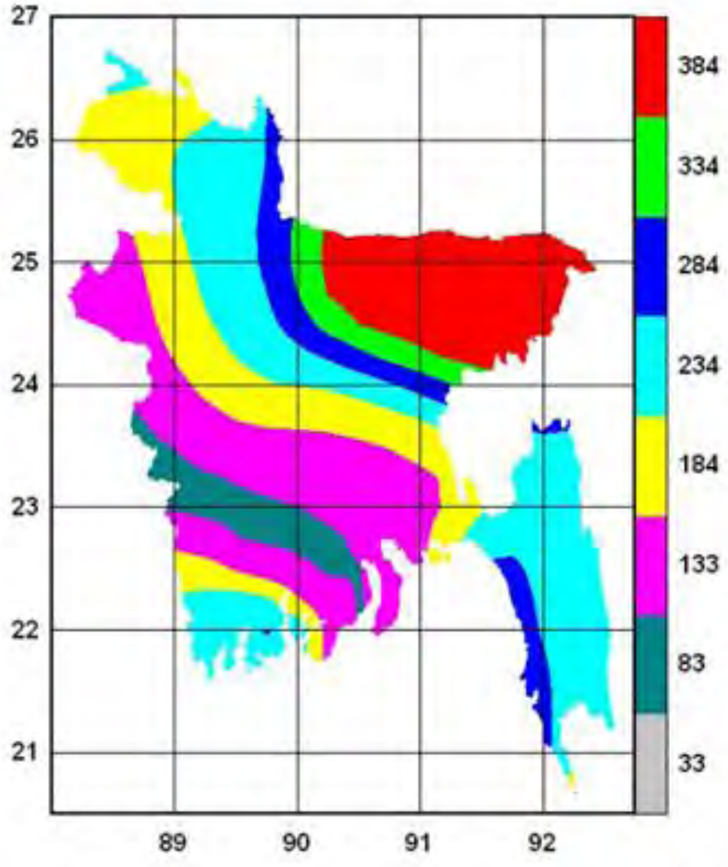


Figure 2.7 Predicted PGA (cm/sec^2) for return period of 2475 years and attenuation law of Abrahamson and Silva 1997 (Al-Hussaini et al. 2012)

Figure 2.9 shows the seismic zone coefficients (MCE) for neighbouring India (BIS 2005) which has zone coefficients equal to 0.36, 0.24 and 0.16. Comparison between Figure 2.8 and Figure 2.9 shows that the Indian seismic zoning map has some agreement across the border with proposed seismic zoning map, however there are some differences in central-eastern (0.12 vs 0.16, 0.2 vs 0.24) and south-eastern (0.28 vs 0.36) parts of Bangladesh. The higher values in Indian territory to the west of Comilla and Chittagong can be accounted to the higher seismicity and closer proximity to the Indian-Burmese plate boundary fault systems. On the other hand, comparing NDMA results (Figure 2.6b) with the proposed BNBC zoning map (Figure 2.8), the PGA in Dhaka is 0.15 g vs. 0.20 g, in Chittagong 0.20 g vs. 0.28 g, in Sylhet 0.32 g vs 0.36 g. In other words, NDMA results are lower, more so in Dhaka and Chittagong. In the (updated) proposed BNBC, the design basis earthquake (DBE) ground motion is taken as 2/3 of the maximum considered earthquake (MCE) ground motion. Comparing with BNBC-1993, for some cities such as Chittagong, Faridpur, Rangpur, Pabna, Tangail, there is increase in design ground motion in the updated BNBC.

Figure 2.8 Proposed Seismic Zoning Map for Bangladesh based on Maximum Considered Earthquake (Al-Hussaini et al. 2012)

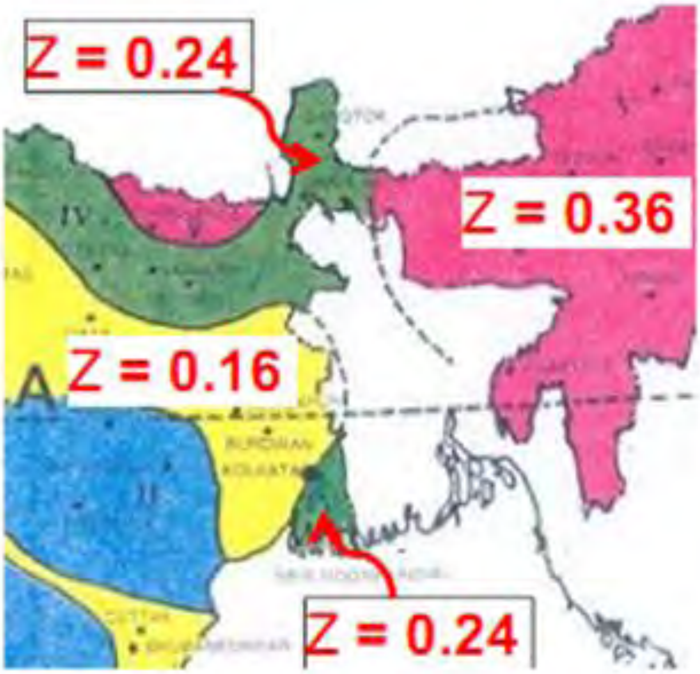


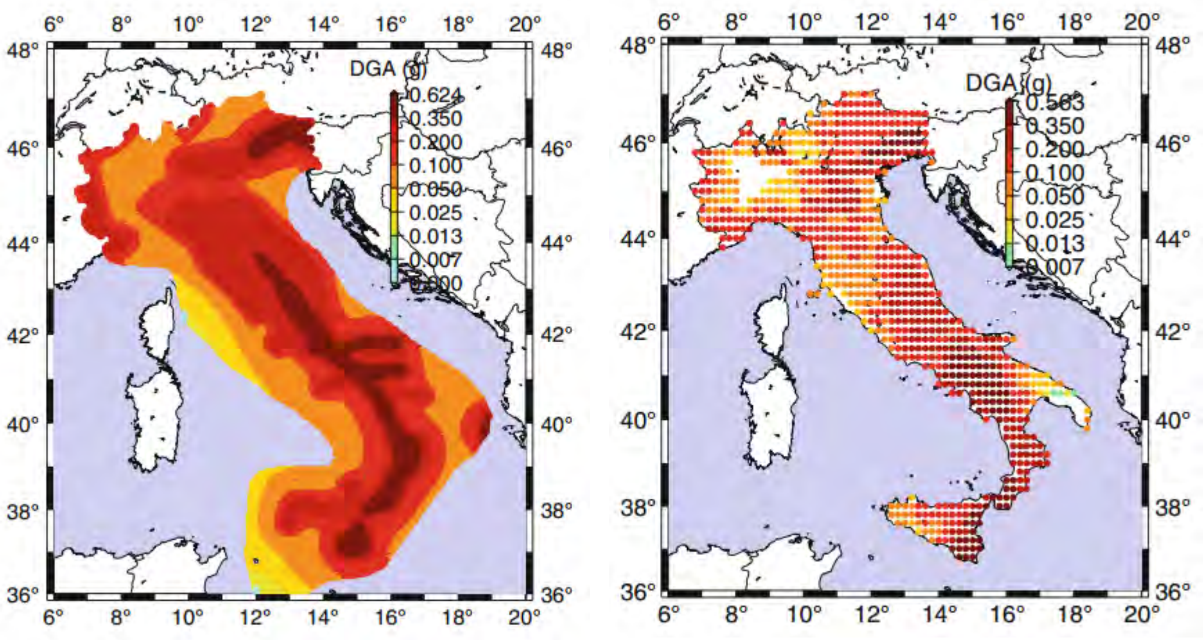
Figure 2.9 Seismic Zoning Map of neighbouring India based on Maximum Considered Earthquake (BIS 2005)

2.6 Neo-Deterministic Seismic Hazard Assessment Studies

The neo-deterministic approach, NDSHA (Panza et al. 2001) means scenario-based methods for seismic hazard analysis, where attenuation relations are not allowed in. Instead, realistic synthetic time series are used to construct earthquake scenarios. The NDSHA procedure provides ground motion parameters based on the seismic wave propagation modeling at different scales- regional, national, and metropolitan- accounting for a wide set of possible seismic sources and for the available information about structural models. This scenario-based method relies on observable data being complemented by physical-mathematical modeling techniques. The basic differences between the NDSHA and the classical DSHA approach is the latter relies on the use of empirical attenuation relations and on a small set of scenario earthquakes. In DSHA, seismic hazard is defined as the median or certain percentile ground motion from a single earthquake or set of earthquakes, and it is calculated from simple statistics of earthquakes and ground motion (Peresan et al. 2011).

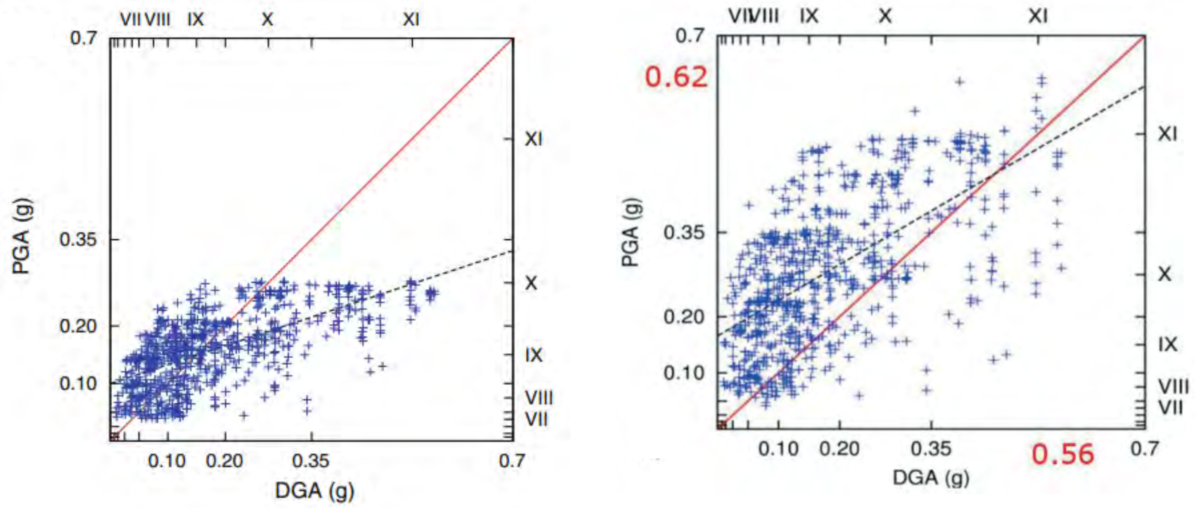
Local site effects can be strongly dependent on the characteristics of the seismic source (Panza et al. 2001). NDSHA derives earthquake ground motions as a tensor product (of earthquake source tensor with the Greens function for the medium) and it avoids using an approximate scalar quantity implied in the attenuation relationships. Moreover, the related uncertainties can be explicitly defined by massive parametric tests. The NDSHA method has been already successfully applied in many countries worldwide (e.g., Italy, India, Egypt, Algeria, China, Slovenia, Croatia).

The comparative analysis of PSHA and NDSHA estimates was performed for the Italian territory by Zuccolo et al. (2011). The PSHA and NDSHA map of Italy is shown in Figure 2.10. The NDSHA provides values larger than those given by the PSHA in high-seismicity areas and in areas identified as prone to large earthquakes, while lower values are provided in low-seismicity areas. The evidenced tendency of PSHA to overestimate hazard in low seismicity areas seems supported by the results from recent studies on precarious unbalanced rocks. In addition, the PSHA expected ground shaking estimated with 10% probability of being exceeded in 50 years (associated with a return period of 475 years) appeared severely underestimated (by about a factor 2) with respect to NDSHA estimates, particularly for the largest values of PGA (Figure 2.11a). When a 2% probability of being exceeded in 50 years is considered (i.e. return period of 2475 years) PSHA estimates in high-seismicity areas become comparable with NDSHA (Figure 2.12b); in this case however, the overall increase related with probabilistic estimates leads to significantly overestimate the hazard in low-seismicity areas.



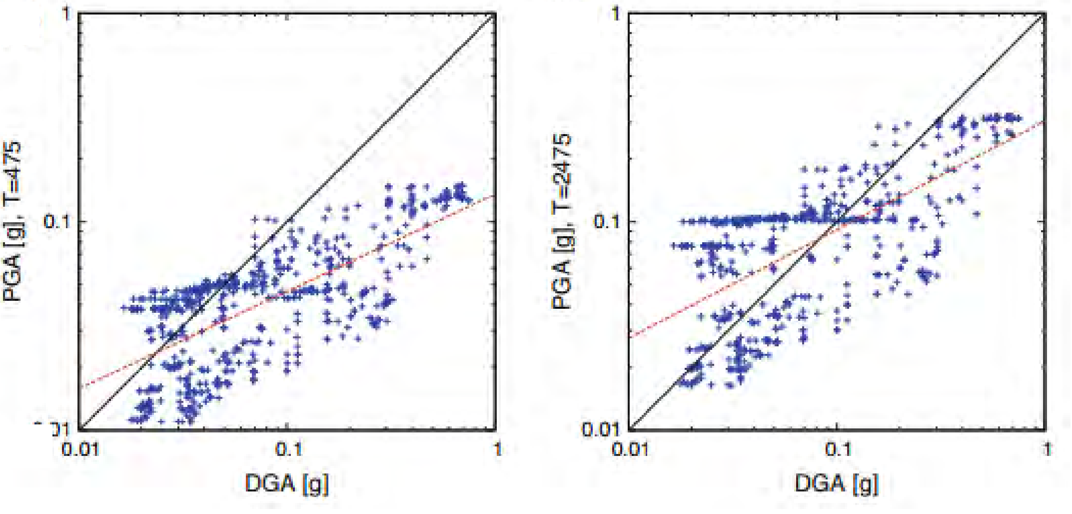
(a) (b)

Figure 2.10 (a) PSHA map computed for Italy (for return period of 2475 years) and (b) NDSHA map computed for Italy with peak ground acceleration (Zuccolo et al. 2011)



(a) (b)

Figure 2.11 Scatter plots comparing the PGA from PSHA analysis and DGA from NDSHA for Italy (Zuccolo et al. 2011) (a) for return period of 475 years, (b) for return period of 2475 years. The linear regression line (dashed line) is shown as well.



(a) (b)

Figure 2.12 Scatter plots comparing the PGA from PSHA analysis and DGA values from NDSHA For Gujrat, India (Magrin et al. 2016) (a) for return period of 475 years, (b) for return period of 2475 years. The linear regression line (dashed line) is shown as well.

Parvez et al. (2003) prepared a national scale map for India and surrounding region following NDSHA. In 2016 Magrin et al. updated the input parameters for India and prepared a map for Gujrat region. The plot from this study comparing peak ground motion from PSHA and NDSHA is presented in Figure 2.11b. It is showing similar findings as that of Zuccolo et al. 2011.

Al-Hussaini (2014) presented NDSHA studies for Bangladesh that was conducted in collaboration with International Centre for Theoretical Physics (ICTP) and University of Trieste, Italy. In that study, a neo-deterministic approach based on the computation of synthetic seismograms complete with all main phases was used. The seismic hazard expressed in terms of maximum displacement, maximum velocity and design ground acceleration (DGA) was extracted from the synthetic seismograms using European code spectrum and mapped over the region of the study. NDSHA studies were carried out to predict design ground motion for the case of repeat of some historical earthquakes in Bangladesh. Computed design ground acceleration (g) in Bangladesh for repeat scenario of Great Indian Earthquake is presented in Figure 2.13. The strongest ground motion ($0.224g$) was in the districts of Mymensingh, Jamalpur, Netrokona, Kurigram and Sunamganj. Dhaka city had a ground motion of 0.08 to $0.15g$. These results appeared to be within the PGA values of current zoning map of the Building code.

Al-Hussaini et al. (2015) presented results from NDSHA study for Bangladesh with updated structural model and Italian code spectrum. Historical earthquakes were considered as well as earthquakes in new locations or potential known faults indicated in recent seismological studies. Some of these scenario earthquakes surpassed the value of updated BNBC. Figure 2.14 presents computed design ground acceleration (g) in Bangladesh for a repeat of 2010 M 5.1 Matlab Earthquake at focal depth of 18 km. Results showed design ground acceleration in the range of 0.001-0.005g around Dhaka city. Earthquake record from Geological survey of Bangladesh (GSB) in Dhaka city showed PGA value of 0.0066g.

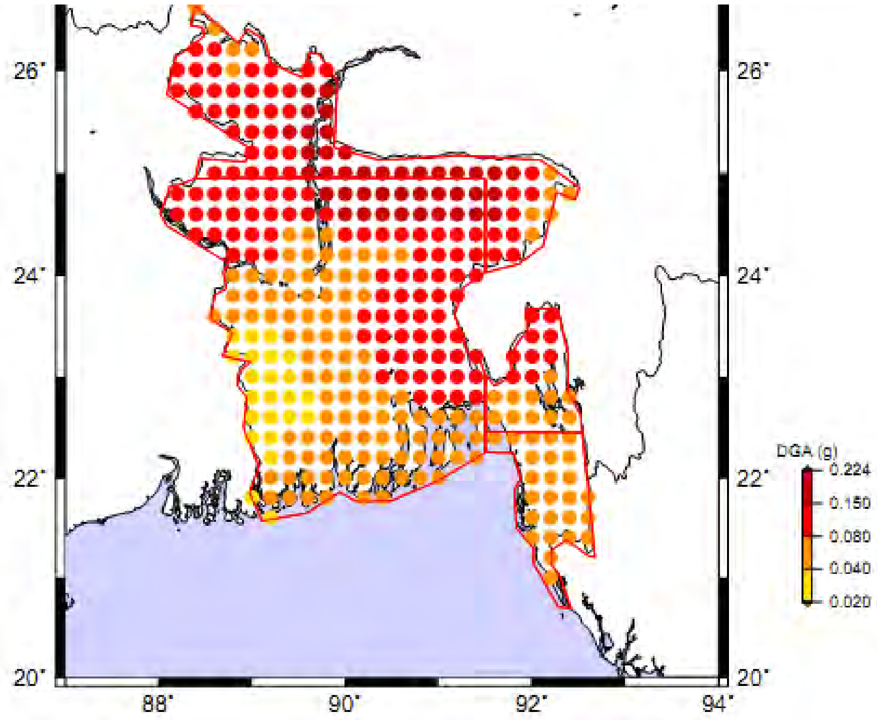


Figure 2.13 Estimated Seismic hazard (ground acceleration in g) using NDSHA for a repeat scenario of 1897 Great Indian Earthquake (Al-Hussaini 2014)

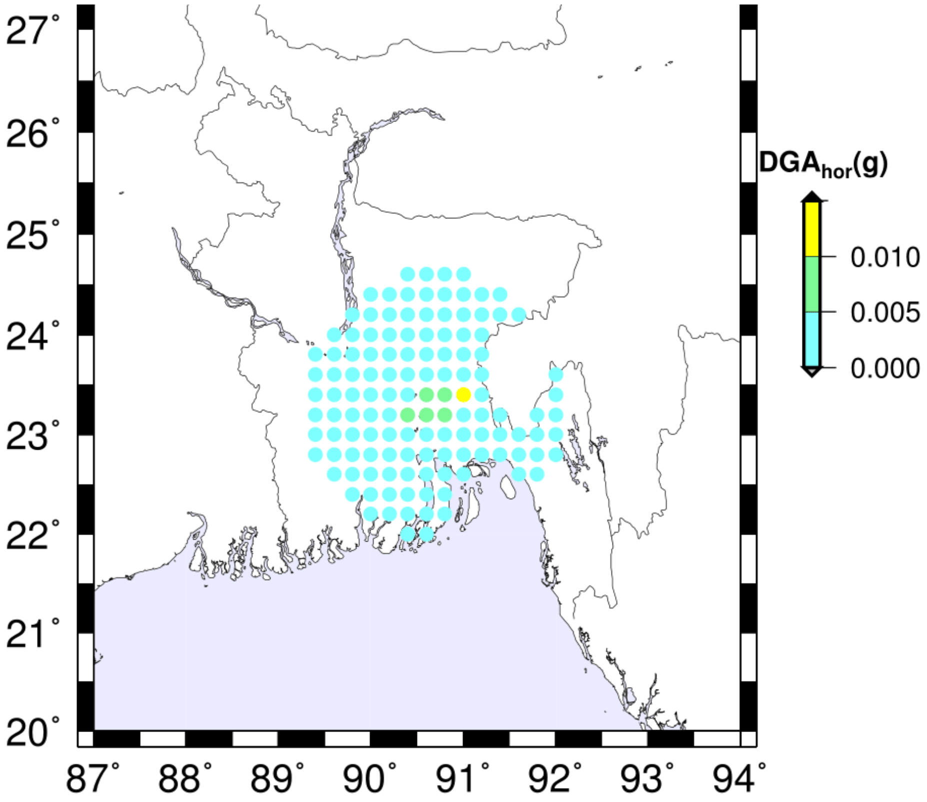


Figure 2.14 Estimated design ground acceleration (g) using NDSHA for a repeat scenario of 2010 M=5.1 Matlab Earthquake (Al-Hussaini et al. 2015)

2.7 Summary

Study of earthquakes and active faults near Bangladesh are suggesting that Bangladesh is alarmingly under a great threat of a major earthquake. So far the seismic hazard analysis for Bangladesh is mostly done by following the PSHA approach. With the increasing seismic hazard studies in the world following DSHA, it is an urgent need for Bangladesh to prepare seismic hazard map based on NDSHA results. This study aims to preparing a national scale map for Bangladesh following the NDSHA approach. Then the estimates by PSHA method can be compared with the results from NDSHA method.

CHAPTER 3

SCENARIO EARTHQUAKE SIMULATION

3.1 General

This chapter describes the primary methodology of neo-deterministic seismic hazard assessment (NDSHA). It explains the input data required for simulation of a single earthquake in the program and the results generated. Repeat scenario of some of the historic earthquake in and near Bangladesh is simulated and their effect on Bangladesh is discussed. Though NDSHA does not use any simplified attenuation equation (like that in probabilistic and deterministic method), the results it generates have been compared with simple Deterministic seismic hazard assessment (DSHA) results using different attenuation equations by other authors to verify its compatibility.

3.2 Methodology of Neo-Deterministic Seismic Hazard Assessment

Neo-deterministic seismic hazard assessment (NDSHA) involves advanced numerical techniques to solve the wave propagation problem using properties of local geological structure and fault models, and thus describes seismic ground motion due to an earthquake at a given distance and magnitude. It permits us to define a set of earthquake scenarios and to simulate the associated synthetic signals without having to wait for a strong event to occur. A more adequate definition of NDSHA, which is based on the possibility of efficiently computing realistic synthetic seismograms by the modal summation technique, is given by Panza et. al. (2001).

Panza (1985) developed an algorithm to construct complete synthetic seismogram for flat layered anelastic models of earth by modal summation technique. It was further developed by Florsch et al. (1991). Using this algorithm, Costa et al. (1993) proposed a procedure for deterministic seismic zoning, which is applied in the present study to prepare a deterministic seismic hazard map for Bangladesh. NDSHA has the advantage that it does not depend on empirical attenuation laws which are simplified. Rather it solves the wave propagation problem with available geophysical data. Synthetic time history is generated and engineering parameters can be extracted to assess the seismic hazard. As a result, distribution of maximum displacement (d_{max}), maximum velocity (v_{max}) and peak ground acceleration (PGA) can be mapped over the investigated area.

Table 3.1 Example of a structure

Thickness (km)	**Density (g/cm^3)**	V_P**(km/s)**	V_S**(km/s)**	Q_P	Q_S	**Depth (km)**	**Layer**
2	2.40	4.32	2.50	990	450	2	1
2	2.75	5.20	3.00	990	450	4	2
4	3.00	6.00	3.46	990	450	8	3
7	3.03	6.14	3.55	990	450	15	4
13	3.15	6.40	3.70	990	450	28	5
10	3.20	6.93	4.00	990	450	38	6
62	3.44	7.79	4.50	990	450	100	7

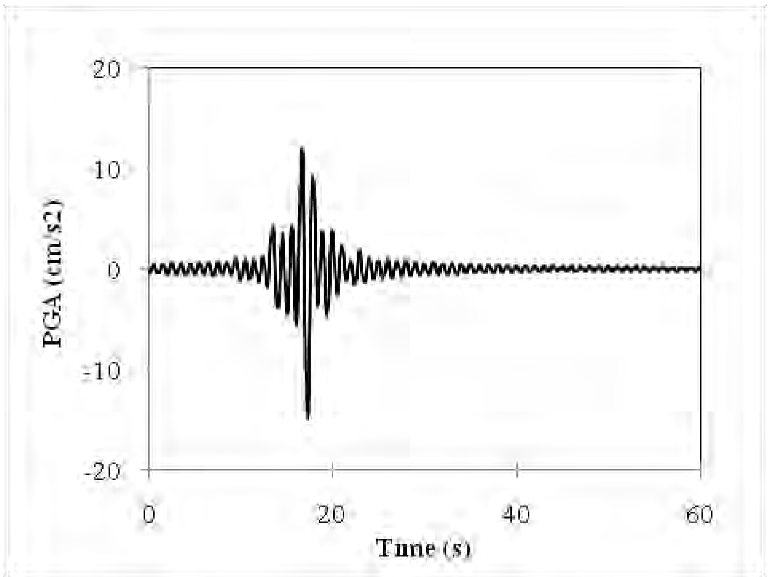


Figure 3.1 Example of Synthetic seismogram generated by means of NDSHA

Parametric tests can be done with NDSHA to examine the effect of various parameters associated with an earthquake. The input data required for a parametric test includes the bedrock structure beneath and focal mechanism of the earthquake. Structures are defined by one dimensional anelastic layers of definite thickness, density, shear wave velocity, p-wave velocity and attenuation parameters(Q_P, Q_S). An example of a model structure with required parameters is shown in Table 3.1. Earthquake data includes epicenter location, focal depth and magnitude along with the focal mechanism i.e. strike, dip, rake angle of the earthquake. After running the model earthquake, the program generates a huge number of seismograms at a definite interval (0.2°) of distance. For a particular location; the radial, transverse and vertical components of displacement, velocity and acceleration can be observed. An example of synthetic seismogram generated by NDSHA is shown in Figure 3.1. While plotting the horizontal peak ground motion, the program sums up the components of radial and transverse motion and shows the maximum value. Such plots with peak ground acceleration can be seen in the following section. The structural models for Bangladesh associated with these runs are described in detail in Chapter 4 Section 4.2.4.

3.3 Scenario Earthquakes

3.3.1 Great Indian Earthquake 1897

The Great Indian earthquake (also known as Assam earthquake) took place on 12 June 1897 in the north of Shillong Plateau. The latitude and longitude was 26˚N and 91˚E; and the focal depth was 60 km. The Shillong Plateau lying between the Dauki fault and Brahmaputra river is a seismically active zone and the source of several major earthquakes (1869 Cachar earthquake, 1930 Dhubri earthquake).

Seeber and Armbruster (1981) proposed a model explaining the cause of all the four major Indian earthquakes (1905, 1934, 1897 and 1950) as thrust earthquakes. The Dauki Fault, as the source of 1897 earthquake, was considered to be a shallow north dipping thrust fault of a nature similar to the Himalayan frontal thrust. There were many publications dealing with tectonics and seismic hazard of this region and all conforming to the thrust tectonics for the Dauki Fault. Gahalaut and Chander (1992) proposed the rupture area to be 170km × 100 km within depths from 15 km at the Dauki fault to 23 km beneath the Brahmaputra valley. Nandy and Dasgupta (1991) observed that the Shillong Plateau was seismically less active than commonly presumed and the 1897 earthquake was not related to the activity of the Dauki fault. The entire concept of this region went through a drastic change with the publication of an important contribution by Bilham and England (2001). The origin of the Shillong Plateau as the source of the great 1897 earthquake was put forward. They modelled a ESE-WNW trending 110 km long buried reverse fault at the northern end of the plateau and named it Oldham fault, that dips 57° towards SSW. Several articles published since supported the existence of a south dipping fault bordering the northern margin of the plateau. For 1897 earthquake, from European seismograms, Richter calculated a surface-wave magnitude of Ms 8.7. The magnitude of this earthquake was reassessed by Ambraseys and Bilham (2003) as magnitude 8.0. Recently, England and Bilham (2015) has updated the model and re-estimated the magnitude to be in the range of 8.15-8.35.

A single earthquake scenario has been run with NDSHA for this 1897 earthquake. For source parameters, values are taken from the model prepared by Bilham and England (2001). A strike value of 115°, dip angle 57° and rake angle 76° are indicating a reverse type focal mechanism. PGA values from repeat scenario of 1897 earthquake are plotted in Figure 3.2.

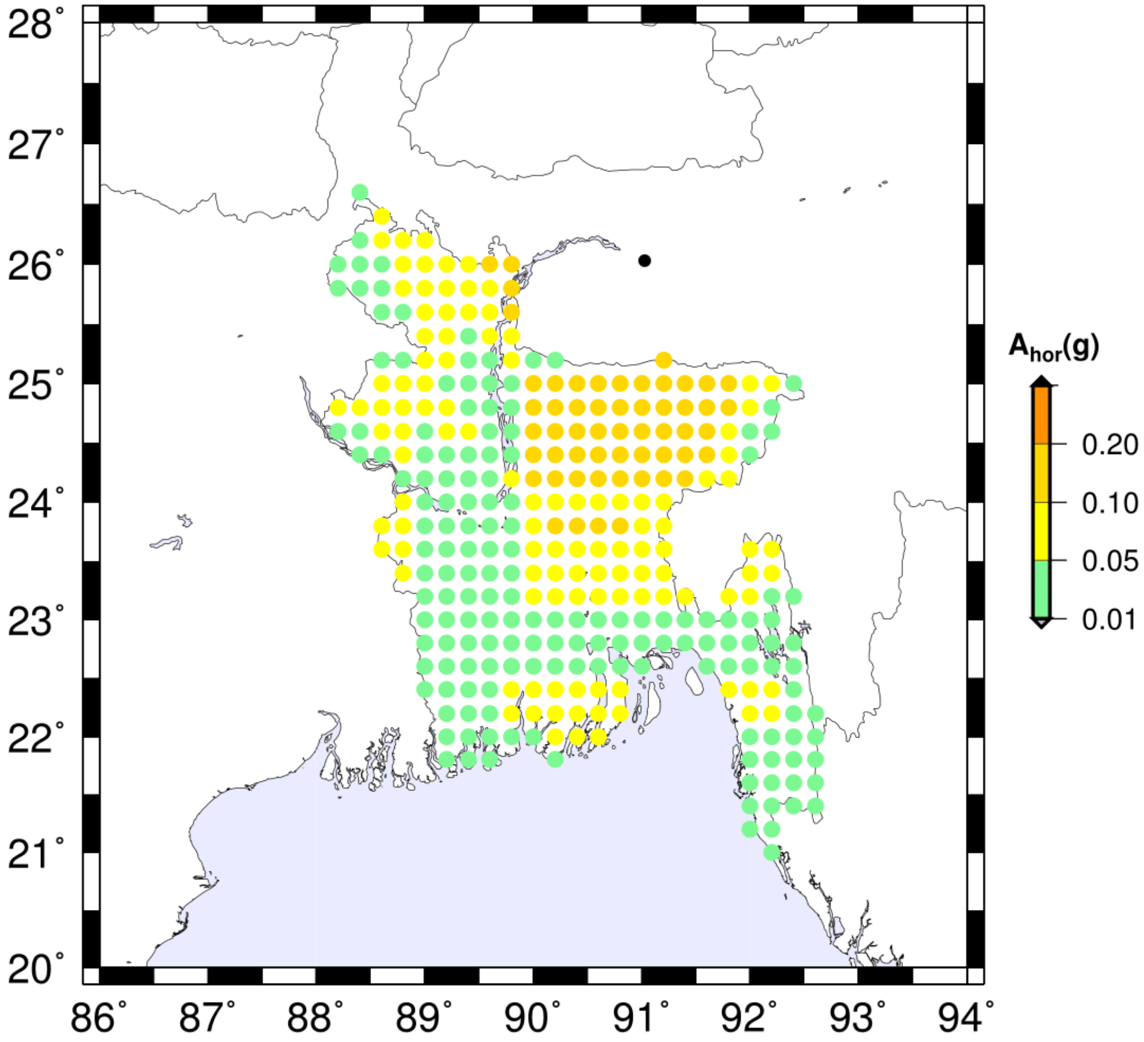


Figure 3.2 Estimated peak ground acceleration (g) using NDSHA for a repeat scenario of 1897 M=8.35 Great Indian Earthquake. The epicenter is indicated by a black dot.

Figure 3.2 is showing higher values up to 0.2g near the India-Bangladesh border zone at the north-east of the country. The same range is seen in Mymensingh, Kishorgonj, Netrokona, Sunamgonj, Kurigram. PGA values in the range of 0.05-0.10g are found in Dhaka, Comilla, Rangpur, Patuakhali etc.

The results from this NDSHA are compared with simple deterministic analysis (DSHA) results. DSHA was done with a fixed magnitude and a fixed distance; and following different attenuation laws by different authors. Attenuation laws proposed by authors such as Abrahamson and Silva 1997 (for USA), Zare et al. 1999 (for Iran) and Al-Hussaini and Islam 2014 (for Bangladesh) were used. These attenuation equations are presented in Appendix C. The DSHA results in PGA (g) for different locations of Bangladesh are compared with the results from NDSHA and also with zone coefficients from updated BNBC and presented in Table 3.2. The nearest coordinates used for these locations are listed in Appendix D.

Table 3.2 Estimated PGA values for 1897 Great Indian earthquake

Location	**PGA (g) from NDSHA**	**PGA (g) from DSHA using different attenuation equations**			**Zone co-efficient from Updated BNBC**
		Zare et al. 1999	**Al-Hussaini and Islam 2014**	**Abrahamson and Silva 1997**	
Bogra	0.040	0.065	0.139	0.107	0.28
Brahmanbaria	0.072	0.064	0.136	0.106	0.28
Chittagong	0.055	0.040	0.050	0.064	0.28
Comilla	0.057	0.054	0.098	0.088	0.20
Cox's Bazar	0.030	0.035	0.032	0.054	0.28
Dhaka	0.104	0.057	0.108	0.093	0.20
Faridpur	0.033	0.052	0.092	0.085	0.20
Jhalokathi	0.040	0.043	0.058	0.069	0.12
Khulna	0.033	0.042	0.058	0.069	0.12
Kurigram	0.143	0.093	0.237	0.151	0.36
Takerhat	0.195	0.140	0.390	0.220	0.36
Mymensingh	0.131	0.092	0.230	0.148	0.36
Meherpur	0.085	0.045	0.065	0.072	0.12
Mongla	0.048	0.040	0.049	0.064	0.12
Pabna	0.030	0.052	0.091	0.085	0.20
Rajshahi	0.039	0.048	0.079	0.079	0.12
Rangamati	0.042	0.043	0.061	0.070	0.28
Rangpur	0.055	0.072	0.164	0.119	0.28
Sylhet	0.113	0.088	0.219	0.143	0.36
Thakurgaon	0.037	0.054	0.098	0.088	0.20

CDMP report (2013) presented the possibility of an earthquake at Dauki fault (India-Bangladesh Border region at North) with a magnitude as high as 8.0. Taking the dip angle 45° and depth 35 km mentioned on that report, a scenario M 8.0 earthquake is simulated at Dauki fault near Jaflong (25.20°N, 92.00°E). The results are shown in Figure 3.3 and Table 3.3.

From Table 3.3, it can be seen that the highest PGA of range 0.3-0.4g are near the epicenter which is exceeding the BNBC estimate of 0.36g. Sylhet, Mymensingh and locations near the Dauki fault are showing PGA values in the range of 0.05-0.20g.

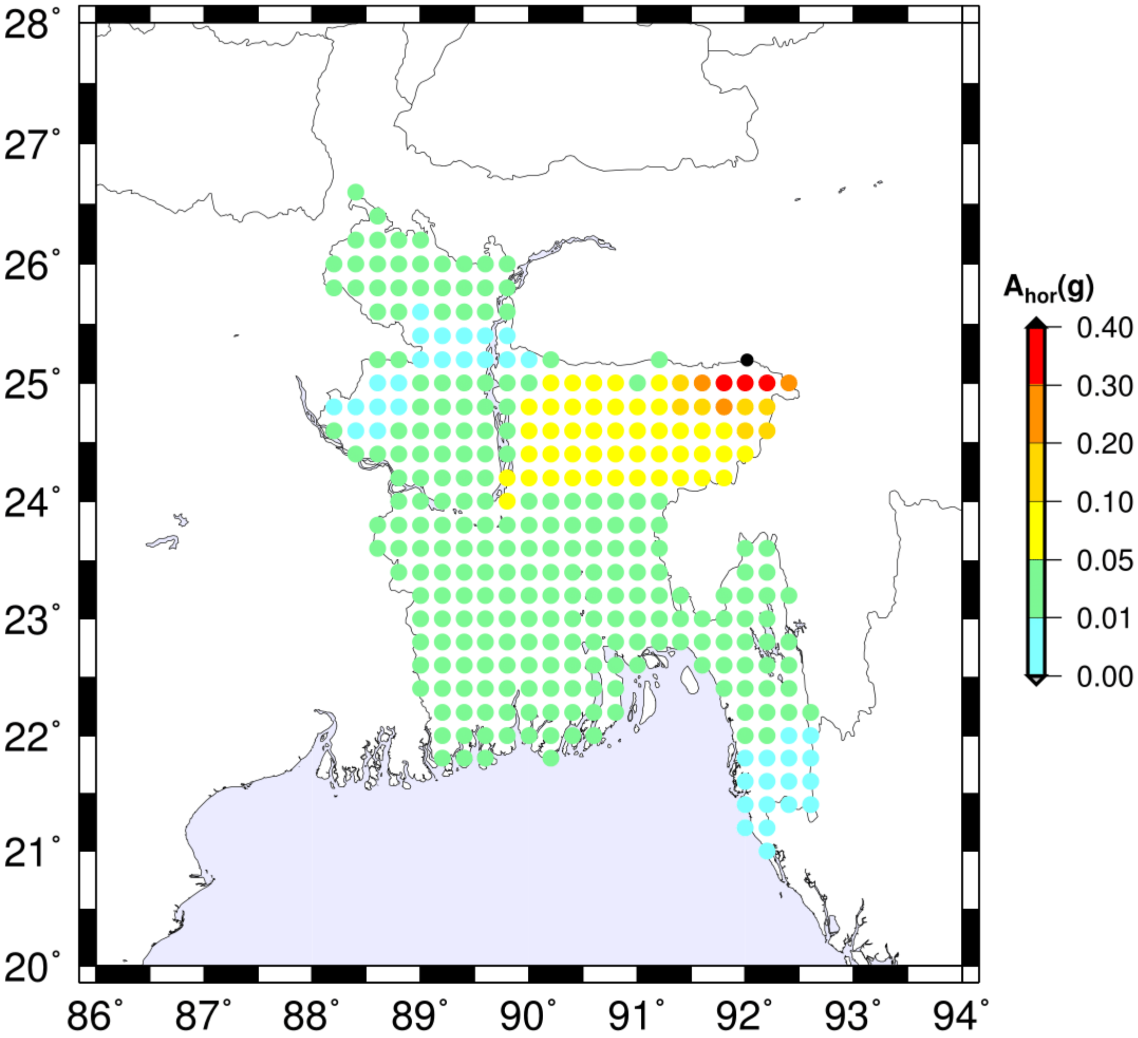


Figure 3.3 Estimated peak ground acceleration (g) using NDSHA for a scenario earthquake of M 8.0 at Dauki fault. The epicenter is indicated by a black dot.

Table 3.3 Estimated *PGA* values for a scenario earthquake at Dauki fault with M 8.0

Location	***PGA* (g) from NDSHA**	***PGA* (g) from DSHA using different attenuation equations**			**Zone co-efficient from updated BNBC**
		Zare et al. 1999	**Al-Hussaini and Islam 2014**	**Abrahamson and Silva 1997**	
Jhalokathi	0.018	0.034	0.049	0.055	0.12
Khulna	0.021	0.032	0.042	0.052	0.12
Mongla	0.027	0.031	0.037	0.049	0.12

Location	**PGA (g) from NDSHA**	**PGA (g) from DSHA using different attenuation equations**			**Zone co-efficient from updated BNBC**
		Zare et al. 1999	**Al-Hussaini and Islam 2014**	**Abrahamson and Silva 1997**	
Rajshahi	0.011	0.031	0.040	0.050	0.12
Comilla	0.030	0.050	0.102	0.084	0.20
Dhaka	0.033	0.045	0.085	0.075	0.20
Faridpur	0.036	0.039	0.063	0.064	0.20
Pabna	0.022	0.035	0.052	0.057	0.20
Rangpur	0.016	0.037	0.059	0.061	0.28
Bogra	0.024	0.039	0.064	0.064	0.28
Brahmanbaria	0.036	0.061	0.138	0.104	0.28
Chittagong	0.012	0.036	0.056	0.060	0.28
Sylhet	0.280	0.193	0.631	0.394	0.36
Jaflong	0.389	0.206	0.710	0.445	0.36
Mymensingh	0.068	0.057	0.125	0.097	0.36
Kurigram	0.022	0.042	0.075	0.070	0.36

3.3.2 Srimangal Earthquake 1918

The Srimangal earthquake of 8th July 1918 was studied by Geological survey of India (Murray, 1926). The epicenter of the earthquake was given as 24.25˚N and 91.70˚E with a focal depth of 14 km. With isoseismal map prepared following the Oldham scale, epicentral parameters for this earthquake were recalculated (Endgahl and Villasenor, 2002) as 24.81˚N, 90.72˚E, Mw 7.5 and focal depth 15 km. As per NEIC and IMD catalogue, the epicentral location was considered as 24.50˚N and 91.00˚E. Mukhopadhyay and Dasgupta (1988) mentioned that the earthquake has occurred in the Sylhet planes (Surma valley) and though spatially it is related to the Sylhet fault, in the regional framework, it could be linked with the Indo-Burmese convergence tectonics.

The focal depth estimate of this earthquake is however contradictory. Steckler et al. (2008) also mentioned that it is unlikely that it occurred in a shallow dipping fault. Because, if it did it must had ruptured the surface. Moreover, in a recent study Singh et al. (2016) also observed that the sedimentary thickness under Sylhet basin is 12-16 km. An earthquake of magnitude greater than 7 is unlikely to take place within this depth. More geological study is required to come to a conclusion about the depth of this earthquake. However, for a scenario earthquake run in this study, it is assumed that the depth is 30 km. The epicenter is assumed near to Srimangal (24.30˚N, 91.71˚E) as per Martin and Szeliga (2010). The focal mechanism of 2 March, 2013 earthquake at this region is used as the representative focal mechanism for this earthquake, which is of oblique-slip reverse type. Table 3.4 shows the estimated PGA values for a scenario run of 1918 Srimangal earthquake.

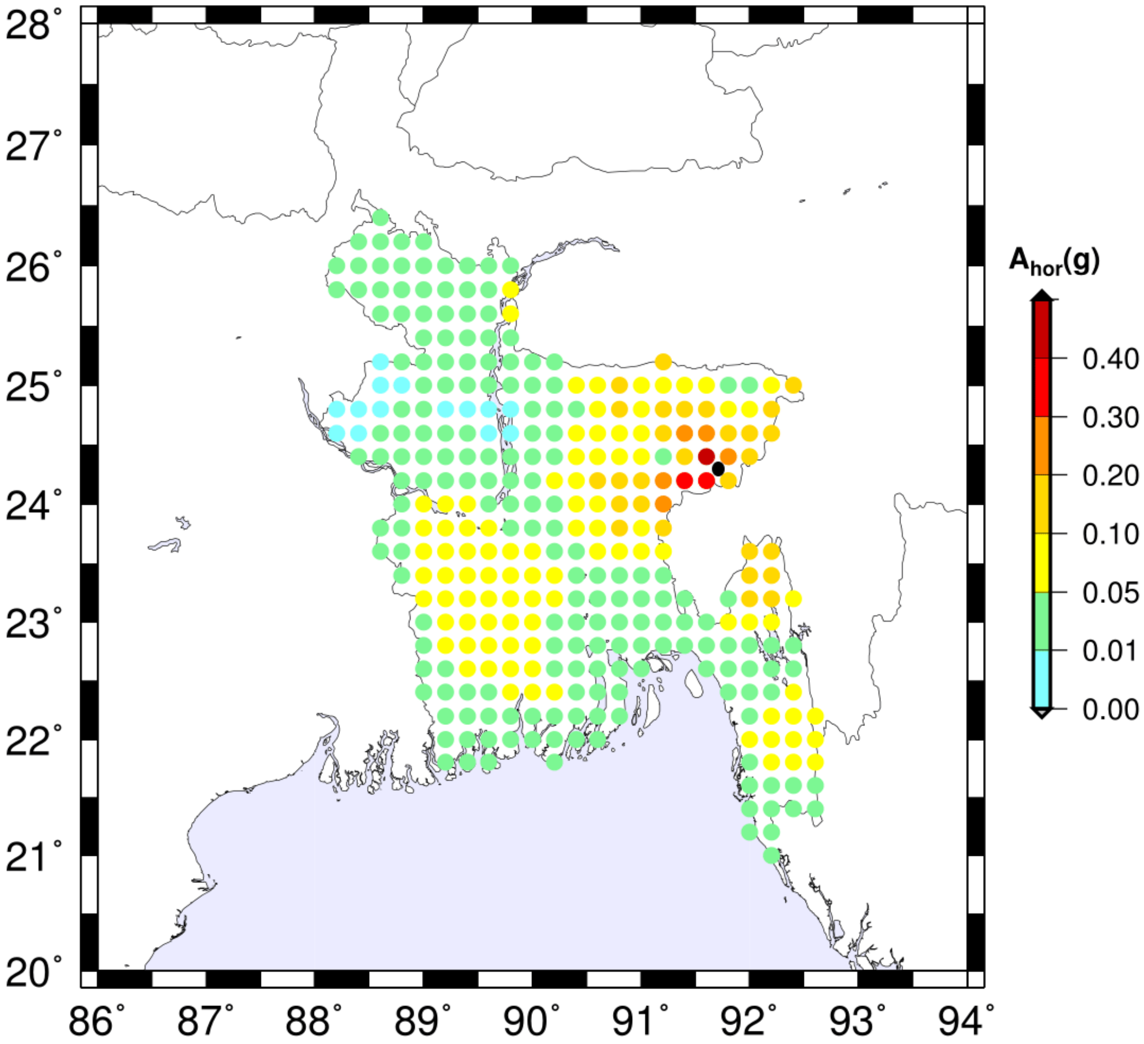


Figure 3.4 Estimated peak ground acceleration (g) using NDSHA for a repeat scenario of 1918 M=7.6 Srimangal Earthquake. The epicenter is indicated by a black dot.

From Figure 3.4, it can be seen that the highest value of PGA is 0.40g near to the epicenter which is more than the BNBC zone co-efficient. For the locations around, such as Srimangal, Brahmanbaria, Netrokona the PGA value is in the range of 0.10-0.30g; whereas for further locations such as Dhaka, Mymensingh, Comilla the values are between 0.05-0.10g. Comparison of this result with attenuation laws by other authors is presented in Table 3.4.

Table 3.4 Estimated PGA values for 1918 Srimangal earthquake

Location	**PGA (g) from NDSHA**	**PGA (g) from DSHA using different attenuation equations**			**Zone co-efficient from updated BNBC**
		Zare et al. 1999	**Al-Hussaini and Islam 2014**	**Abrahamson and Silva 1997**	
Khulna	0.068	0.028	0.044	0.047	0.12
Meherpur	0.041	0.025	0.033	0.040	0.12
Rajshahi	0.019	0.025	0.032	0.040	0.12
Jhalokathi	0.049	0.032	0.055	0.054	0.12
Comilla	0.045	0.063	0.148	0.115	0.20
Dhaka	0.054	0.046	0.097	0.081	0.20
Faridpur	0.050	0.035	0.065	0.061	0.20
Pabna	0.054	0.029	0.047	0.049	0.20
Rangamati	0.039	0.043	0.089	0.076	0.28
Rangpur	0.031	0.026	0.038	0.043	0.28
Brahmanbaria	0.209	0.084	0.214	0.162	0.28
Chittagong	0.029	0.035	0.066	0.061	0.28
Cox's Bazar	0.031	0.026	0.037	0.043	0.28
Sylhet	0.052	0.092	0.238	0.180	0.36
Srimangal	0.405	0.180	0.890	1.090	0.36
Shaistaganj	0.310	0.139	0.421	0.328	0.36
Mymensingh	0.047	0.047	0.101	0.084	0.36
Kurigram	0.053	0.029	0.046	0.048	0.36

3.3.3 Arakan Earthquake 1762

The 2 April 1762 great Arakan earthquake is considered to come from a megathrust rupture reaching northward to the south-eastern coast of Bangladesh. It can also be considered as a Burmese earthquake, taking place on the plate boundary along the Arakan coast. GEM technical report (2013) attempts to clear the dispute regarding this earthquake saying, due to the only source Oldham (1833), who only had reports from colonial outposts at places like Chittagong and Calcutta, 1762 earthquake has been wrongly represented as a Chittagong earthquake with a modest magnitude. The magnitude is more realistically greater than 8.

Wang et al. (2013) performed field investigations along the coast of Myanmar to confirm 3-4 m emergence along Cheduba island and up to 5-6 m uplift at Ramree island. They suggest that a rupture length of 500 km is associated with this magnitude 8.5 earthquake having epicenter near the above mentioned islands. From some recent field investigations at Bangladesh, Mondal et al. (2014) suggests the uplift of terrace upto 2-2.5m along Teknaf coast. Moreover they think that the rupture of 1762 earthquake was extended as far north as the Sitakund anticline to the north of the city of Chittagong and activated two mud volcanoes there. With some paleo-seismic studies of the three uplifted terraces in the Teknaf coast, they suggest that similar earthquakes of great magnitude have ruptured the Chittagong-Arakan coast in the historic past. Cummins (2007) also mentioned the extension of fault rupture up to north of Chittagong and he had proposed a fault model with 700 km length and magnitude 8.8.

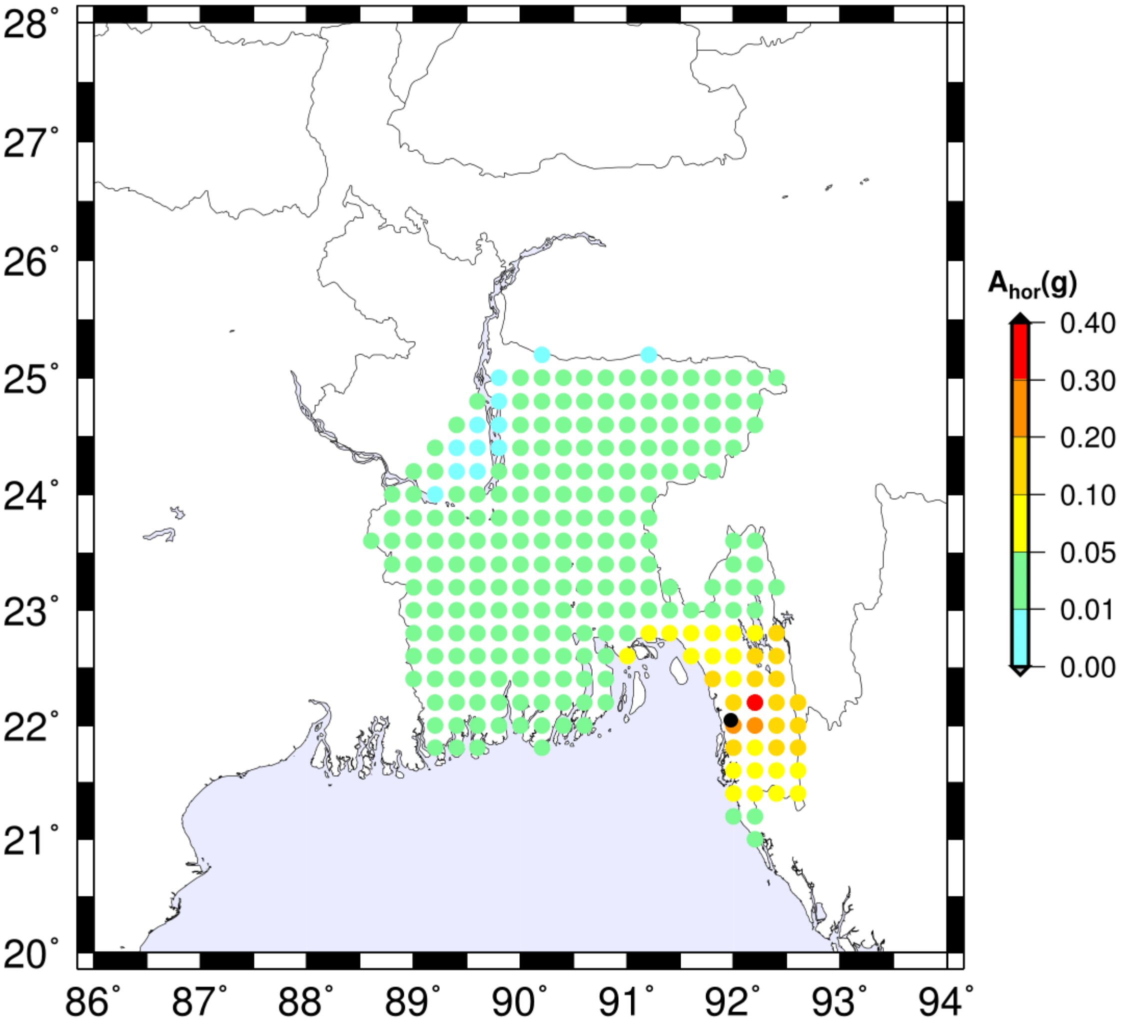


Figure 3.5 Estimated peak ground acceleration (*g*) using NDSHA for a repeat scenario of 1762 Earthquake with M 7.5. The epicenter is indicated by a black dot.

In this NDSHA method, the point source assumption is being used. An epicenter near Ramree island (roughly latitude 19˚N), would not show much damaging effect in Chittagong around 300 km north of it. So to understand the damage caused in Chittagong, a model with epicenter in Chittagong (22˚N, 92˚E) is simulated but with a lower magnitude of 7.5 (from NDMA catalogue). The focal mechanism of 13 December 2009 earthquake is used as the representative focal mechanism which is of thrust type. The results are shown in Figure 3.5 and comparison with other attenuation laws are shown in Table 3.5. Figure 3.5 is showing the highest value of PGA at Chittagong up to $0.4g$ which is exceeding the BNBC zone co-efficient i.e. $0.28g$.

Table 3.5 Estimated PGA values for 1762 Arakan earthquake with M 7.5

Location	**PGA (g) from NDSHA**	**PGA (g) from DSHA using different attenuation equations**			**Zone co-efficient from updated BNBC**
		Zare et al. 1999	**Al-Hussaini and Islam 2014**	**Abrahamson and Silva 1997**	
Khulna	0.036	0.026	0.040	0.044	0.12
Mongla	0.030	0.027	0.043	0.046	0.12
Jhalokathi	0.019	0.033	0.062	0.058	0.12
Dhaka	0.023	0.028	0.046	0.048	0.20
Faridpur	0.033	0.025	0.038	0.042	0.20
Pabna	0.010	0.021	0.025	0.033	0.20
Comilla	0.019	0.037	0.073	0.066	0.20
Bandarban	0.322	0.136	0.430	0.357	0.28
Kaptai	0.156	0.106	0.288	0.232	0.28
Chittagong	0.111	0.118	0.332	0.272	0.28
Cox's Bazar	0.086	0.091	0.236	0.188	0.28
Rangamati	0.064	0.071	0.172	0.136	0.28
Sylhet	0.014	0.024	0.033	0.039	0.36
Mymensingh	0.016	0.022	0.028	0.035	0.36

The possibility of a mega earthquake (M>8) at the Chittagong Coastal fault is discussed in the some recent research (Cummins 2007, Steckler et al. 2008, Wang et al. 2013). Though this zone is not seismically much active but recent research are suggesting the occurrence of a mega historic earthquake in 1762. To estimate the effect of such an earthquake, a scenario earthquake of M 8.5 is simulated at the Bay of Bengal (21.5˚N, 91.5˚E) with the same thrust type focal mechanism (Figure 3.6). The highest values are seen at the coastal region of Chittagong i.e. 0.2-0.5g. The results also show up to 0.2g PGA at the north most parts of Bay of Bengal such as Bhola, Patuakhali, Barguna. Depending on the location of the epicenter of the earthquake, the peak values may be higher in the coastal regions of Bangladesh. The results are compared with other attenuation laws and presented in Table 3.6. So it can be seen that an earthquake of M 8.5 may exceed the BNBC estimates by a big margin. However more convincing research works are required to prove the possibility of such a mega earthquake in this region which is seismically less active.

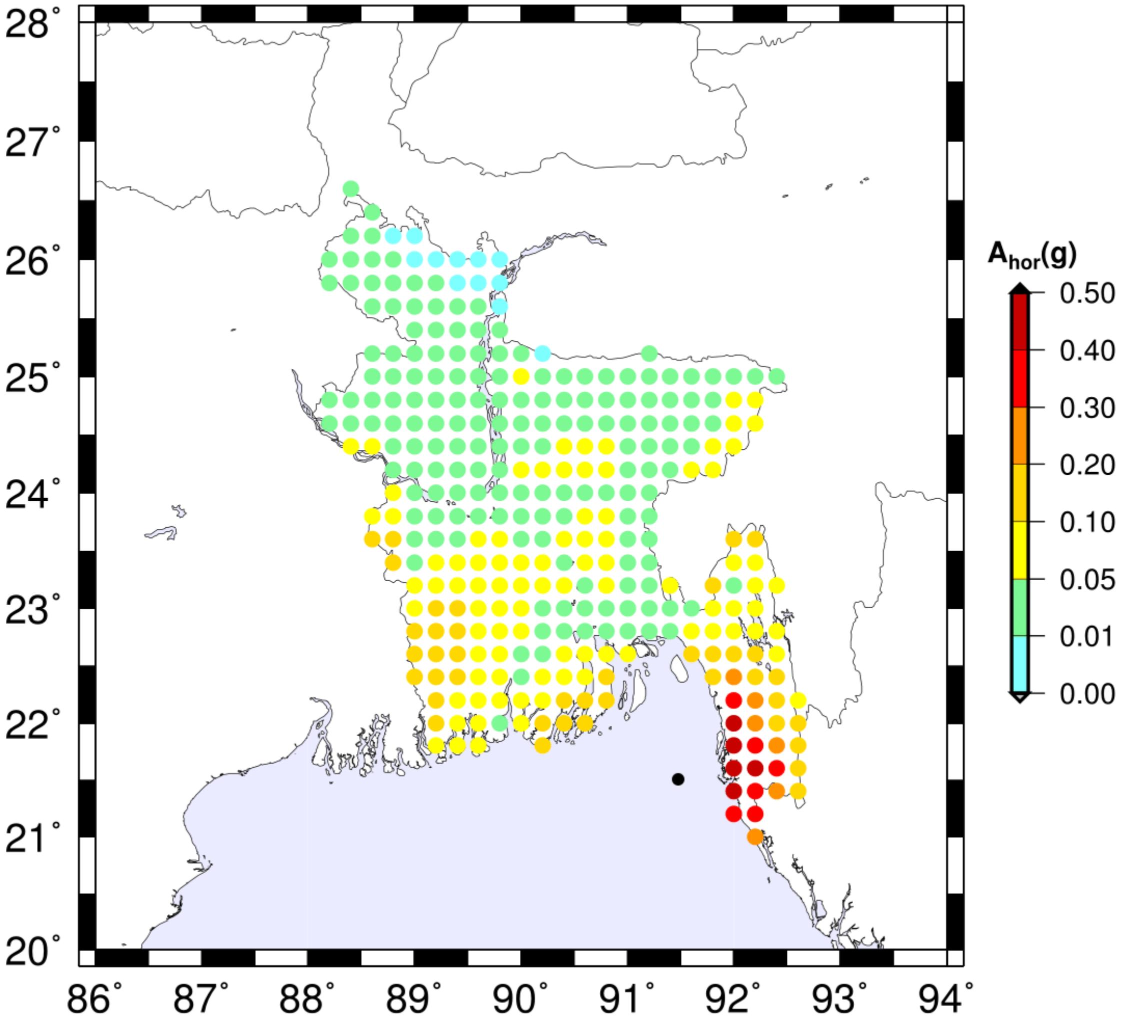


Figure 3.6 Estimated peak ground acceleration (g) using NDSHA for a scenario earthquake of M 8.5 at Bay of Bengal. The epicenter is indicated by a black dot.

Table 3.6 Estimated PGA values for a scenario M 8.5 earthquake at Bay of Bengal

Location	**PGA (g) from NDSHA**	**PGA (g) from DSHA using different attenuation equations**			**Zone co-efficient from updated BNBC**
		Zare et al. 1999	**Al-Hussaini and Islam 2014**	**Abrahamson and Silva 1997**	
Rajshahi	0.053	0.043	0.049	0.069	0.12
Khulna	0.090	0.064	0.128	0.106	0.12
Meherpur	0.098	0.046	0.061	0.075	0.12
Mongla	0.085	0.069	0.147	0.114	0.12
Comilla	0.044	0.074	0.164	0.121	0.20
Dhaka	0.056	0.062	0.120	0.102	0.20
Faridpur	0.062	0.058	0.105	0.096	0.20
Pabna	0.024	0.049	0.071	0.080	0.20
Bogra	0.028	0.044	0.052	0.070	0.28
Chittagong	0.191	0.147	0.423	0.229	0.28
Cox's Bazar	0.458	0.231	0.752	0.366	0.28
Alikadam	0.314	0.144	0.410	0.225	0.28
Rangamati	0.085	0.100	0.258	0.161	0.28
Sylhet	0.040	0.050	0.073	0.079	0.36
Mymensingh	0.043	0.048	0.067	0.078	0.36
Kurigram	0.008	0.039	0.036	0.062	0.36

From the comparison with other attenuation laws (Table 3.2 and Table 3.6), it can be seen that in most of the cases the present study is predicting lower values than that by Abrahamson and Silva and Islam et al. In some of the cases it is showing good conformity with the equations except in the places near to the epicenter, where it is showing higher values than Zare et al. and lower values than Al-Hussaini & Islam. Overall NDSHA is showing reasonable results compared to simple DSHA results following different attenuation equations. Therefore, in the next chapter, a national scale map for Bangladesh with NDSHA is prepared and presented.

CHAPTER 4

NEO DETERMINISTIC COMPUTATION AT NATIONAL SCALE

4.1 General

This chapter includes the neo-deterministic seismic hazard computation at regional or national scale. At first the methodology and the selected input parameters for the computation are described in detail. The results are presented in the form of peak ground displacement, peak ground velocity and peak ground acceleration. The NDSHA map is then compared with PSHA results and the Bangladesh National Building Code (BNBC).

4.2 Input Parameters for National Scale Map

The neo-deterministic seismic hazard assessment (NDSHA) technique has already been used to produce deterministic seismic hazard maps for many parts of the world (e.g. Panza et al. 1999, 2002; Aoudia et al. 2000; Bus et al. 2000; Markusic et al. 2000; Zivcic et al. 2000; El-Sayed et al. 2001, Parvez et al. 2003; Zuccolo et al. 2011). NDSHA is highly dependent on the knowledge of the source and propagation effects. Therefore, properly defined structural models and seismic sources must be used as input parameters after exploiting all available literature. Generally, the input data includes four main groups of parameters: (i) Earthquake Catalogue; (ii) Seismogenic Source Zones; (iii) Fault Plane Solutions and (iv) Structural Models. A brief description of each input parameter for Bangladesh is given in the following sections.

4.2.1 Earthquake Catalogue

Earthquake catalogue is undoubtedly the most essential data for any type of seismic hazard analysis. The earthquake data set used in this study is covering the time interval from 1762 to 2015. The earthquake catalogue for Bangladesh can be divided into three groups: (i) since 1963, based on the WWSSN network and on modern instrumentation; (ii) the period 1900–1962, based on the early instrumental data; and (iii) pre-1900, based on pre-instrumental and historical macro seismic information. The database from the international agencies like International Seismological Centre (ISC), National Earthquake Information Center (NEIC), Global Centroid Moment tensor Project (Global CMT) and national agencies like National Disaster Management Authority of India (NDMA), Bangladesh Meteorological Department

(BMD) etc have been used. Some of the historical events have been included in this study, which are re-assessed in terms of magnitude and location. The catalogue has been prepared for the time span from 1762 to 2015. In NDSHA, catalogue completeness at moderate-to-low magnitudes is not necessary, contrary to PSHA. The spatial distribution of events of magnitude 5 and above is considered here. However a catalogue for magnitudes greater than 4 has been prepared for this study to have a broad idea of the seismic activity of this region. The catalogue is presented in Appendix A and accordingly the seismicity map of Bangladesh and surrounding region is showed in the following Figure 4.1.

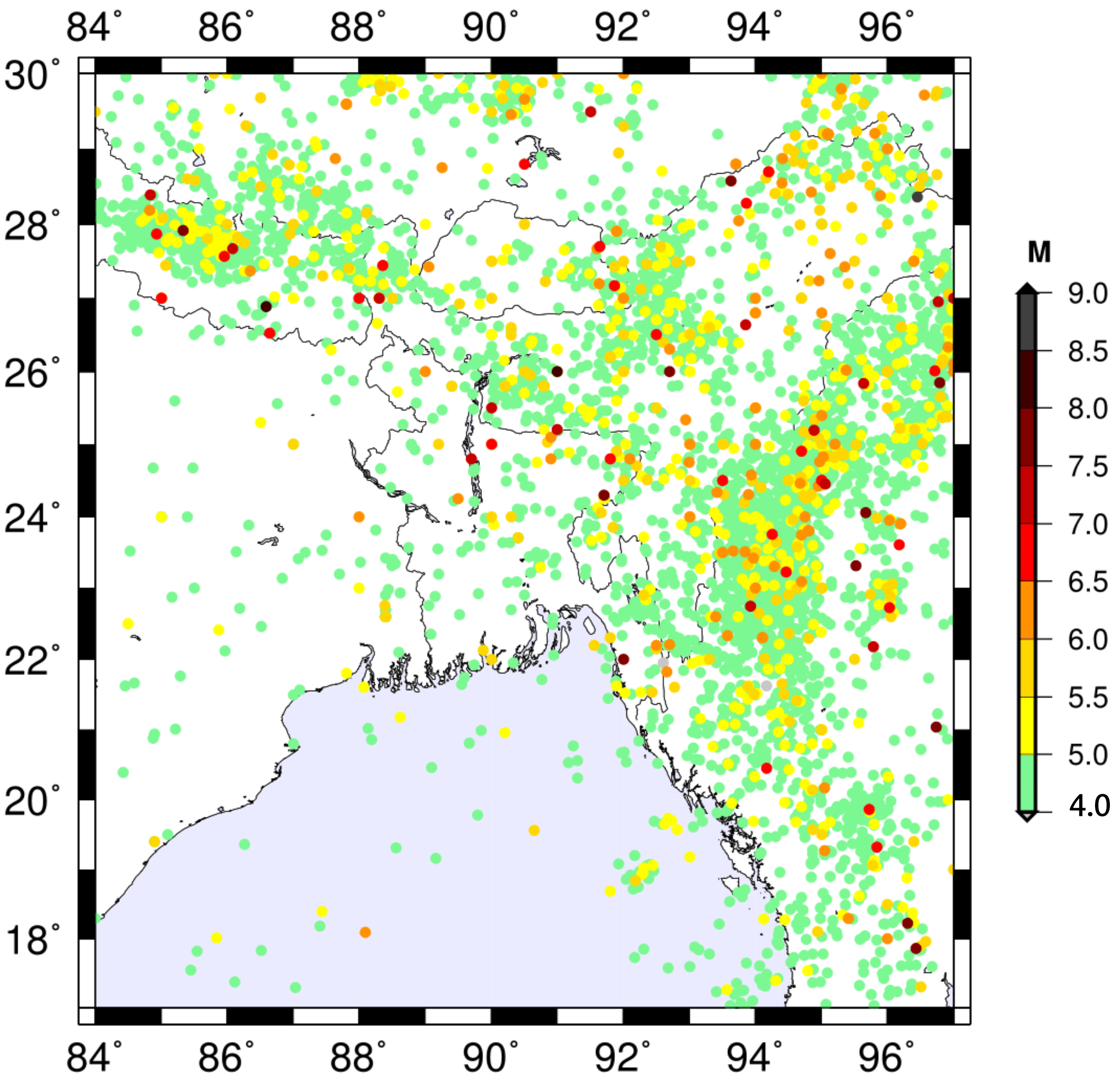


Figure 4.1 Seismicity map of Bangladesh and surrounding region

4.2.2 Seismogenic Source Zones

Seismically active fault zones around Bangladesh have been studied from available literature and explained in detail in Chapter 2. Parvez et al. (2013) defined 40 seismogenic zones for Indian subcontinent, including 6-7 zones around Bangladesh. However the study was in a broad scale for Indian subcontinent and therefore many of these zones were quite big. Al-Hussaini and Hasan (2006) studied the zonal seismicity characteristics for Bangladesh. They had used two approaches, one using Bolt's (1987) findings and the other based on the cluster of major earthquake epicenters. This study has some resemblance to the later approach but it is more based on the tectonics of active and probable fault zones. Eight (8) seismogenic zones have been defined for Bangladesh (Figure 4.2). These zones are identified and classified on the basis of seismicity and location of major and minor faults in and around Bangladesh (Table 4.1).

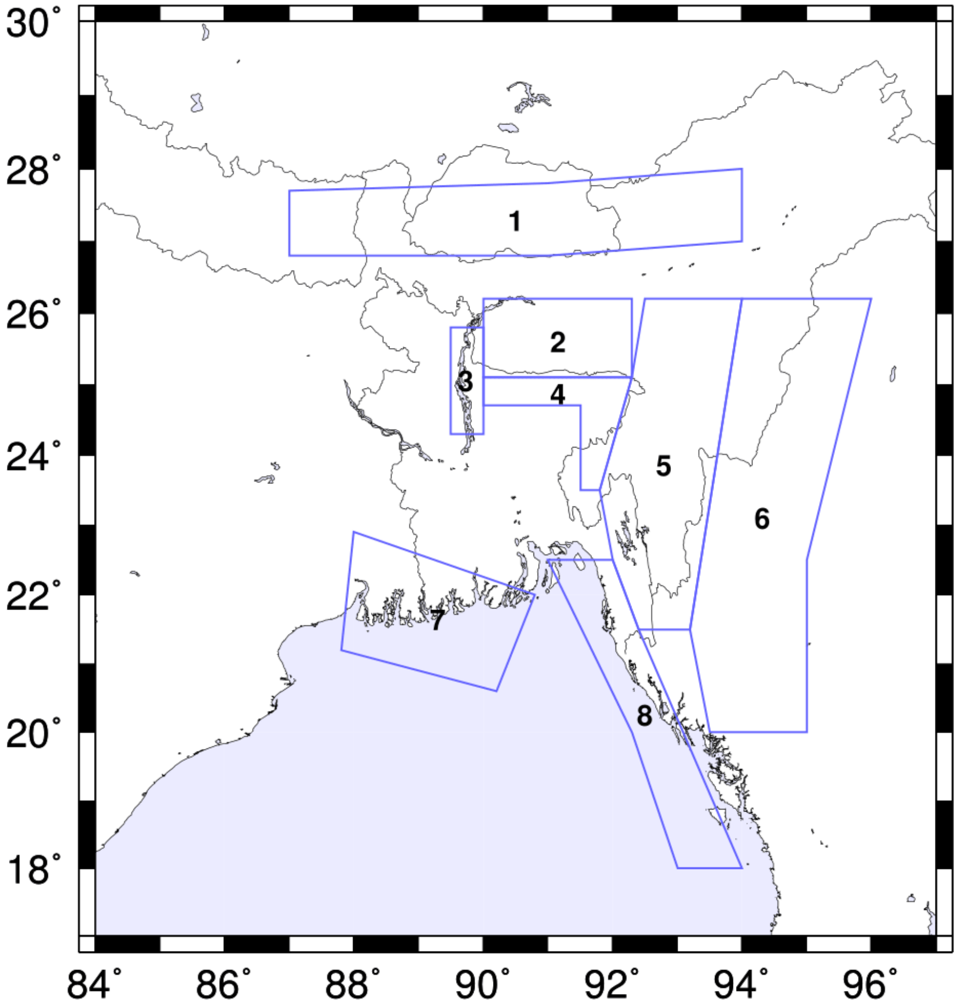


Figure 4.2 Seismogenic Zones defined for Bangladesh

Table 4.1 Seismogenic Source Zones

Zone	Location
1	Main Boundary Thrust Fault Zone
2	Dauki Fault Zone
3	Madhupur Fault Zone
4	Sylhet Tripura Fault Zone
5	Kaladan Fault Zone
6	Indo-Burmese Plate Boundary Fault Zone
7	Southwest Coastal Fault Zone
8	Chittagong Coastal Fault Zone

The seismic source zones are dense around the Northern and Eastern part of the country and along the Main Plate Boundary. However a gap is seen in the middle of the Bengal basin as it is relatively quite in seismic activity. The characteristics of these 8 seismogenic zones are described in the following section.

4.2.3 Fault Plane Solutions

Neo-deterministic method takes into account the focal mechanism of the source which includes the strike, dip and rake angle associated with the fault. Fault plane solutions in this study are taken from the Global Centroid-Moment-Tensor (CMT) Project catalogue (Previously Harvard CMT Project) and are plotted in Figure 4.3. The table containing all focal mechanism data used to plot Figure 4.3 is presented in Appendix B. Moreover, published focal mechanism solutions by different researchers have been used for the large historical earthquakes that occurred before 1977. For each seismogenic zone; a representative fault plane solution is defined by looking at the mechanism associated with the strongest event or with the best obtained event. The studied region is dominated by reverse and strike-slip fault plane solutions, although normal faulting is also seen in a few zones.

The zone 1 Main boundary fault shows mainly reverse or thrust type faulting. However some earthquakes with strike slip or oblique mechanisms can also be seen in this zone. The 2009 Sikkim earthquake (M 6.9) was an intra-plate earthquake with strike-slip focal mechanism. As it is more likely that an earthquake with reverse mechanism will cause more damage than a strike-slip one, the representative focal mechanism for this zone is taken from the 25 April, 2015 Nepal earthquake (M 7.9) which had a reverse mechanism.

For zone 2 Dauki fault, there is not enough focal mechanism data available. Because this zone did not show much seismic activity in near past. But the zone is identified as a potential one because of the existence of a reverse fault at North and South end of Shillong plateau, and evidence of historical earthquakes (e.g. 1897 Great Indian earthquake, 1930 Dhubri earthquake). For this zone the focal mechanism of 1897 Great Indian earthquake (M 8.65) was taken from the findings of Bilham and England (2001). They proposed that the reverse fault plane was dipping south at 57˚ with a rake of 76˚.

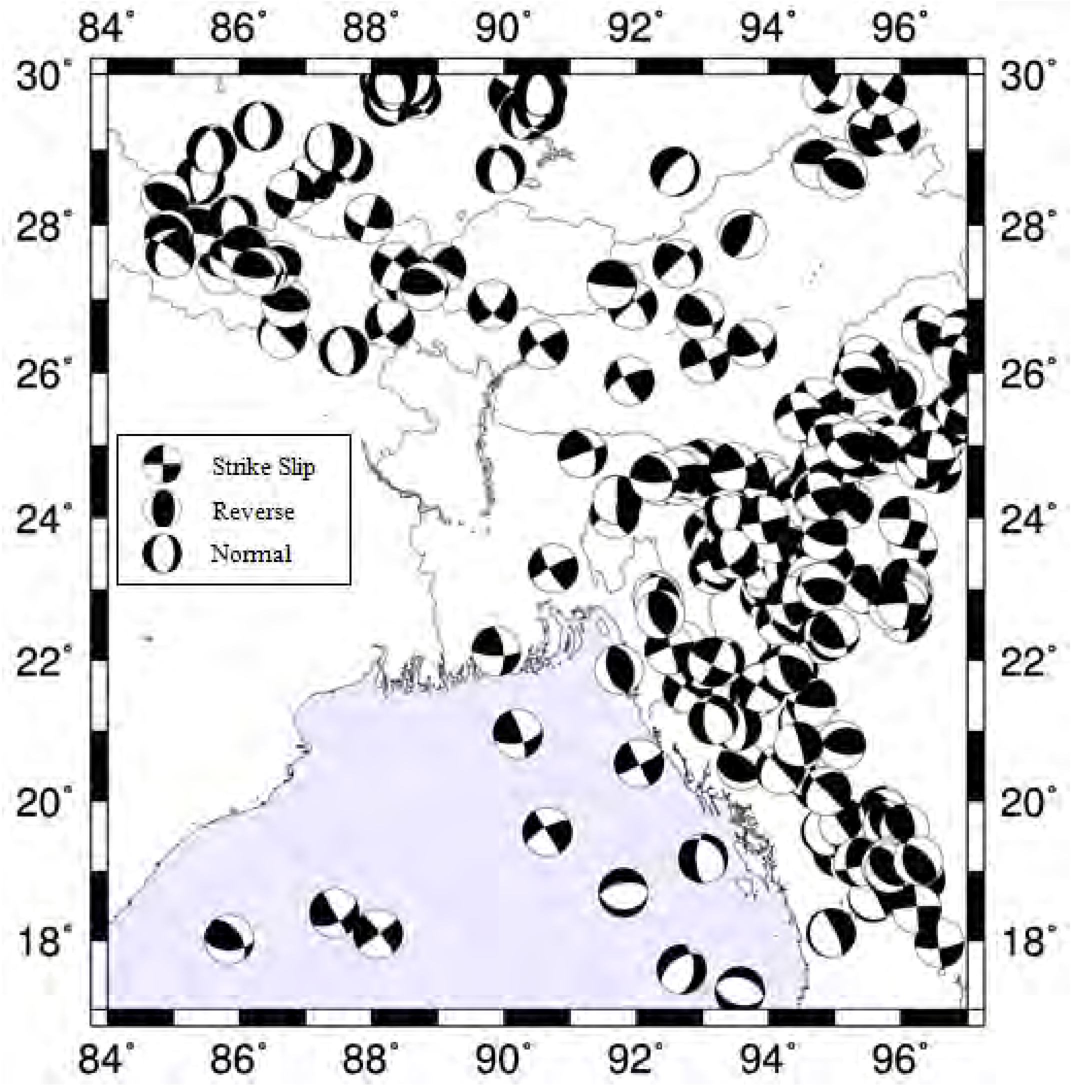


Figure 4.3 Fault plane solutions taken from Global CMT catalogue ranging between 1977 to 2015

Zone 3 Madhupur Fault zone also has not shown any seismic activity in near past. This zone is considered as the source of 1885 Bengal earthquake (M 7.0). Many of the recent geological research (CDMP report 2013, Steckler et al. 2008) also suggest the existence of this east-dipping blind fault which resulted in an uplifted terrace in Madhupur region. As there is no focal mechanism available for this intra-plate fault, this study assumes a strike slip focal mechanism for this zone similar to that of Matlab earthquake 2010.

Zone 4 Sylhet Tripura Fault Zone shows mainly oblique focal mechanism. 1918 Srimangal earthquake (M 7.6) may have occurred due to the rupture of this segment. Though this zone has not shown any large earthquake in near past, but it shows regular seismic activity with magnitude around 5. This study takes the focal mechanism of 2 March 2013 earthquake (M 5.2) for this zone which is oblique-slip reverse in type.

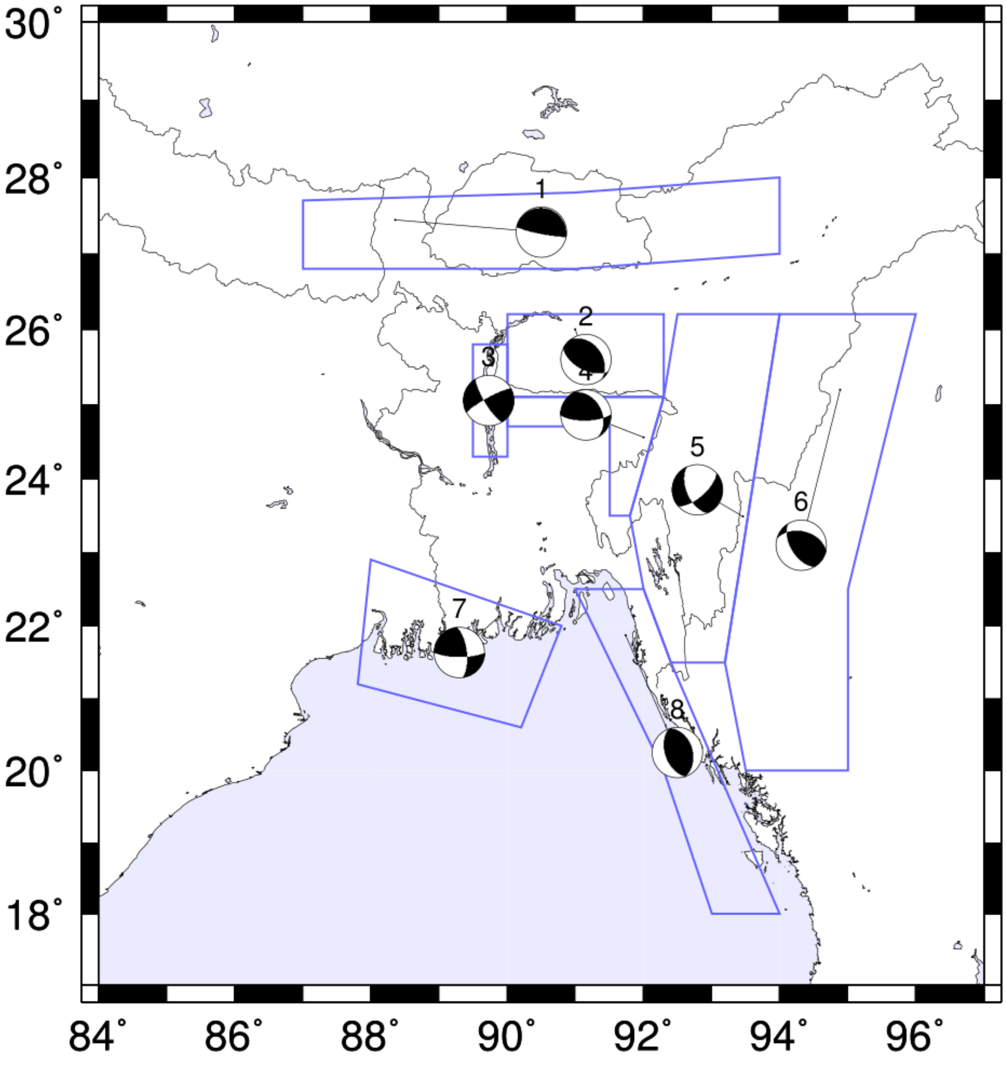


Figure 4.4 Representative focal mechanism for each seismogenic zone

Zone 5 Kaladan fault zone is seismically active and shows a varied type of focal mechanism. The south part of it around Chittagong did not show a large earthquake in recent times, but its

North portion had experienced large earthquakes like 1869 Cachar earthquake (M 7.5). This study takes the focal mechanism of 3 January 2016 earthquake (M 6.7) for this zone which is an oblique-slip normal faulting.

Zone 6 Indo-Burmese Plate boundary fault shows the most frequent seismic activities in the study region. This zone is dominated by reverse or thrust type faulting. The focal mechanism of 6 August 1988 earthquake (M 7.2) has been taken as the representative one for this zone.

Zone 7 Southwest Coastal Fault Zone is seismically less active. This zone is an intra-plate fault and so a strike-slip focal mechanism is very evident for it. The focal mechanism of 12 June 1989 earthquake (M 5.8) is taken as a representative one for this zone.

Finally Zone 8 Chittagong Coastal Fault zone also comes into consideration due to some recent geological research as that of Madhupur zone. The 1762 earthquake is considered to have ruptured this segment starting from Myanmar coast to Chittagong (Wang et al. 2013). This zone is also suspected to be an extension of Sumatra subduction zone (Dasgupta & Nandy 1995, Steckler et al. 2008). This study takes the focal mechanism of 13 December 2009 (M 4.9) earthquake for this zone which is of thrust type. The representative focal mechanism for each zone is shown in Figure 4.4.

4.2.4 Structural Model

Structural models are one of the basic input parameters of NDSHA. Structural models with different lithospheric properties are identified and separated in regional polygons. These structural models are represented by a number of horizontal layers; described by its thickness, density, P (compression) and S (shear) wave velocities and corresponding Q (attenuation) values. The structural models are representative of regional average bedrock properties within each polygon. The properties of the structures are usually defined by the inversion analysis of the receiver functions, received from the seismic stations. Due to lack of seismic data from Bangladesh, so far the data from the active seismic stations in surrounding India have been used to define the crustal structure of Bengal basin. Parvez et al. (2003) proposed a suitable structural model for Indian subcontinent after investigating all available geophysical and geological information for the study area (e.g. Ram & Mereu 1977; Roecker 1982; Lyon-Caen 1986; Singh 1987,1988,1994; Bourjot & Romanowicz 1992; Ramesh et al. 1993; Mohan & Rai 1995; Srinagesh & Rai 1996; Curtis & Woodhouse 1997; Mohan et al. 1997;

Prakasam & Rai 1998; Cotte et al. 1999; Johnson &Vincent 2002; Kayal & Mukhopadhyay 2002). Recently, these models have been updated (Magrin et al. 2016) with the data from more recent publications (Ravi Kumar et al. 2001, Ravi Kumar and Mohan 2005, Prasad et al. 2005; Mandal 2006; Murty et al. 2008,Tewari et al. 2009, Julia et al. 2009; Acton et al. 2010, Srinagesh et al. 2011, Mitra et al. 2005, 2011). Relatively higher resolution cellular model, with structures defined for cells of 1° × 1° are defined as substitutes to the previous model by Parvez et al. (2003).

Acton et al. (2011) used the data from broadband seismic stations (Figure 4.5) across West Bengal and Darjeeling-Sikkim, therefore determining the shear wave velocities of this area. Singh et al. (2013) investigated the near surface shear velocity of Indian region with the data from 144 seismic stations in India (Figure 4.6). The results showed lower shear wave velocities beneath regions of large sedimentation.

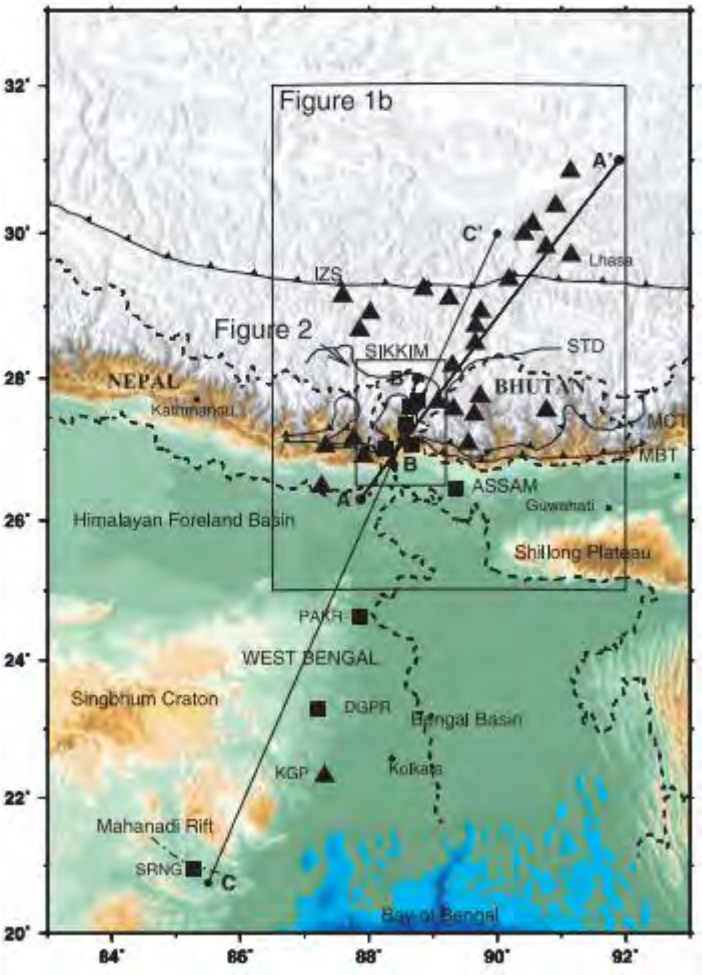


Figure 4.5 Summary map showing the location of seismographs providing data (Acton et al. 2011)

Recently with the seismic data available from 11 seismic stations (Figure 4.7) in Bangladesh, Singh et al. (2016) determined the crustal structure (Figure 4.8) beneath Dhaka, Madhupur and Sylhet region. They have used the data of seismic stations operated jointly by Dhaka University and Lemont-Doherty Earth Observatory of Columbia University at New York. Additional data from seismic station operated by Indian Meteorological Department was also used. The structural models for Bangladesh are updated with these recent findings.

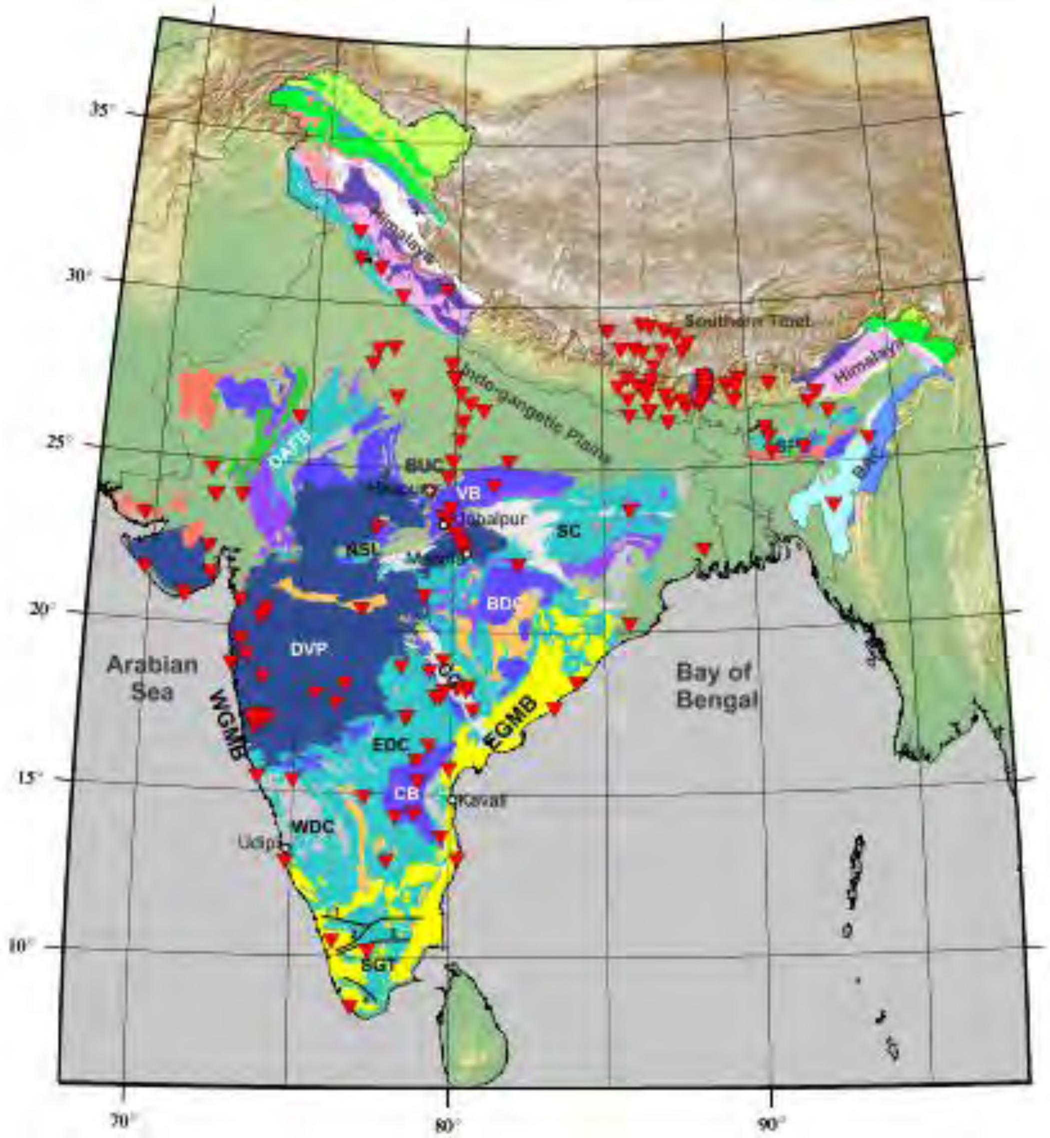


Figure 4.6 Location of broadband seismic stations (inverted triangles) on the Indian subcontinent (Singh et al. 2013)

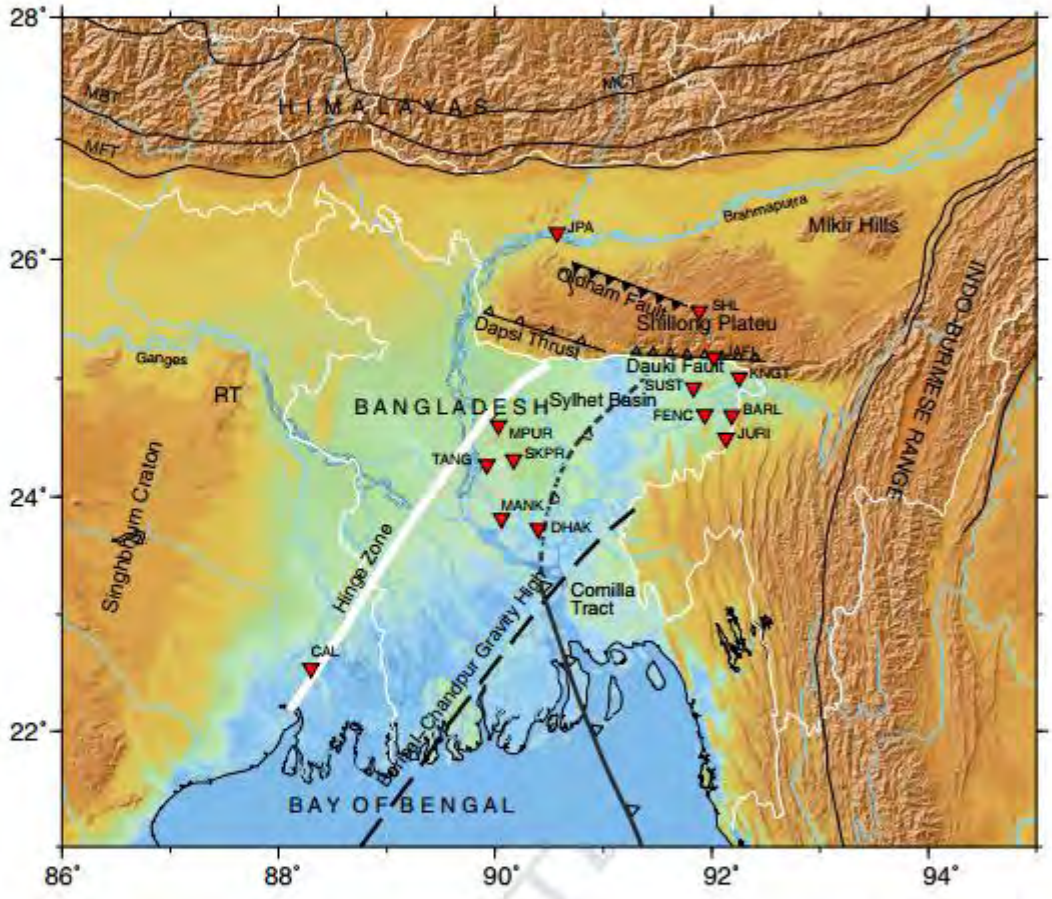


Figure 4.7 Tectonic setting and location of broadband seismic stations from the Bengal Basin and surrounding region (Singh et al. 2016)

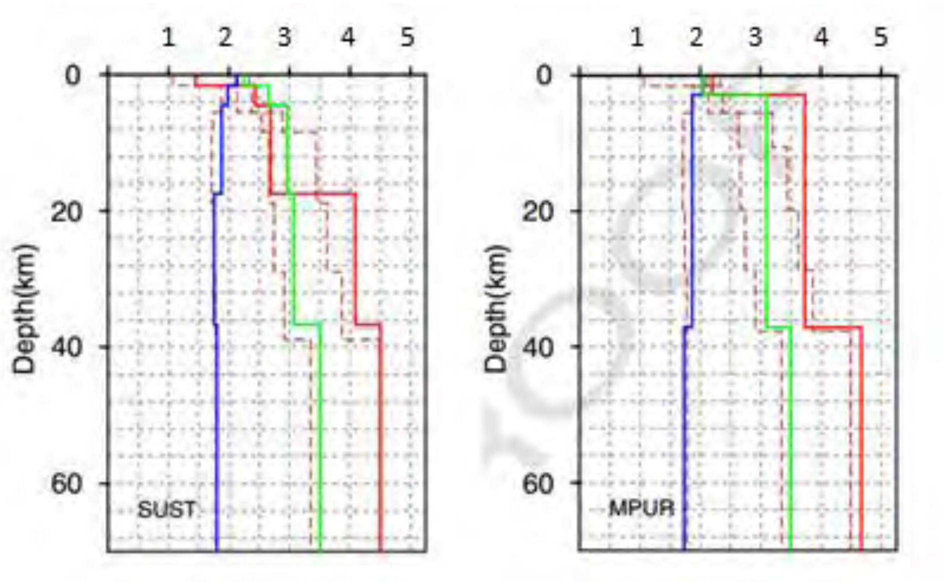


Figure 4.8 Results of inversion of receiver function at Sylhet seismic station (SUST) and Madhupur seismic station (MPUR). Specific of line color are: blue: v_P/v_S ratio, green: density (gm/cm^3), red: v_S (km/s) (Singh et al. 2016)

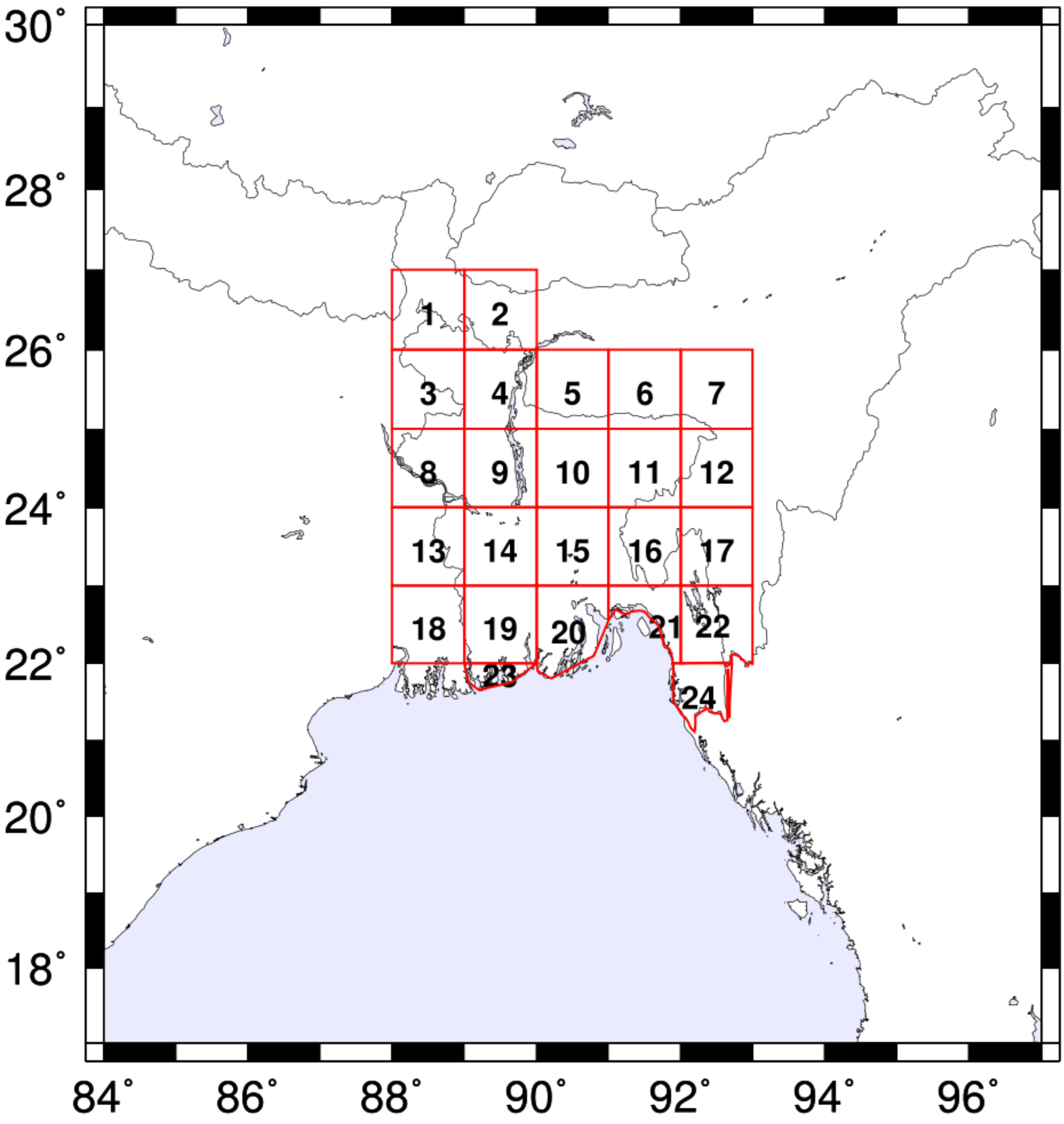
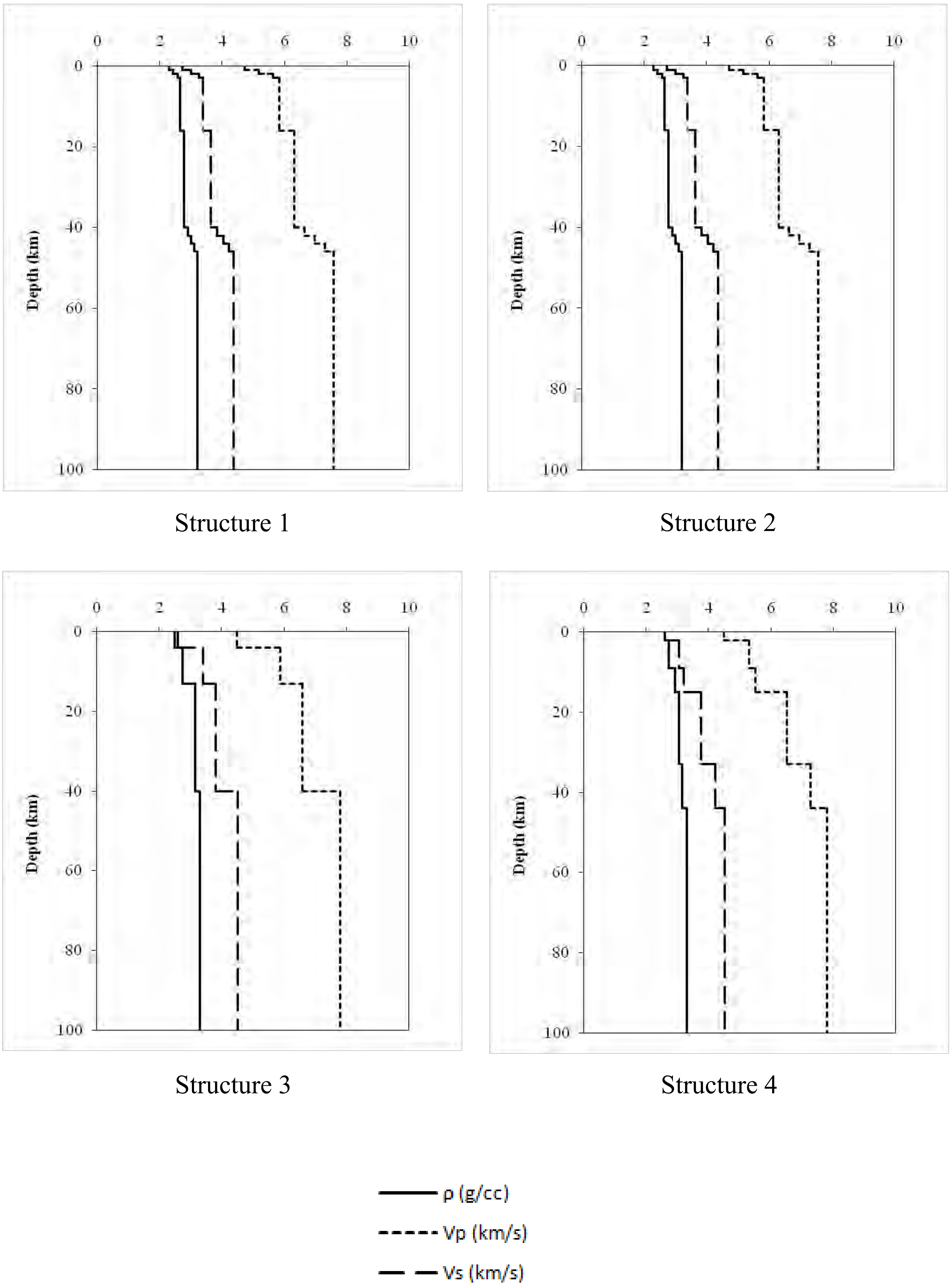


Figure 4.9 Structural polygons with different structural models

In the present study Bangladesh is divided into 24 structural polygons of 1° × 1° in area shown in Figure 4.9 . The average structural model of each polygon used in the computations is shown in Figure 4.10, to a depth of 100 km. The parameters include shear wave velocity (v_S), P-wave velocity (v_P) and density (ρ).



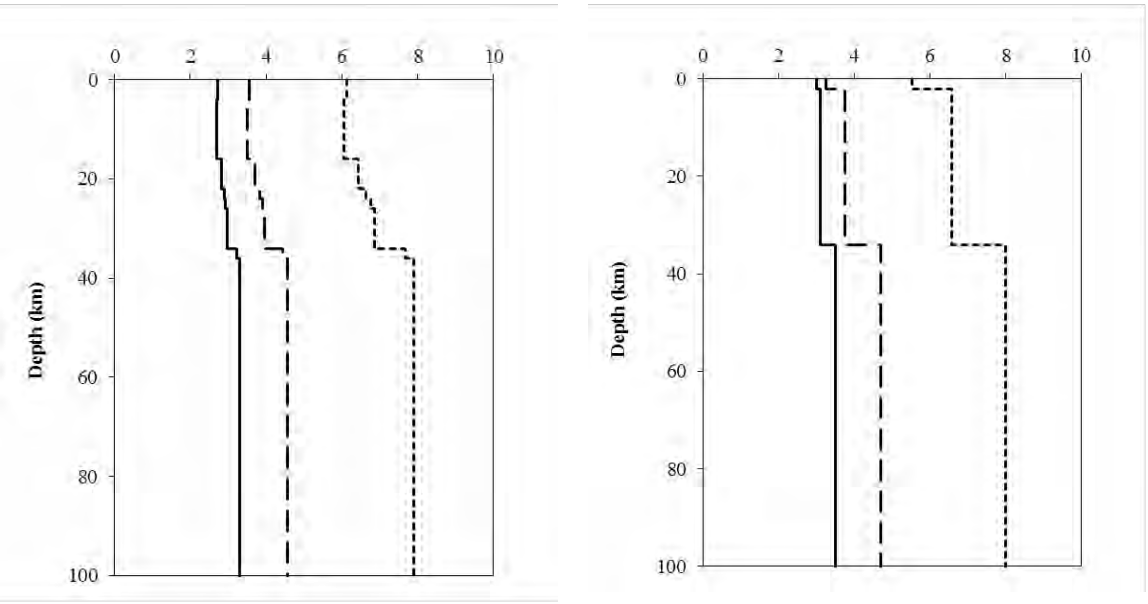
Structure 1

Structure 2

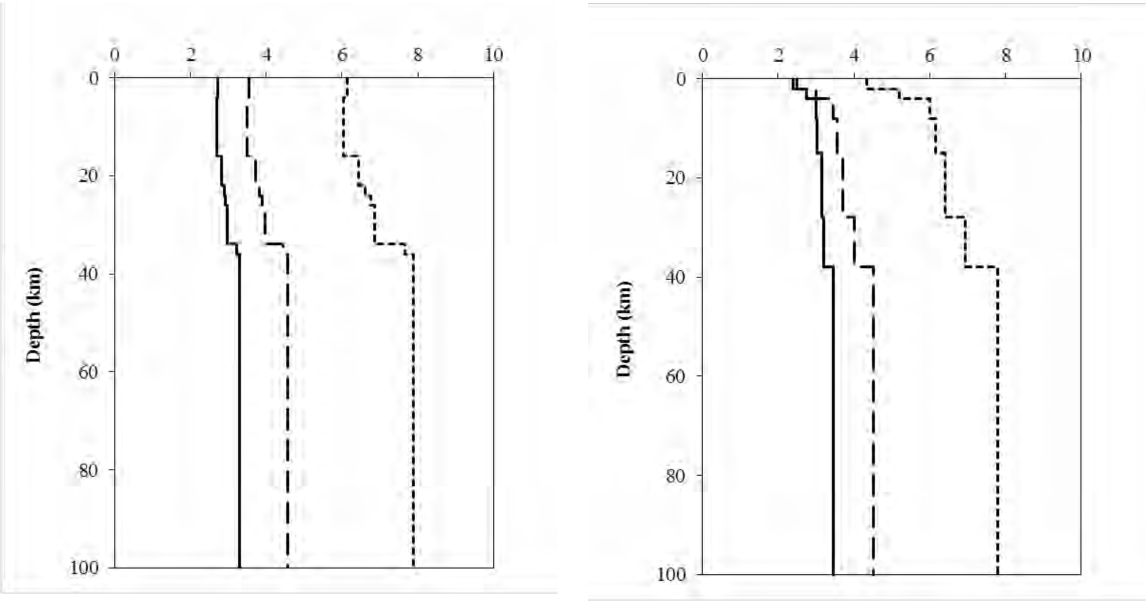
Structure 3

Structure 4

Figure 4.10 Average lithospheric structure for Bangladesh upto 100 km. Density ρ (g/cm^3), Shear wave velocity v_S (km/s), P-wave velocity v_P (km/s)

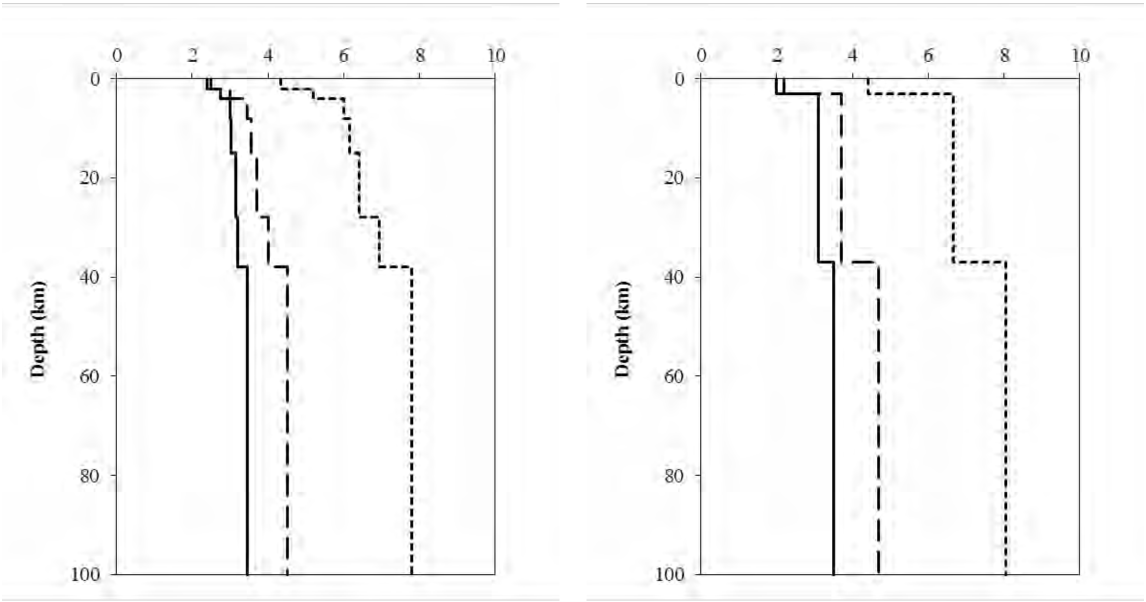


Structure 5 Structure 6



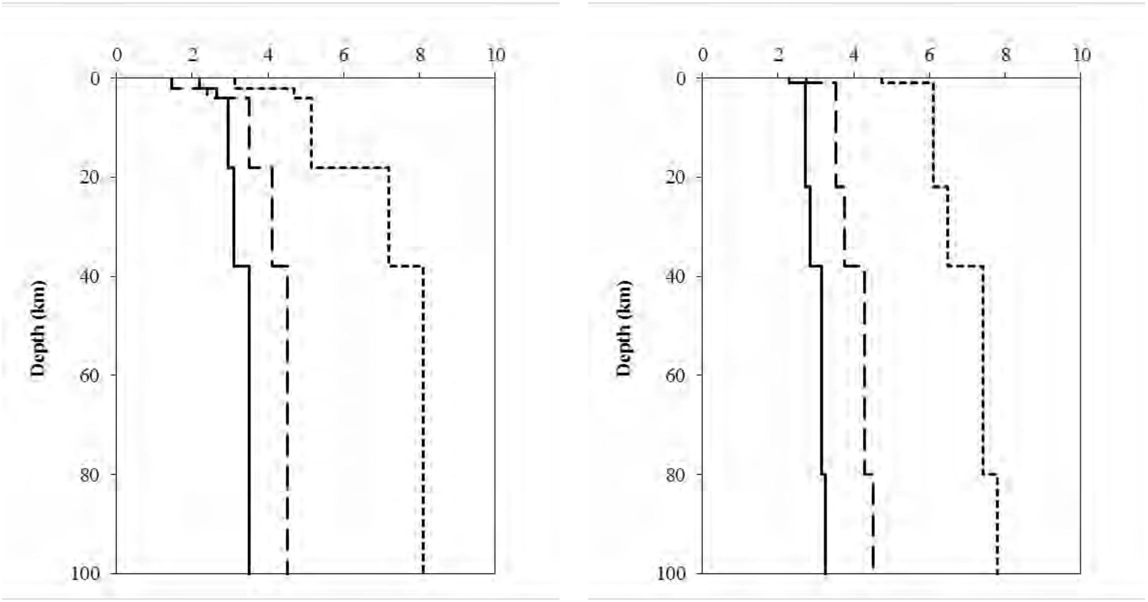
Structure 7 Structure 8

Figure 4.10 (Continued) Average lithospheric structure for Bangladesh upto 100 km. Density ρ (g/cm^3), Shear wave velocity v_S (km/s), P-wave velocity v_P (km/s)



Structure 9

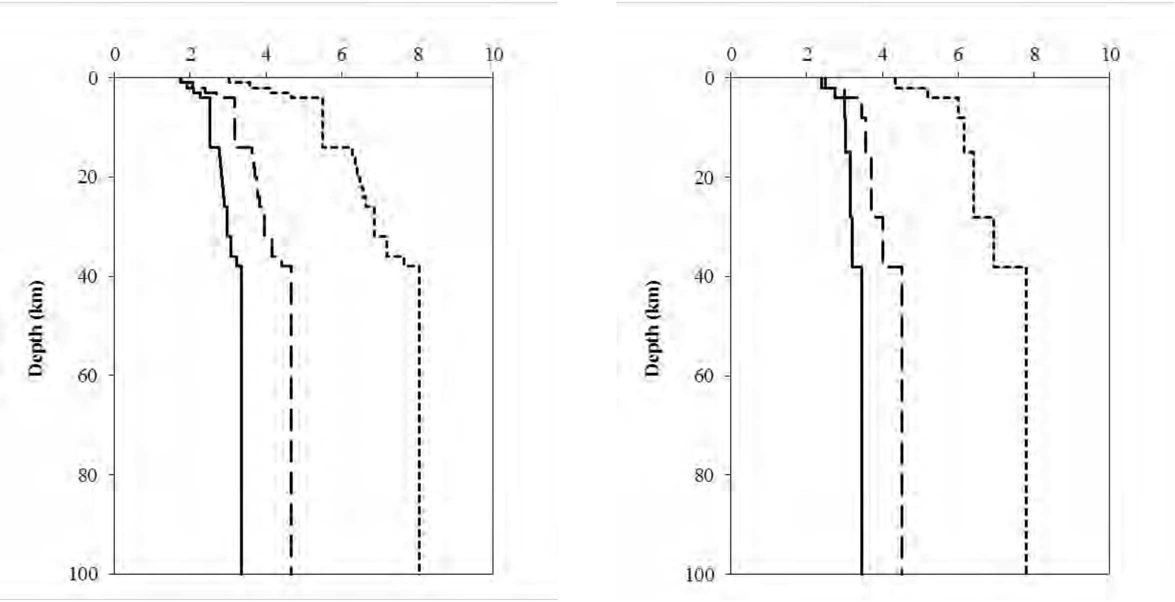
Structure 10



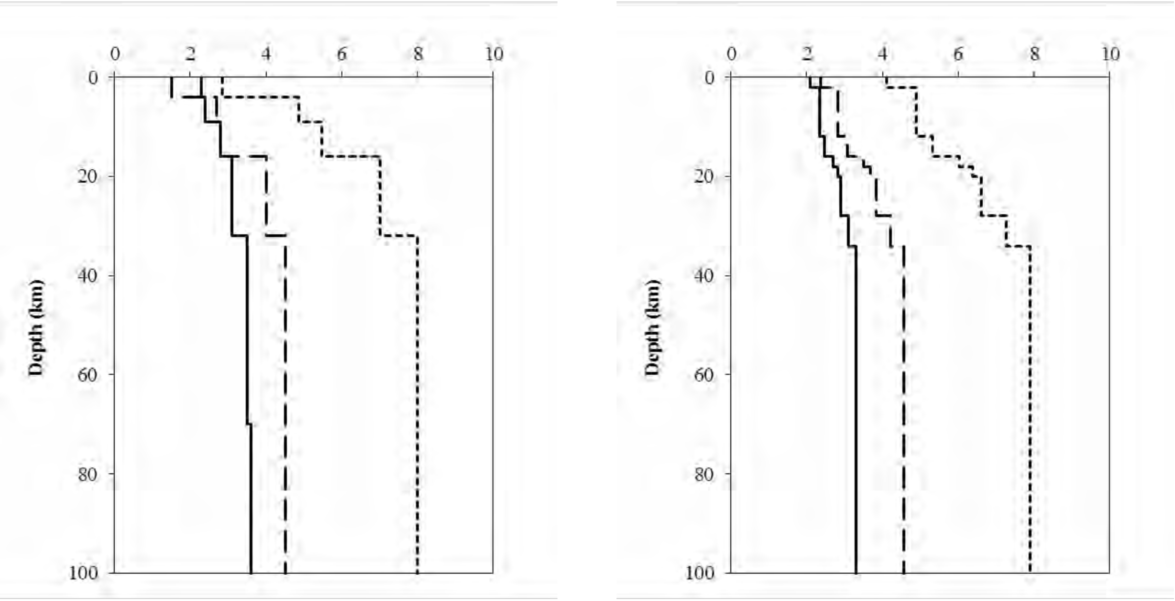
Structure 11

Structure 12

Figure 4.10 (Continued) Average lithospheric structure for Bangladesh up to 100 km. Density ρ (g/cm^3), Shear wave velocity v_S (km/s), P-wave velocity v_P (km/s)

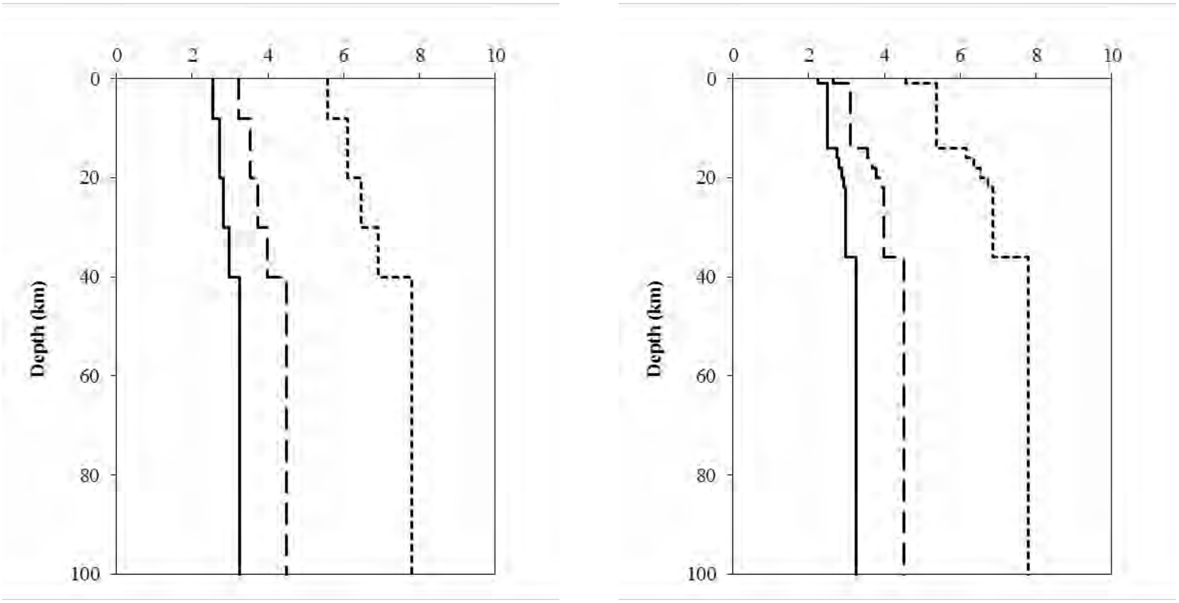


Structure 13 Structure 14

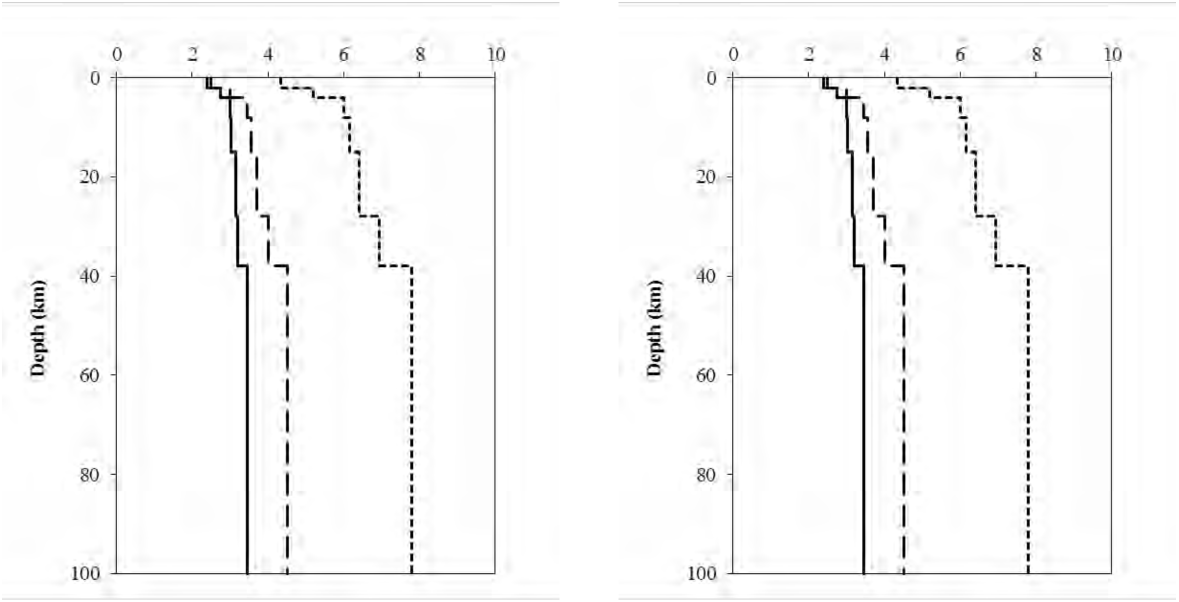


Structure 15 Structure 16

Figure 4.10 (Continued) Average lithospheric structure for Bangladesh up to 100 km. Density ρ (g/cm^3), Shear wave velocity v_S (km/s), P-wave velocity v_P (km/s)

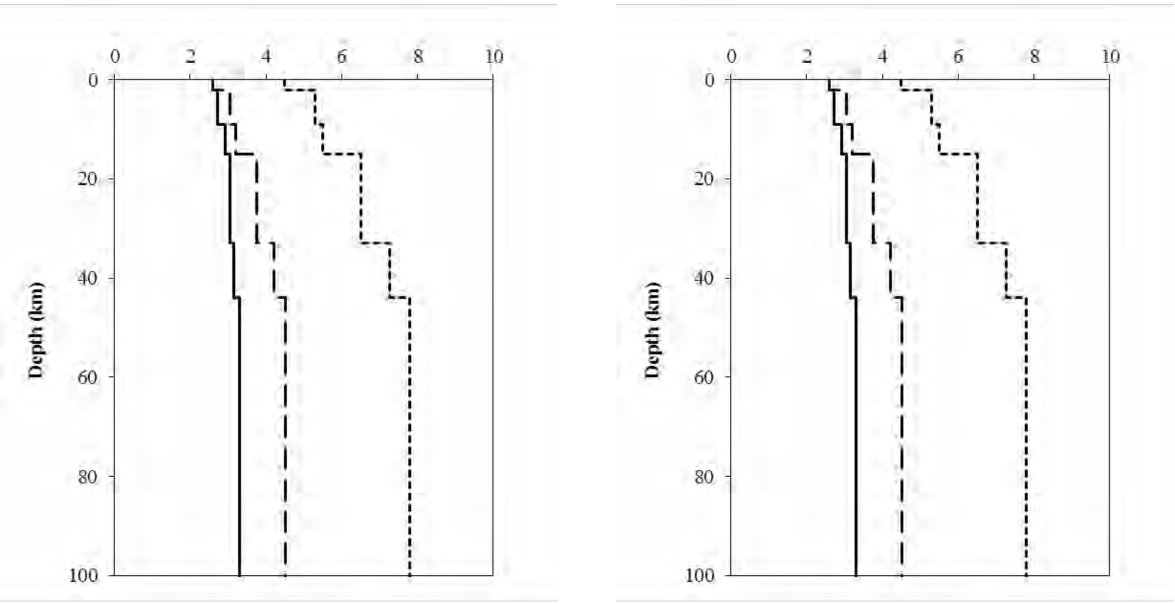


Structure 17 Structure 18

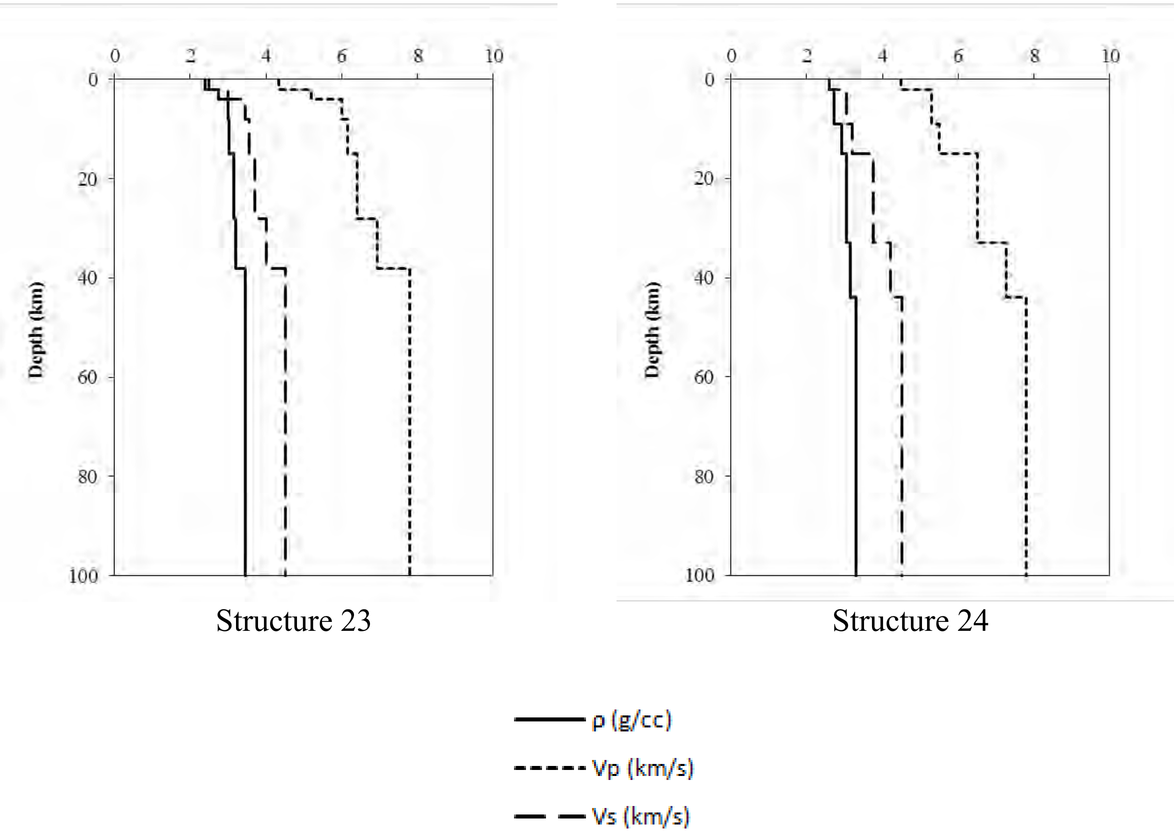


Structure 19 Structure 20

Figure 4.10 (Continued) Average lithospheric structure for Bangladesh up to 100 km. Density ρ (g/cm^3), Shear wave velocity v_S (km/s), P-wave velocity v_P (km/s)



Structure 21 Structure 22



Structure 23 Structure 24

Figure 4.10 (Continued) Average lithospheric structure for Bangladesh up to 100 km. Density ρ (g/cm^3), Shear wave velocity v_S (km/s), P-wave velocity v_P (km/s)

The Quality Factor Q related to attenuation of seismic wave is also needed to complete the structural model. The Q-structure beneath India has been studied by Singh (1991), Yu et al. (1995), Mitchell et al. (1997), Parvez et al. (2001). Parvez et al. (2003) developed the structural models for India and surrounding region with high Q values conforming to the studies mentioned. This Q-structure was further updated by Magrin et al. (2016) based on the attenuation study across Eurasia of Mitchell et al. (2008) and the study of Gung and Romanowicz (2004). Figure 4.11 illustrates the Q map presented by Mitchell et al. (2008). The Q_S (for S-wave) and Q_P (for P-wave) values considered in the uppermost crustal layer for each structural polygon in the present study are presented respectively in Figure 4.12 and Figure 4.13.

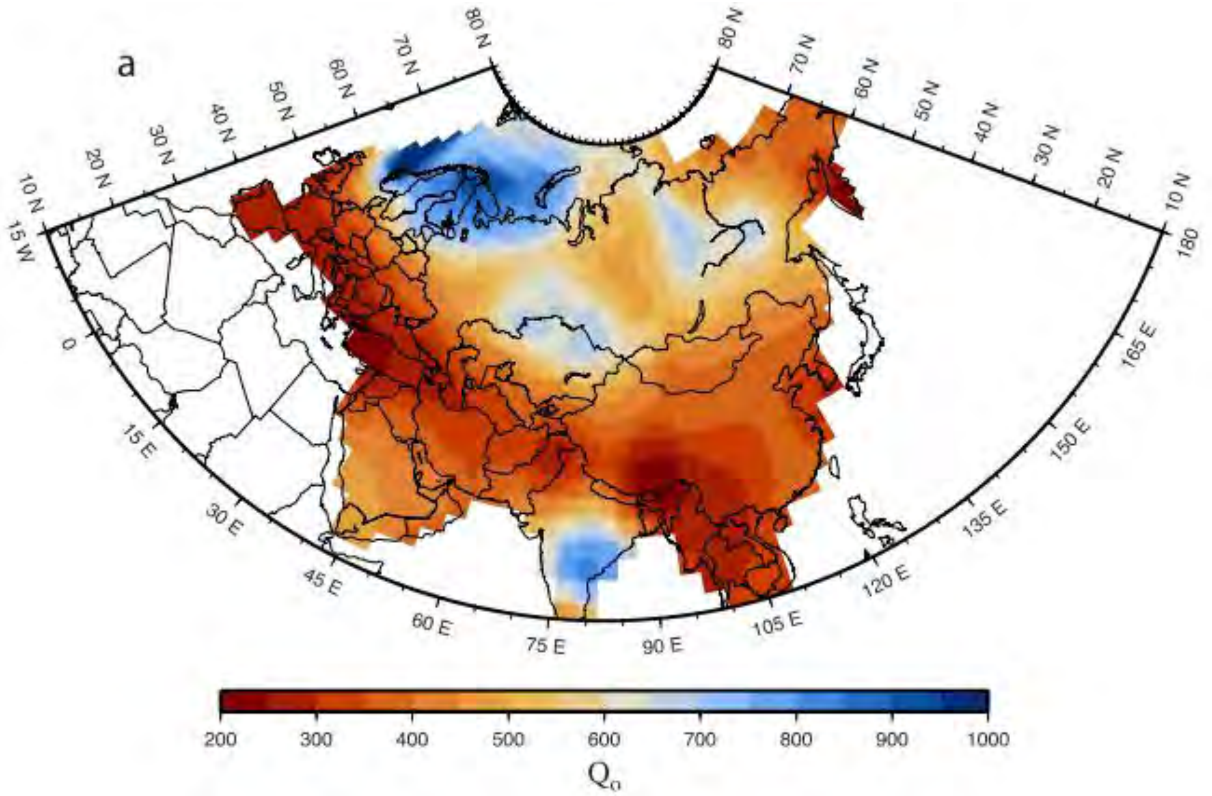


Figure 4.11 Tomographic map of Q_o(Q at 1 Hz) of Eurasia (Mitchell et al. 2008)

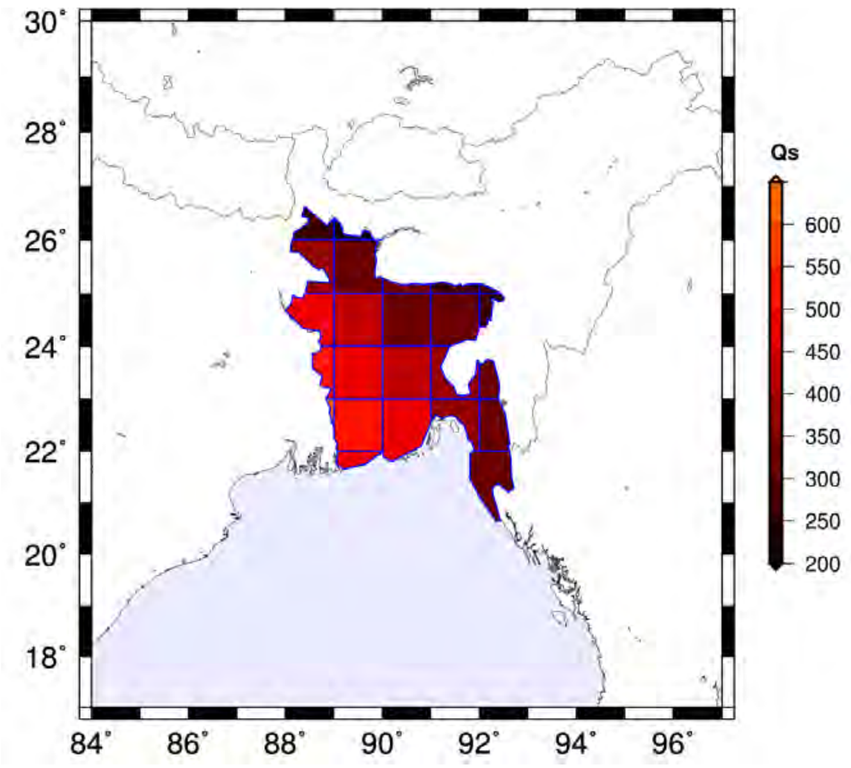


Figure 4.12 Quality factor (Q_S) used for uppermost crustal layer of each structure of Bangladesh

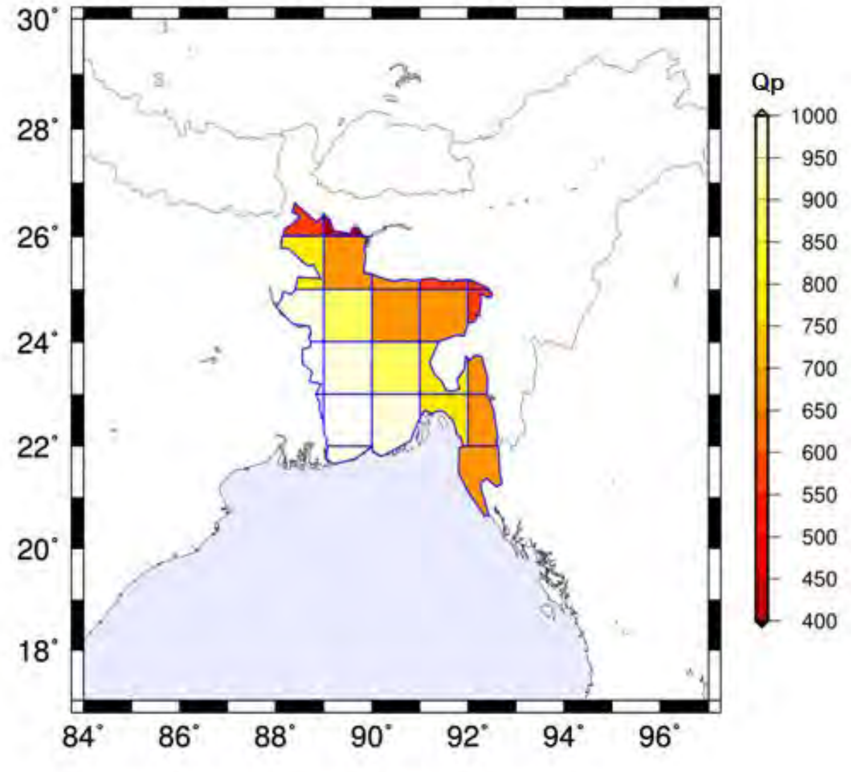


Figure 4.13 Quality factor (Q_P) used for uppermost crustal layer for each structure of Bangladesh

4.3 Computation

The computation method described in Zuccolo (2009) is followed in the present study. The flow chart of NDSHA method is presented in Figure 4.14.

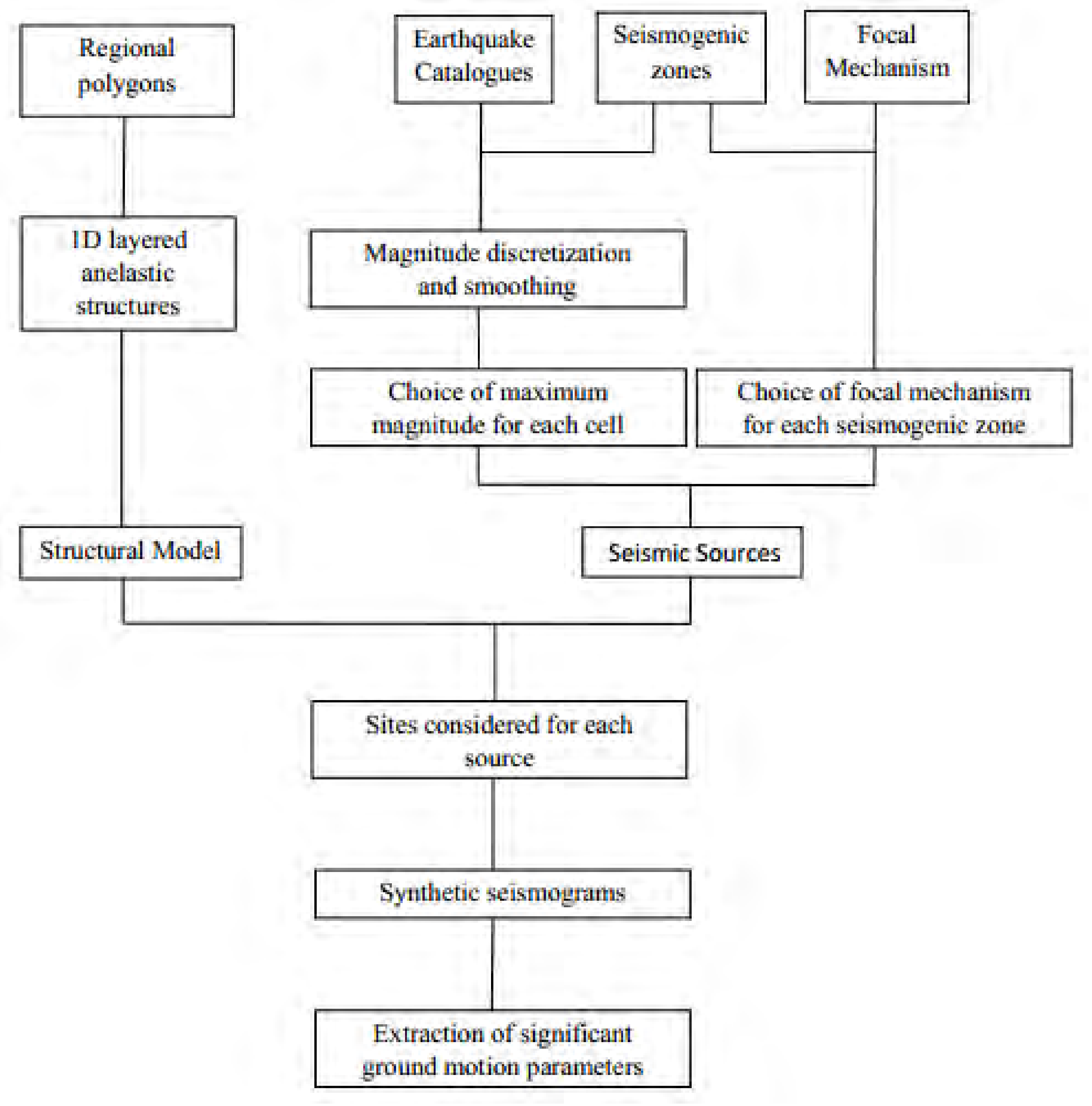


Figure 4.14 Flow chart of NDSHA method

In NDSHA method the seismicity data are handled in a specific way allowing space distribution of seismicity. The earthquake epicenters in the catalogue are discretized into 0.2°×0.2° cells, assigning to each cell the maximum magnitude recorded within it. Then a smoothing procedure is applied to account for errors in locating the epicenters and for their extension in space (rupture length). A centred smoothing window with radius equal to 3 cells is defined in order to assign the magnitude of the central cell to the other cells of the window, if they are characterized by a magnitude lower than the magnitude of the central cell (Figure 4.15). Only the cells located within the seismogenic zones are retained and if the resulting magnitude in each cell is lower than 5, a magnitude 5 is assigned by default (Figure 4.16). This choice is made in the hypothesis that, wherever a seismogenic zone is defined, damaging earthquakes may occur, and the value of 5 is conventionally taken as lower bound for the magnitude of damaging earthquakes. This procedure for the definition of earthquakes location and magnitudes for the NDSHA makes the method pretty robust against uncertainties in the earthquake catalogue, which is thus not required to be complete for magnitudes lower than 5.

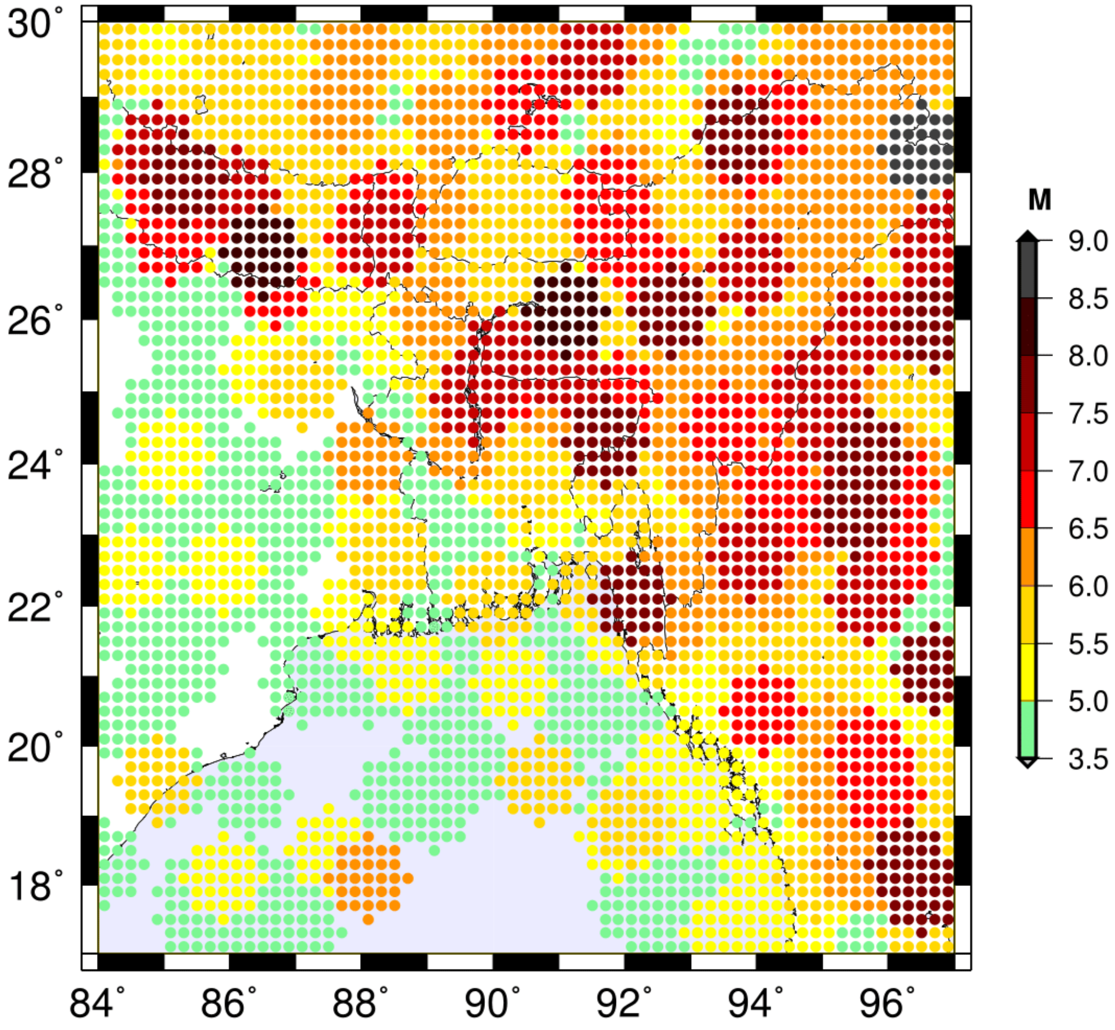


Figure 4.15 Discretization of maximum magnitude with a smoothing parameter of 3

A double-couple point source, with a focal mechanism consistent with the properties of the corresponding seismogenic zone and a depth, which is a function of magnitude (10 km for M

< 6, 20 km for 6≤M<7 and 30 km for M ≥7), is placed at the centre of each cell. Keeping the hypocentral depth fixed (for classes of magnitude) and shallow is important due to the large errors generally affecting the hypocentral depth reported in the earthquake catalogues and due to the fact that strong ground motion is mainly controlled by shallow sources (Vaccari et al., 1990). The depth magnitude function for Italy (10 km for M < 7, 15 km for M ≥ 7) is modified for the geologic condition of Bangladesh. Bangladesh is the largest river delta in the world and is underlain by thick sedimentary layers ranging from 12 km to 20 km over the crust (Johnson and Nur Alam 1991, Curray 1991, Maurin and Rangin 2009, Singh et al. 2016). Due to this, there is less possibility of a very shallow earthquake with high magnitude to occur in this region. CDMP report (2013) also suggests the depth of the active faults at about 30-35 km.

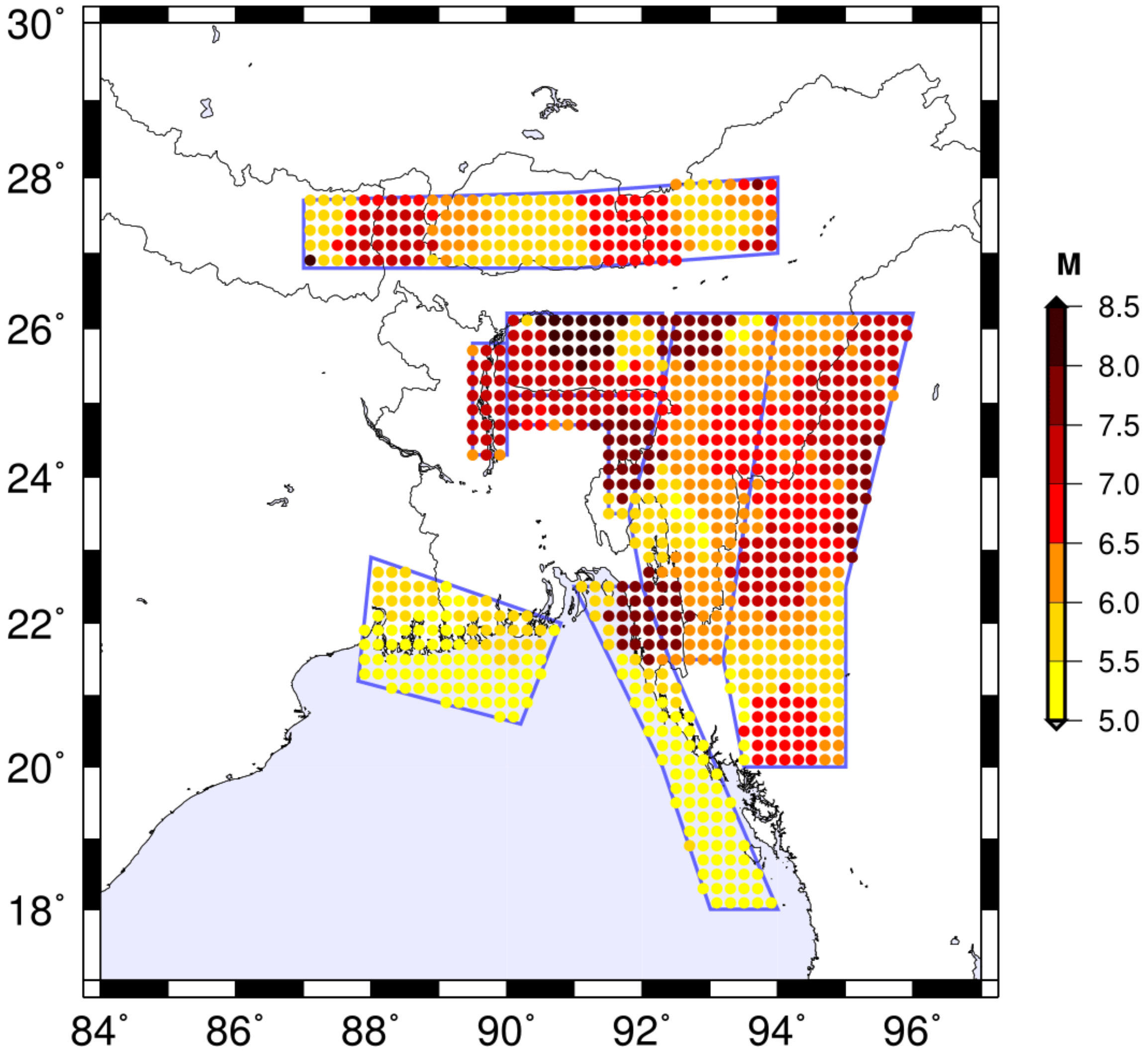


Figure 4.16 Smoothed magnitude over the seismogenic zones

Once the structures and the sources have been defined, sites are considered at the vertices of the grid (0.2°×0.2°) that covers the whole territory. To optimize the number of computed seismograms, the source-site distance is kept below an upper threshold, which is taken to be a function of the magnitude associated with the source. The maximum source-site distance is set equal to 200 km, 400 km, and 800 km, respectively, for $M < 6$, $6 \leq M < 7$ and $M \geq 7$. The synthetic signals for P-SV-waves (radial and vertical components) and SH-waves (transversal component) are computed by the modal summation technique for an upper frequency content of 1 Hz. The seismograms are originally computed for a seismic moment of 10^{-7}Nm and then the amplitudes are properly scaled according to the smoothed magnitude associated with the cell of the source using the moment magnitude relation given by Kanamori (1977) and the spectral scaling law proposed by Gusev (1983).

At each site, the horizontal components obtained from the synthetic seismograms generated are first rotated to North-South and East-West directions, and then the vector sum is computed. The largest amplitude resulting signal, due to any of the surrounding sources, is selected and associated with that particular site. Therefore maps of seismic hazard that describe the maximum ground shaking at the bedrock can be produced. The maps of peak displacement, peak velocity and peak acceleration are shown respectively in Figure 4.17, Figure 4.18 and Figure 4.19. The Fourier spectra of displacements and velocities show that an upper frequency limit of 1 Hz is sufficient to take into account the dominating part of the seismic waves, while this is not true for accelerations (Panza et al. 1999). Peak Ground Acceleration is obtained by computing the response spectrum of each synthetic signal for periods of 1 second and longer (i.e. the periods considered in the generation of the synthetic seismograms) and extending the spectrum, at frequencies higher than 1 Hz, using a design response spectrum from Italian code (Panza et al. 1996). This extension is done by scaling the chosen normalized response spectrum of code (normalized elastic acceleration spectra of the ground motion for 5% critical damping) with the response spectrum computed at frequencies below 1 Hz.

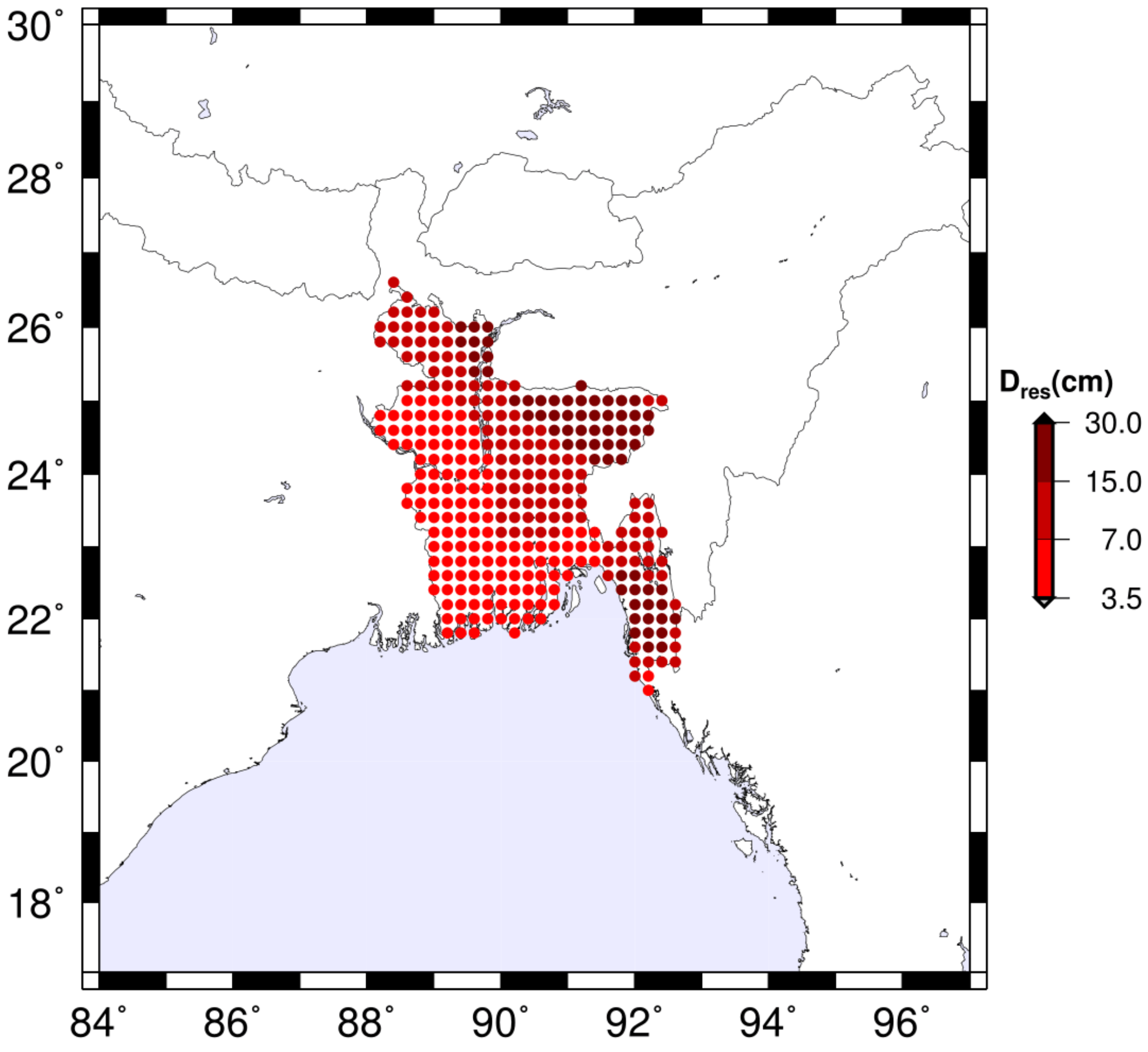


Figure 4.17 Spatial distribution of estimated peak ground displacement in cm

Figure 4.17 shows the spatial distribution of peak ground displacement in cm for Bangladesh. The highest values are obtained in northeast and southeast parts of the country which is in the range of 15-30 cm. The region includes Kurigram, Mymensingh, Sylhet and Chittagong. Peak ground displacement of range 7-15 cm is seen in the region of Dinajpur, Rangpur, Tangail, Brahmanbaria, Narshingdi, Dhaka, Comilla. In the other parts of the region; such as Rajshahi, Khulna, Barisal; the maximum displacement is less than 7 cm.

Figure 4.18 depicts the spatial distribution of peak ground velocity in cms^{-1} for Bangladesh. The maximum values of 30-60 cm/sec are seen in Sylhet region. Chittagong and Mymensingh are second highest with values between 15-30 cm/sec. Border region at North near the Dauki fault shows peak velocity of the range 15-60 cm/sec. In the area of Rangpur, Bagura, Tangail, Comilla the peak values are up to 15 cm/sec. The peak velocity in Rajshahi, Pabna, Dhaka, Chadpur, Noakhali, Barisal is in the range of 4-8 cm/sec. The rest of the areas such as Jessore, Khulna, Satkhira has the minimum limit of 2-4 cm/sec.

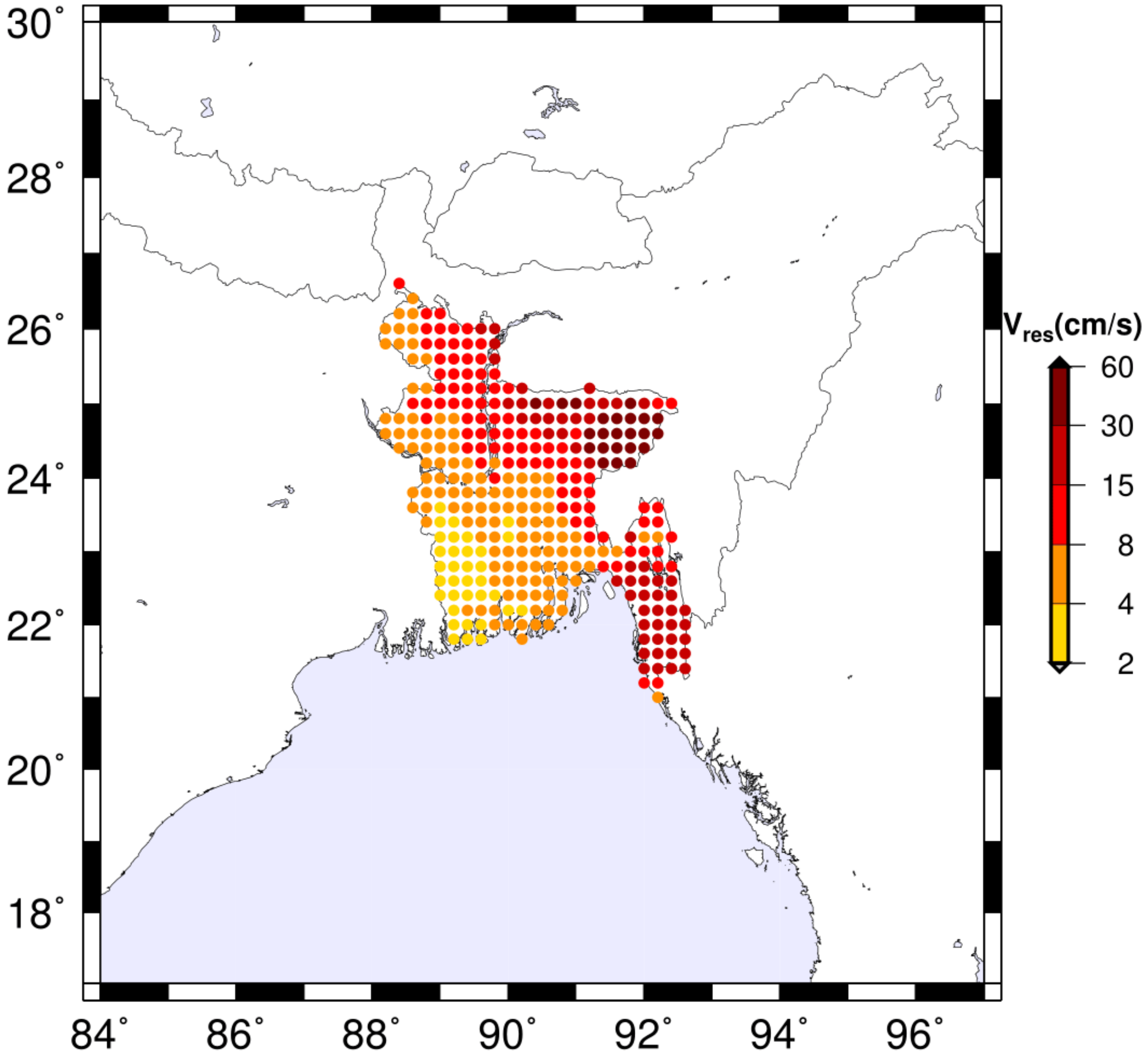


Figure 4.18 Spatial distribution of estimated peak ground velocity in cm/s

The national seismic hazard map for Bangladesh by NDSHA method is presented in Figure 4.19. It is in the form of peak ground acceleration for bedrock in g. The maximum values have been estimated over the northeast and southeast region of the country where the epicenters of many of the historical earthquakes are listed such as 1762 earthquake, 1897 Great Indian earthquake, 1918 Srimangal earthquake, 1930 Dhubri earthquake. The peak ground acceleration values obtained for Sylhet region, in the epicentral zone of 1918 Srimangal earthquake, range between 0.30g to 0.63g. The Bangladesh-India border region

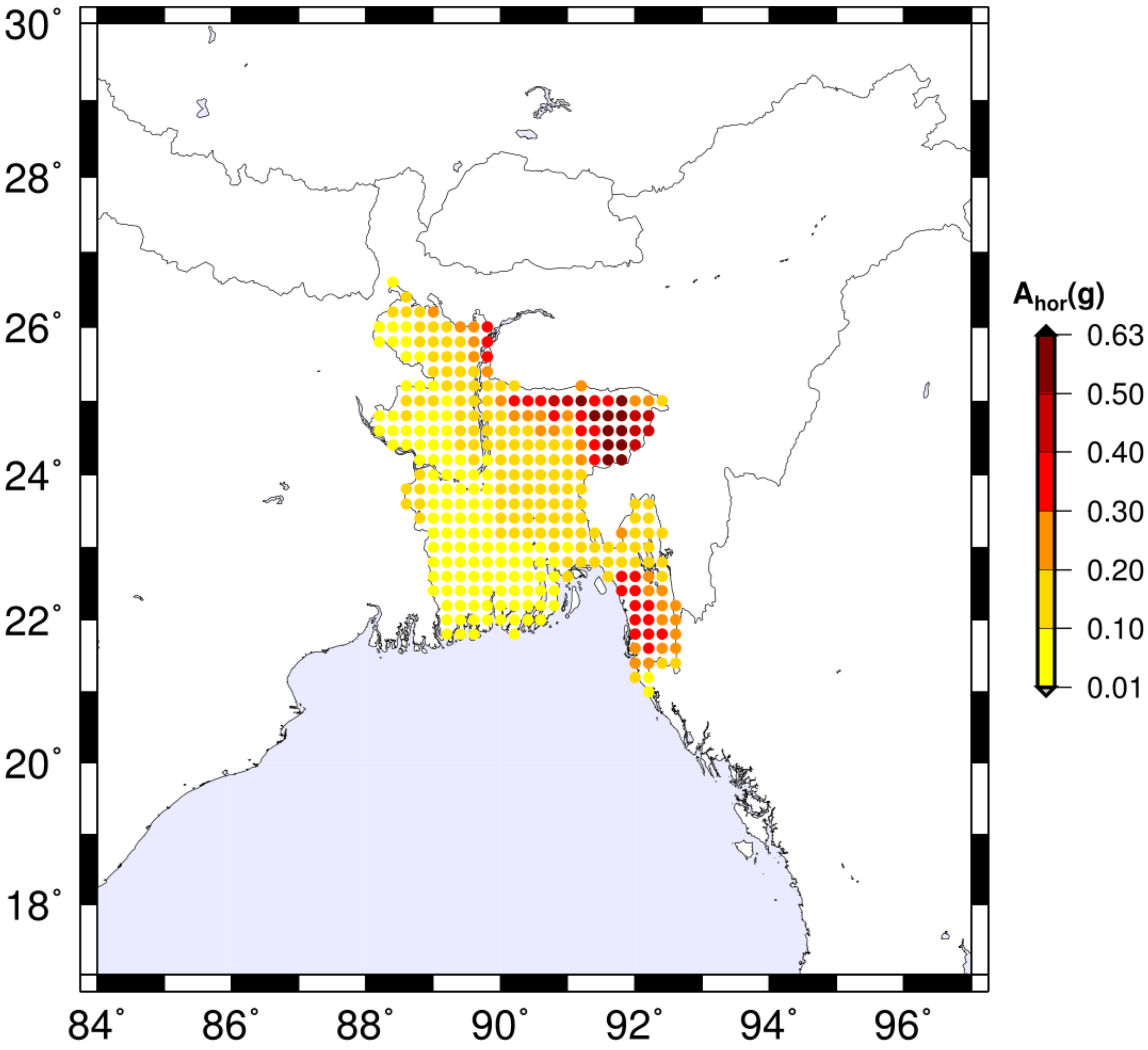


Figure 4.19 NDSHA map for Bangladesh with estimated peak ground acceleration in g

near Dauki fault zone is showing high values ranging from 0.2-0.63g. Jamalpur and Mymensingh have peak acceleration values between 0.2 and 0.3g. In parts of Kurigram and Lalmonirhat, the estimated values are 0.2-0.4g. In parts of the suspected epicentral zone of 1762 earthquake, i.e. Chittagong, the second biggest metropolitan city of Bangladesh, the PGA reaches up to 0.40g. Besides this, Bandarban and Rangamati region falls in the range of 0.2-0.3g. The capital and biggest metropolitan city of Bangladesh, Dhaka, with relevant industrial and economical importance, lie in the 0.1-0.2g range of the PGA map. The same range is applicable for the region of Rangpur, Bogura, Tangail, Chadpur, Comilla etc. The rest of the parts such as Dinajpur, Rajshahi, Pabna, Jessore, Barisal, Mongla etc. are in minimum hazard range i.e. below 0.1g. So for Bangladesh the most severe hazard is in Sylhet, Chittagong and their surroundings, thus this finding is conforming with some previous studies (e.g. Dasgupta and Nandy 1995, Steckler et al. 2008, Kundu and Galahaut 2011, Al-Hussaini et al. 2012).

4.4 Comparison with Probabilistic Hazard Map

In this study a seismic hazard map with bedrock motion for Bangladesh is proposed using the neo-deterministic seismic hazard assessment method through generation of synthetic seismogram. The previous seismic hazard maps for Bangladesh as mentioned in Chapter 2, are based on probabilistic seismic hazard assessment approach. A comparative analysis between neo-deterministic and probabilistic seismic hazard maps is done in this section. The comparison is carried out in terms of Peak Ground Acceleration (PGA) in g. The parameters of ground motion represent different physical quantities. In PSHA, the hazard maps are defined only in terms of PGA, which is the horizontal peak ground acceleration with 10% or 2% probability of being exceeded in 50 years. The PGA is obtained by treating in probabilistic terms both the available information about the seismicity observed within each seismogenic zone and the seismic wave attenuation laws. Recent codes are considering larger return periods to account for large earthquakes with long recurrence periods. Thus following the International Building code, the seismic hazard map for Bangladesh building code is also updated considering the Maximum Credible Earthquake to correspond to a return period of 2475 years which is equivalent to 2% probability of exceedance in 50 years. Figure 2.7 shows results of PSHA studies for a return period of 2475 years using the attenuation law of Abrahamson and Silva (1997). These values are converted into g and then a scatter plot is made (Figure 4.20) associated to PGA values from both PSHA and NDSHA method.

The NDSHA maps are generally intended to provide an upper bound for expected ground motion, compatible with seismic history and seismotectonic of the region. Therefore a better agreement is naturally expected with PSHA map defined with a lower probability of exceedance, and thus corresponding to a rather long return period (i.e. 2475 years).From Figure 4.20, it can be seen that NDSHA is giving larger values than PSHA in the areas where the strongest events have been observed; this fact supports the idea that probabilistic estimates tend to underestimate the hazard where the largest earthquakes, which are characterized by a longer return period, may occur. The black thick line corresponds to identical values estimated by PSHA and NDSHA. The plot also highlight the fact that the

PSHA provides estimates larger than those given by the NDSHA for small values of ground shaking, while the PSHA estimates are comparatively low where the largest events occurred in the past and where the most severe ground shaking is expected. Therefore the standard NDSHA, which does not depend upon the sporadicity of the earthquakes, gives conservative estimates in high-seismicity areas. The results of this study are showing conformity with the findings of NDSHA studies done for Italy and India (Figure 2.12).

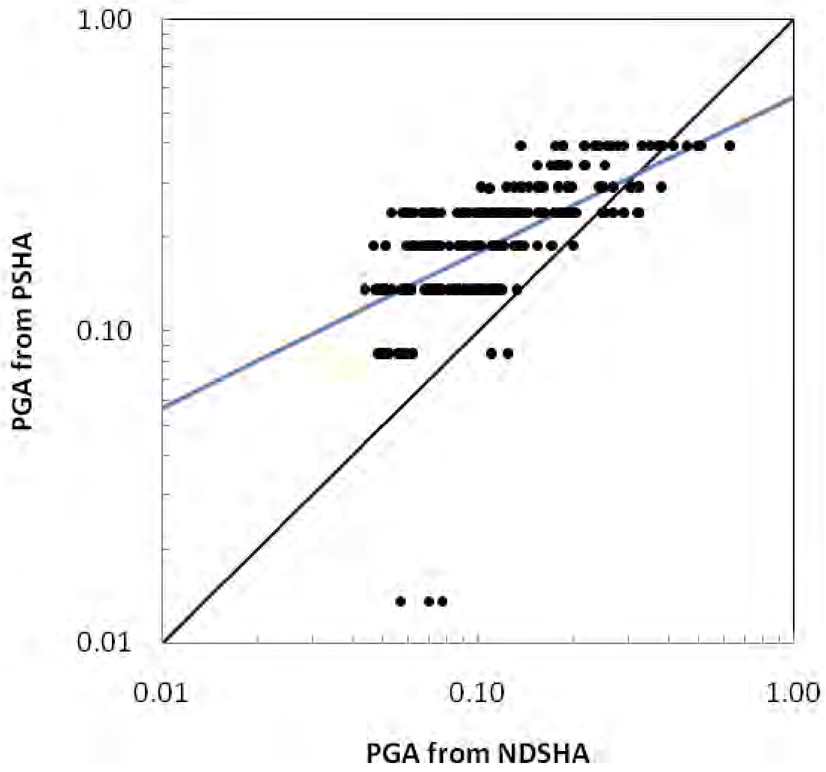


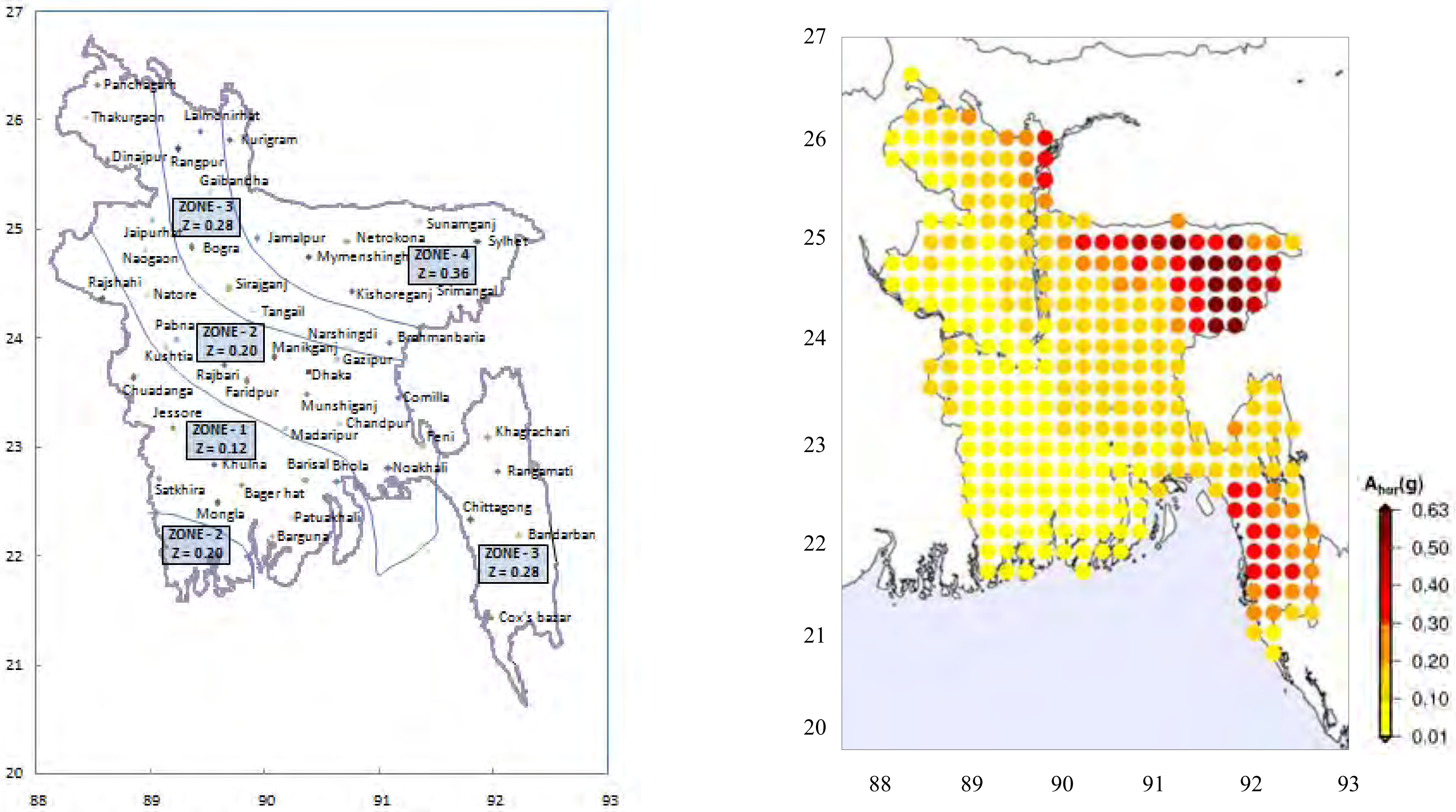
Figure 4.20 Scatter plots comparing the PGA from PSHA analysis (Figure 2.7) and PGA from NDSHA (Figure 4.19). PGA values from PSHA correspond to estimates for return period of 2475 years. The solid black line corresponds to the values for which both estimations coincide. The linear regression line is shown as well in blue colour.

The differences between the maps obtained from the two different approaches are due to many elements, among which are the different criteria followed in the compilation of the input earthquake catalogue, the simplified ground motion prediction equations used in PSHA and the seismicity parametrisation adopted in the two approaches. The NDSHA approach, in fact, accounts mainly for the largest past earthquakes (M>5), whereas PSHA requires considering also moderate size earthquakes for which the catalogue completeness is not always guaranteed.

Comparison of the result with the updated Bangladesh National Building Code (updated BNBC) which is awaiting publication and PSHA results using different attenuation relationships (courtesy: Prof. Dr. Tahmeed M. Al-Hussaini) are presented in Table 4.2. The seismic zoning map by updated BNBC and the NDSHA map by this study are presented in Figure 4.20. For south-west zone of Bangladesh e.g., Khulna, Pabna, Rajshahi, Barisal; the NDSHA estimates are lower than that of BNBC. For the central region like Dhaka, Faridpur etc. the PGA values are still less than estimates by BNBC. However the PGA values are showing increase in the India-Bangladesh border region at North near Dauki fault and also in the north-east and south-east parts of the country near Chittagong Tripura fault belt. The NDSHA estimates in the Sylhet zone is up to 1.75 times the BNBC estimates. This can be a serious concern for this seismically active zone with several historical earthquakes. The estimate for Chittagong zone has also surpassed the BNBC values by up to 1.43 times.

Table 4.2 Comparison of NDSHA results with BNBC and other attenuation relationships

Location	**PGA (g) from NDSHA**	**PGA (g) from updated BNBC**	**PGA (g) from PSHA using different attenuation relationships**				
			Iyengar and Raghu Kanth 2004	**Al-Hussaini and Islam 2014**	**Abrahamson and Silva 1997**	**Zare et al. 1999**	**Atkinson and Boore 1995**
Bogra	0.104	0.28	0.216	0.195	0.228	0.247	0.356
Brahmanbaria	0.155	0.28	0.305	0.287	0.286	0.314	0.462
Chittagong	0.323	0.28	0.267	0.207	0.271	0.239	0.417
Comilla	0.137	0.20	0.168	0.174	0.182	0.231	0.281
Cox's Bazar	0.250	0.28	0.270	0.210	0.272	0.230	0.417
Dhaka	0.115	0.20	0.159	0.166	0.066	0.224	0.266
Faridpur	0.081	0.20	0.137	0.130	0.157	0.195	0.238
Jhalokathi	0.051	0.12	0.072	0.081	0.108	0.152	0.156
Khulna	0.056	0.12	0.081	0.076	0.108	0.149	0.173
Kurigram	0.382	0.36	0.272	0.288	0.271	0.297	0.386
Meherpur	0.109	0.12	0.075	0.085	0.109	0.156	0.149
Mongla	0.063	0.12	0.118	0.085	0.153	0.154	0.252
Pabna	0.059	0.20	0.163	0.134	0.173	0.197	0.276
Rajshahi	0.073	0.12	0.102	0.104	0.128	0.173	0.186
Rangamati	0.196	0.28	0.236	0.183	0.247	0.241	0.402
Rangpur	0.156	0.28	0.212	0.215	0.233	0.255	0.340
Sylhet	0.628	0.36	0.427	0.426	0.409	0.422	0.642
Thakurgaon	0.076	0.20	0.149	0.199	0.175	0.231	0.232



(a) (b)

Figure 4.21 (a) Seismic zoning map of Bangladesh (updated BNBC), (b) NDSHA map of Bangladesh (present study)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This chapter summarizes the major findings of the present study. The main objective of this study was conducting neo-deterministic seismic hazard assessment (NDSHA) for Bangladesh. In addition, deterministic seismic hazard assessment (DSHA) estimates using attenuation relationships have been computed for comparison with NDSHA results. The seismic hazard studies done so far for Bangladesh, which are mostly by Probabilistic approach, are reviewed. An updated earthquake catalogue is prepared for Bangladesh up to year 2015. The active faults in and near Bangladesh are studied from literature and seismic zones capable of creating major earthquakes are identified as input parameters for NDSHA. The bedrock structure beneath Bangladesh is also studied from literature and finalized as inputs. Before preparing the national scale map, repeat scenarios of some historical earthquakes are simulated and the conformity of the results with DSHA results is checked. The NDSHA national scale map for Bangladesh is compared with the other probabilistic maps and updated BNBC. It is expected that this research will make a useful contribution to the seismic hazard assessment studies for Bangladesh.

5.2 Conclusions

The following conclusions can be drawn from the present study:

(i) The updated earthquake catalogue for Bangladesh and surrounding region (Figure 4.1) shows that the areas near main plate boundary at north and east are seismically very active with occurrence of large earthquakes. Though the region in Bangladesh has not seen any major earthquake for more than 85 years, evidence of historical earthquakes proves its capability of generating major earthquakes ($M>7$).

(ii) The 1993 Bangladesh National Building Code (BNBC) was based on probabilistic approach for return period of 200 years. Following the International Building Code, the revised seismic zoning map of BNBC is based on return period of 2475 years. However PSHA approach has under estimated the PGA values for several recent major earthquakes e.g. Bhuj (Gujrat, India) 2001, Bam (Iran) 2003, Sumatra (Indonesia) 2004, Haiti 2010 etc. (Peresan et al. 2011); therefore comparing this PSHA map with the results from neo-deterministic computation was of much importance.

(iii) Repeat scenarios of some historical earthquakes were simulated following NDSHA before preparing the national scale map. NDSHA results from 1897 Great Indian earthquake, 1918 Srimangal earthquake and 1762 Arakan earthquake simulation; and also scenario earthquake at Dauki fault and Bay of Bengal are compared with simple DSHA results using different attenuation laws. The NDSHA estimates were showing lower values than other attenuation laws where the ground shaking is less. But it showed higher values near the epicenter which also crossed the BNBC prescribed values in north-east and south east regions of the country. However the results showed good conformity with other attenuation relations and therefore seemed reasonable.

(iv) The national scale seismic hazard map for Bangladesh by NDSHA method was prepared with input parameters- structural model, earthquake catalogue (M>5), seismogenic zones and focal mechanisms. From the map, PGA value in the range of 0.01-0.10g was observed in the south-west region of the country. The central region including Dhaka showed PGA value in the range of 0.10-0.20g. The highest values were observed in the north-east parts of the country near India-Bangladesh border region which is in the range of 0.40-0.63g, thus exceeding the BNBC estimates of 0.36g up to 1.75 times. Similarly, for Chittagong region the NDSHA value (0.20-0.40g) is up to 1.43 times the estimate of BNBC (0.28g). Therefore, the PGA estimates of BNBC in the north-east and south-east region of the country may need to be revised after critical evaluation.

(v) NDSHA estimates of PGA values were higher than PSHA estimates in areas with high seismic risk e.g. north-east and south-east parts of the country (Sylhet and Chittagong region). However the PGA values were lower than that of PSHA in seismically less active areas like south-west parts of the country (Khulna region). The comparison showed conformity with previous researches by NDSHA method for Italy and India.

5.3 Recommendations for Future Research

The present study was focused on constituting seismic hazard assessment map for Bangladesh using the concept of neo-deterministic study. Some recommendations for future studies are presented below:

(i) With seismic instruments data being more available for Bangladesh in near future, the structural model of bedrock may be updated to provide better results. Moreover, with focal mechanism information being available by more geologic studies, the blind faults like Madhupur fault can be properly characterized.

(ii) The present study is showing the ground motion parameters on bedrock. With the inclusion of local site effects, the PGA value is expected to increase. Systematic study can be done following NDSHA for the major cities of Bangladesh to find out the effects of site amplification.

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APPENDIX A Earthquake Catalogue

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence*
1762	4	2	7	30	0	22.00	92.00		7.50	1
1764	6	4	0	0	0	24.00	88.00		6.00	1
1822	4	3	0	0	0	23.50	91.00		6.00	1
1826	10	28	0	0	0	28.00	85.00		6.00	1
1826	10	29	0	0	0	27.00	85.00		6.00	1
1828	7	8	0	0	0	24.50	94.50		5.00	1
1830	12	31	0	0	0	22.00	91.00		5.00	1
1833	8	26	0	0	0	27.50	86.50		7.50	1
1833	10	4	0	0	0	27.00	85.00		6.50	1
1833	10	18	0	0	0	27.00	84.00		6.00	1
1833	11	16	0	0	0	27.70	85.30		5.00	1
1834	7	8	0	0	0	25.80	89.40		6.30	1
1834	7	21	0	0	0	25.80	89.40		6.00	1
1839	1	14	0	0	0	27.80	95.60		5.00	1
1839	5	11	0	0	0	25.30	86.50		5.00	1
1841	2	9	0	0	0	26.20	91.80		5.60	1
1842	2	5	21	15	0	25.00	87.00		5.50	1
1842	10	23	0	0	0	26.20	91.80		5.00	1
1842	11	11	0	0	0	25.00	90.00		6.50	1
1843	4	6	0	0	0	28.00	95.00		5.70	1
1843	6	15	0	0	0	27.00	94.70		5.00	1
1843	6	16	0	0	0	27.20	95.40		5.70	1
1843	6	17	0	0	0	27.00	94.70		5.70	1
1843	8	10	0	0	0	27.00	88.30		5.50	1
1843	9	2	0	0	0	26.00	93.00		5.00	1
1843	9	3	19	30	0	26.00	93.00		5.00	1
1843	12	18	16	20	0	26.20	91.80		5.70	1
1845	8	6	0	0	0	24.80	91.80		6.50	1
1845	8	22	12	30	0	26.20	91.80		5.70	1
1845	8	24	6	0	0	26.20	91.80		5.00	1
1846	10	17	0	0	0	24.80	90.40		6.30	1
1846	10	18	8	45	0	24.00	90.00		6.00	1
1846	12	10	0	0	0	27.00	94.00		6.00	1
1846	11	30	0	0	0	26.30	92.70		6.30	1
1849	1	22	0	0	0	26.00	92.00		5.70	1
1849	1	23	8	15	0	26.30	91.00		5.00	1
1849	1	26	5	0	0	26.30	91.00		5.00	1
1849	2	27	21	0	0	27.00	88.30		6.00	1
1851	1	8	0	0	0	22.30	91.80		5.50	1
1851	2	9	13	55	0	22.60	88.40		5.70	1
1851	10	15	0	0	0	25.30	91.70		5.00	1
1852	4	30	0	0	0	27.00	88.00		6.50	1
1852	5	1	0	0	0	27.00	88.30		7.00	1
1852	8	9	4	37	0	23.70	90.40		5.70	1
1858	8	24	19	8	0	19.00	95.00		7.50	1
1861	2	16	0	0	0	22.60	88.40		5.70	1
1862	6	18	0	0	0	27.00	88.30		5.00	1
1863	3	29	22	0	0	27.00	88.30		5.70	1
1863	7	8	20	15	0	27.00	88.30		5.00	1
1863	8	11	14	15	0	27.00	88.30		5.00	1
1865	12	16	22	0	0	27.00	88.30		5.00	1
1865	12	19	0	0	0	22.20	92.50		6.00	1
1866	1	23	0	0	0	21.80	87.80		5.00	1
1866	5	23	0	0	0	27.00	85.00		7.00	1
1868	6	30	0	0	0	24.90	91.90		5.50	1
1868	9	30	0	0	0	24.00	85.00		5.00	1
1869	1	10	0	0	0	26.00	92.70		7.50	1
1869	4	17	0	0	0	25.60	91.90		5.00	1
1869	7	7	0	0	0	27.00	85.00		6.50	1
1869	8	9	0	0	0	27.00	88.30		5.70	1

Year	**Month**	**Day**	**Hour**	**Minute**	**Second**	**Latitude**	**Longitude**	**Depth**	**Magni-tude**	**Refe-rence**
1869	8	9	0	0	0	27.00	88.30		5.70	1
1875	9	3	0	0	0	26.50	93.00		5.70	1
1880	6	19	0	0	0	24.50	94.00		6.30	1
1882	10	13	0	0	0	24.80	92.80		5.00	1
1885	7	14	0	55	0	24.80	89.70		7.00	1
1885	7	14	0	0	0	24.00	90.00		5.70	1
1885	7	24	0	0	0	25.00	89.20		5.70	1
1897	6	12	11	6	0	26.00	91.00		8.10	1
1897	6	22	0	0	0	19.40	84.90		5.50	1
1898	4	20	0	0	0	24.80	92.80		6.30	1
1899	9	25	0	0	0	27.00	88.30		6.00	1
1901	4	21	0	0	0	29.50	90.10	0	6.80	2
1902	12	13	17	8	0	30.00	85.00		6.70	1
1903	12	3	21	26	0	19.50	95.00		6.50	1
1905	2	17	11	42	0	26.00	96.00	0	7.10	2, 1
1906	8	31	14	57	3	27.00	97.00	100	7.00	2
1906	9	29	0	0	0	22.60	88.40		5.00	1
1908	12	12	12	54	57	26.95	96.77	15	7.00	2, 3
1909	2	17	0	0	0	27.00	87.00		5.00	1
1909	8	4	0	0	0	28.80	90.50	0	6.50	2
1911	12	7	0	0	0	23.00	88.00		5.00	1
1912	5	23	2	24	4	21.04	96.74	15	7.50	2, 3
1915	2	3	2	39	0	29.50	91.50		7.10	1
1915	11	14	0	0	0	26.00	92.00		5.00	1
1915	12	3	2	39	25	27.70	91.64	15	6.50	2, 3
1915	12	5	0	0	0	26.00	92.00		5.00	1
1918	2	4	17	54	0	29.60	87.80		6.00	1
1918	7	8	10	22	9	24.30	90.71	15	7.60	2, 3, 5
1920	8	15	6	59	0	22.20	93.20		6.00	1
1923	4	24	22	3	0	29.60	87.80		5.50	1
1923	8	10	15	58	0	22.60	93.40		6.00	1
1923	9	9	22	3	47	24.94	90.72	15	7.10	2, 3, 1
1924	1	30	0	0	0	25.00	93.00		6.00	1
1924	2	14	18	55	0	26.00	96.00		5.50	1
1924	8	1	14	42	0	26.00	96.00		5.50	1
1924	8	13	23	57	5	29.50	90.00	35	5.80	2, 1
1924	9	2	2	3	0	23.00	95.00		5.50	1
1924	10	8	20	32	56	30.88	89.65	15	6.50	2 , 1
1925	12	15	7	44	0	30.00	85.80		5.50	1
1926	5	10	8	19	1	26.00	97.00	80	6.20	2
1926	8	6	13	17	0	26.00	96.00		5.50	1
1926	8	18	23	58	0	24.50	94.50		5.50	1
1926	9	8	15	49	0	23.00	95.00		5.50	1
1926	10	23	14	30	0	25.00	93.00		5.50	1
1926	12	4	11	15	0	29.60	87.80		6.00	1
1927	3	15	16	56	3	24.50	95.00	130	6.50	2 , 1
1927	5	20	10	51	0	24.50	94.50		5.50	1
1927	7	15	21	10	0	27.00	96.00		5.50	1
1927	8	25	22	56	38	22.00	90.00		5.50	1
1928	7	9	15	47	0	27.00	96.00		5.50	1
1928	8	30	12	12	0	27.00	96.00		5.50	1
1928	10	12	7	26	0	23.00	95.00		5.50	1
1929	3	25	3	47	0	29.00	94.50	35	5.60	2 , 1
1929	8	8	0	0	0	19.40	96.40		5.50	1
1929	8	8	12	57	18	19.32	95.84	15	6.60	2, 3
1929	10	29	18	33	0	26.00	96.00		5.50	1
1930	5	5	13	46	2	17.86	96.43	35	7.50	2, 3, 1
1930	7	2	21	3	44	25.93	90.18	15	7.20	2, 3, 5
1930	7	3	0	19	5	25.80	90.20		5.50	1
1930	7	4	18	54	44	25.80	90.20		5.50	1
1930	7	4	21	34	0	25.80	90.80		5.50	1
1930	7	8	4	32	24	25.80	90.80		5.50	1
1930	7	8	9	43	0	25.80	90.80		5.50	1

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magnitude	Reference
1930	7	11	7	6	0	25.00	93.50		5.50	1
1930	7	13	14	0	12	25.80	90.80		5.50	1
1930	9	13	17	58	0	23.00	96.00		5.50	1
1930	9	22	14	19	1	25.00	94.00	35	6.30	2, 5
1930	12	3	16	36	0	17.30	96.50		5.50	1
1930	12	3	18	51	47	18.23	96.30	10	7.50	2, 3, 7
1931	1	27	20	9	20	25.85	96.79	15	7.60	2, 3, 1
1931	2	10	1	22	5	25.50	96.00	35	5.80	2, 1
1931	9	6	5	38	0	18.50	96.00	35	5.60	2 , 1
1932	3	6	0	17	5	25.50	92.50	35	5.60	2 , 1
1932	3	24	16	8	3	25.00	90.00	35	5.60	2 , 1
1932	3	25	4	29	0	30.00	89.20		5.50	1
1932	3	27	8	44	4	24.50	92.00	35	5.60	2 , 1,7
1932	8	14	4	39	37	25.84	95.64	110	7.00	2 , 1
1932	8	14	7	10	0	22.00	95.50		5.50	1
1932	11	9	18	30	0	26.50	92.00	35	5.60	2 , 1
1933	3	6	13	5	3	26.00	90.50	35	5.60	2 , 1,7
1933	7	3	15	9	0	19.00	97.00	35	5.60	2
1933	12	4	14	40	0	25.80	95.70		5.20	1
1934	1	15	8	43	26	26.88	86.59	15	8.30	2, 3, 1
1934	1	16	4	59	22	28.00	86.00		5.60	1
1934	6	2	5	54	2	24.50	95.00	130	6.50	2 , 7, 1
1934	7	21	0	0	0	25.80	89.40		5.50	1
1935	3	21	0	4	0	24.25	89.50	80	6.20	2 , 1, 7
1935	3	21	4	48	8	27.00	85.00		5.50	1
1935	4	23	16	45	4	24.00	94.75	110	6.20	2 , 7, 1
1935	5	21	4	22	3	28.75	89.25	140	6.20	2 , 7, 1
1936	2	11	4	48	0	27.50	87.00	50	5.60	2 , 1
1936	2	21	6	20	4	23.00	96.00	35	5.80	2, 1
1936	5	30	7	8	38	25.70	90.50		5.30	1
1936	6	9	0	2	42	27.50	87.00		5.50	1
1936	6	18	14	56	27	26.60	90.30		5.80	1
1936	9	7	2	30	49	27.50	87.00		5.70	1
1937	3	9	20	19	14	27.00	92.00		5.70	1
1937	3	21	16	12	0	25.50	94.00		5.90	1
1937	8	15	11	36	0	30.00	90.00		5.80	1
1937	8	31	14	15	11	26.01	96.71	15	6.60	2, 3
1937	9	9	23	37	0	24.90	94.70		5.70	1
1938	1	29	4	13	0	27.50	87.00	35	5.80	2, 1
1938	2	26	12	10	43	28.00	90.50		5.70	1
1938	4	13	1	10	17	26.00	91.00		5.20	1
1938	4	14	1	16	35	23.23	94.46	105	6.80	2, 7
1938	5	6	3	41	0	24.50	95.00	100	5.80	2 , 1
1938	5	6	3	41	8	24.50	95.00		5.80	7
1938	8	16	4	28	1	22.75	93.92	75	7.20	2, 3, 7
1938	11	21	1	11	2	30.00	95.00	35	6.10	2, 1
1939	5	27	3	45	47	24.40	94.08	66	6.80	2, 3, 5,7
1939	6	4	22	36	0	28.50	86.50		5.70	1
1939	6	19	21	56	4	23.50	94.00	35	5.80	2, 1
1940	2	13	11	46	28	27.00	92.00		5.70	1
1940	5	11	21	0	2	23.75	94.25	80	6.50	2 , 1
1940	8	2	3	3	59	28.00	90.50		5.20	1
1940	10	4	4	35	5	30.00	92.00	35	6.10	2, 1
1941	1	21	12	41	46	27.17	91.86	15	6.80	2, 3, 5
1941	1	27	2	30	1	26.50	92.50	180	6.50	2 , 1,7
1941	2	23	9	56	4	28.00	96.00	90	5.50	2 , 7
1941	5	22	1	0	3	27.50	93.00	35	5.60	2 , 1,7
1941	9	6	3	17	47	27.00	92.00		5.80	1
1942	2	21	21	46	52	24.00	90.30		5.90	1
1942	8	19	18	29	0	18.00	96.00		6.00	1
1942	9	3	7	44	0	29.80	95.30		5.90	1
1943	2	8	21	5	24	27.00	92.00		6.00	1
1943	10	23	17	23	21	26.64	93.85	15	7.20	2, 3, 5

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1944	12	24	14	46	0	24.70	92.20		5.90	1
1945	5	19	5	2	53	25.10	90.90		6.10	1
1945	9	19	10	40	0	29.50	84.00		5.50	1
1946	2	5	19	34	0	19.50	95.00		5.90	1
1946	3	7	21	40	0	27.50	96.40		5.90	1
1946	3	16	14	15	0	26.40	92.60		5.60	1
1946	3	31	11	30	0	23.00	96.00		5.40	1
1946	7	2	11	12	0	30.00	92.00		5.70	1
1946	9	12	15	17	24	24.05	95.67	15	8.00	2, 3, 1
1946	9	12	15	20	27	23.31	95.52	15	7.80	2 , 1,7
1947	3	8	14	33	0	24.90	94.70		5.50	1
1947	5	8	18	44	0	23.80	94.80		6.20	1
1947	7	29	13	43	25	28.58	93.63	20	7.80	2, 3, 1,7
1947	8	23	4	34	0	23.80	94.80		6.20	1
1947	8	23	14	1	0	23.80	94.80		6.00	1
1947	9	11	7	22	0	23.90	96.20		6.00	1
1947	9	11	10	30	0	23.90	96.20		5.90	1
1947	11	29	17	56	4	27.90	91.90		5.90	1
1948	2	4	4	45	0	23.80	94.80		6.00	1
1948	3	1	16	50	0	26.80	94.00		5.50	1
1948	9	28	21	36	0	22.30	94.10		6.00	1
1948	10	7	1	18	32	27.90	91.90		5.50	1
1948	11	28	21	43	0	26.80	94.00		6.00	1
1949	7	15	11	0	0	24.00	93.00		6.00	1
1949	11	13	5	27	0	21.00	95.00		5.50	1
1949	12	10	19	37	14	26.00	89.00		6.00	1
1950	2	13	7	22	0	29.80	95.30		5.50	1
1950	2	23	11	1	0	29.80	95.30		6.00	1
1950	2	26	3	35	46	27.22	90.82	15	6.00	3, 1
1950	8	15	14	9	35	28.36	96.45	15	8.60	2, 3, 5
1950	8	15	18	38	49	28.52	95.73	25	6.20	2, 3
1950	8	15	21	1	35	27.34	96.78	25	5.80	3
1950	8	15	21	42	22	25.34	92.94	25	6.00	2, 3, 1
1950	8	15	23	44	45	28.50	95.13	25	5.80	3
1950	8	16	5	33	12	28.66	96.75	25	5.80	2, 3
1950	8	16	6	42	5	28.38	95.89	25	6.20	2, 3
1950	8	16	11	28	0	27.50	96.40		6.00	1
1950	8	16	12	38	27	27.90	91.90		5.50	1
1950	8	16	15	29	30	29.06	94.87	25	6.60	2, 3, 1
1950	8	16	16	36	1	28.18	94.97	25	6.00	3, 1
1950	8	16	17	51	35	27.49	92.80	15	6.70	2, 3, 1
1950	8	16	19	25	40	28.72	95.96	25	6.40	2, 3, 1
1950	8	16	21	44	0	29.20	95.10		6.00	1
1950	8	16	23	21	27	26.86	96.97	25	5.70	2, 3
1950	8	17	1	54	18	28.43	94.84	25	6.50	2, 3, 1
1950	8	17	3	44	0	29.20	95.10		5.50	1
1950	8	17	5	29	19	29.62	94.77	25	6.20	2, 3, 1
1950	8	17	8	5	0	29.20	95.10		6.00	1
1950	8	17	23	56	34	27.90	91.90		6.00	1
1950	8	18	1	7	57	29.21	95.81	20	6.40	2, 3
1950	8	18	11	20	0	29.20	95.10		6.00	1
1950	8	18	16	58	54	29.72	96.56	25	6.10	2, 3
1950	8	20	9	3	42	29.47	95.06	25	6.40	2, 3, 1
1950	8	20	10	37	0	29.20	95.10		5.50	1
1950	8	21	8	29	47	33.04	91.48	15	5.80	2
1950	8	21	18	43	0	29.20	95.10		6.10	1
1950	8	21	22	55	0	28.80	93.70		6.00	1
1950	8	22	2	22	41	29.93	95.51	25	6.00	2, 3, 1
1950	8	22	6	43	15	28.97	94.58	25	6.30	2, 3, 1
1950	8	22	17	20	0	29.20	95.10		6.00	1
1950	8	23	3	9	25	29.21	95.02	25	6.00	2, 3, 1
1950	8	23	18	47	3	28.50	96.48	25	5.90	2, 3
1950	8	24	1	27	53	28.25	96.67	25	6.30	2, 3, 1

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1950	8	25	8	14	0	29.20	95.10		5.50	1
1950	8	25	13	3	0	29.20	95.10		6.00	1
1950	8	26	6	33	13	27.23	94.96	25	7.00	2, 3, 1
1950	8	27	10	59	0	29.20	95.10		6.00	1
1950	8	27	11	0	6	29.18	94.60	25	6.20	3, 1
1950	8	29	9	5	0	29.20	95.10		6.00	1
1950	8	31	1	26	0	27.50	96.40		5.50	1
1950	8	31	19	52	38	28.61	95.33	25	6.10	2, 3, 1
1950	9	1	7	12	4	29.69	95.30	25	6.00	3, 1
1950	9	1	23	44	43	29.59	95.23	25	5.50	3, 1
1950	9	2	16	14	44	29.76	96.75	25	5.90	2, 3
1950	9	3	2	55	0	28.70	94.20		6.00	1
1950	9	3	23	30	0	29.20	95.10		6.00	1
1950	9	4	8	12	39	29.71	96.73	25	5.70	3
1950	9	5	20	18	0	29.30	92.00		5.50	1
1950	9	10	10	30	0	29.20	95.10		5.50	1
1950	9	11	0	18	0	26.80	95.00		6.00	1
1950	9	11	9	39	54	28.61	94.16	25	6.00	2, 3, 1
1950	9	13	11	7	41	27.60	95.13	25	7.00	2, 3, 1
1950	9	14	2	31	0	29.20	95.10		6.00	1
1950	9	25	12	25	0	24.00	93.00		5.50	1
1950	9	30	7	29	0	28.87	94.41	20	6.70	2, 3, 1
1950	10	8	4	50	19	28.55	94.40	25	6.60	2, 3, 1
1950	10	16	15	42	35	28.22	95.46	25	6.20	3, 1
1950	10	29	6	2	32	27.42	95.35	25	6.40	3, 1
1950	10	30	9	4	56	26.10	96.81	25	5.70	3
1950	11	12	21	30	32	27.23	94.81	25	6.40	3, 1
1950	11	16	9	8	59	25.38	96.90	15	5.70	3, 1
1950	11	18	0	44	0	24.90	94.70		6.70	1
1950	11	21	7	10	0	29.00	96.00		6.00	1
1950	12	3	6	26	58	28.77	95.69	25	6.60	2, 3, 1
1950	12	29	22	35	24	23.85	91.84	15	6.30	2, 3, 1
1951	1	1	1	33	0	29.00	96.00		5.50	1
1951	1	3	21	14	0	28.70	94.20		6.60	1
1951	1	4	23	13	0	28.70	94.20		5.60	1
1951	2	8	21	14	0	27.50	95.50		5.80	1
1951	2	21	2	24	0	28.70	94.20		5.80	1
1951	3	6	18	58	17	28.66	95.43	15	6.40	2, 3, 1
1951	3	12	14	52	22	27.99	94.67	25	6.50	2, 3, 1
1951	4	7	20	29	15	25.95	90.58	15	6.80	3, 1
1951	4	14	23	40	57	28.28	93.86	15	6.50	2, 3, 1
1951	4	22	3	37	44	28.84	94.58	25	6.50	2, 3, 1
1951	5	28	15	59	24	28.93	86.68	15	6.00	2, 3, 1
1951	7	9	9	3	0	21.00	95.00		5.50	1
1951	7	13	6	36	0	27.50	96.40		5.50	1
1951	7	21	1	32	29	28.62	96.53	25	5.80	2, 3
1951	10	1	23	59	0	22.30	94.10		6.00	1
1951	10	18	5	2	0	28.80	93.70		6.00	1
1951	11	6	0	50	0	29.00	96.00		5.50	1
1951	11	18	9	35	55	31.06	91.26	30	7.70	2
1951	12	3	6	57	0	30.00	92.00		5.50	1
1952	1	15	2	31	0	23.80	94.80		6.00	1
1952	2	16	21	44	3	29.43	95.92	15	5.50	3, 1
1952	3	6	9	11	28	29.88	90.77	15	5.50	3, 1
1952	3	14	18	19	0	30.00	92.00		5.50	1
1952	4	30	1	49	12	26.62	95.07	35	6.00	3, 1
1952	5	26	2	46	37	28.40	94.49	20	6.00	2, 3, 1
1952	7	26	14	26	0	18.30	95.40		6.00	1
1952	8	17	16	2	15	30.65	91.60	25	7.50	2
1952	8	25	1	44	54	28.14	93.91	15	6.00	2, 3, 1
1952	9	15	17	59	0	30.00	92.00		5.50	1
1952	10	19	10	44	28	27.80	85.70		5.50	1
1952	11	7	4	33	0	25.50	94.00		6.00	1

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1952	11	19	10	23	32	29.68	86.51	15	6.00	2, 3, 1
1952	11	28	5	34	0	25.00	95.20		6.00	1
1954	2	23	6	40	36	27.67	91.60	15	6.50	2, 3, 1
1954	3	21	23	42	16	24.45	95.06	184	7.40	2 , 1
1955	3	27	14	38	48	29.67	90.17	15	6.20	2, 3, 1
1955	5	4	0	17	1	27.05	96.93	15	5.80	2, 3
1955	8	4	6	40	50	30.67	86.43	15	5.40	2
1955	8	21	16	4	7	23.98	95.84	15	6.00	2, 3, 1
1955	9	8	4	45	2	25.00	95.00	150	5.70	2
1955	9	20	0	0	0	27.50	90.00		5.60	1
1955	9	20	20	21	1	27.50	90.00		5.70	2
1955	11	23	0	0	0	26.50	90.00		5.10	5
1955	11	23	2	33	4	26.50	90.00		5.00	2
1955	12	14	10	51	52	21.82	92.66	35	6.50	2, 3, 5
1955	12	29	8	25	35	29.85	90.19	15	5.90	2, 3
1956	1	21	0	0	0	23.50	93.50		6.10	5
1956	1	21	17	35	3	23.00	94.00		6.10	2
1956	2	29	20	51	22	23.30	94.28	53	6.20	2, 3, 1
1956	2	29	21	26	3	23.42	93.97	50	6.40	2, 3, 1, 8
1956	3	3	10	13	47	23.38	94.22	52	6.00	2, 3, 1
1956	3	14	0	0	0	25.20	90.80		5.00	5
1956	3	23	0	0	0	30.00	90.00		5.00	1
1956	6	12	3	12	30	25.03	90.85	15	6.00	2, 3, 1
1956	7	12	15	1	30	22.65	94.05	90	6.30	2, 5
1956	7	16	15	7	12	22.18	95.78	34	7.00	2, 3, 1
1956	8	22	19	40	18	27.97	95.21	15	5.80	2, 3, 1
1956	9	19	23	47	50	23.74	94.70	115	6.10	2 , 1
1956	12	21	3	27	45	26.61	96.21	15	6.00	2, 3, 1
1956	12	30	21	59	15	23.38	94.12	50	6.00	2, 3, 1
1956	12	31	21	59	1	23.00	94.00		5.20	2 , 1
1957	4	14	7	11	58	30.52	84.35	15	6.50	2
1957	5	28	0	0	0	25.40	95.00		6.00	1
1957	5	28	5	51	41	25.53	95.06	80	5.20	2
1957	7	1	0	0	0	24.50	93.50		6.80	5
1957	7	1	19	30	24	24.31	93.89	65	6.20	2, 3
1957	12	12	0	0	0	24.50	93.00		5.50	1
1958	1	4	0	0	0	27.00	92.00		5.00	1
1958	1	6	11	24	15	25.65	96.80	15	5.80	2, 3
1958	1	23	5	30	13	30.62	84.13	15	5.90	2
1958	2	9	9	31	9	24.75	90.69	25	5.00	2 , 1, 1
1958	2	13	0	0	0	27.50	92.00		5.50	1
1958	2	13	0	11	39	27.70	92.56	15	5.50	2
1958	3	22	10	11	34	23.51	93.84	50	6.40	2, 3, 5
1958	10	28	5	22	52	25.22	96.19	35	6.00	3, 1
1958	11	3	14	31	39	30.44	84.54	15	5.20	2
1958	11	23	20	15	0	28.79	86.94		5.50	1
1959	2	14	22	25	52	27.60	96.46	15	6.00	2, 3, 1
1959	2	22	3	30	45	28.95	91.93	20	5.70	2 , 1
1959	4	9	17	8	40	25.65	94.74	60	5.20	2, 1
1959	4	13	0	0	0	22.00	93.30		5.90	5
1959	5	22	8	31	13	25.30	96.17	35	5.00	2 , 1
1959	5	24	11	28	22	26.15	90.19	20	5.40	2, 3
1959	6	7	8	33	0	24.00	94.00		5.40	1
1959	6	10	4	25	0	30.00	91.00		5.70	1
1959	8	27	23	53	18	25.09	96.13	35	5.70	2, 3, 1
1959	11	2	5	9	0	28.00	93.00		5.00	1
1959	11	2	13	15	40	21.54	92.43	35	5.70	2, 3, 1
1960	5	26	20	5	0	26.82	92.68	0	5.00	2 , 1
1960	7	29	10	42	48	26.49	90.30	15	6.50	2, 3, 1
1960	8	21	3	29	5	27.00	88.50	29	5.50	2 , 1
1960	11	15	9	5	0	23.65	94.32		5.50	1
1961	2	4	8	51	5	24.86	95.34	141	5.80	2 , 1
1961	6	14	0	41	1	24.55	94.69	91	5.80	2 , 1

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1961	9	29	22	36	30	28.00	87.00		5.50	1
1961	11	6	7	59	4	26.70	91.90		5.00	1
1961	12	25	11	19	10	27.00	90.00		5.50	1
1962	1	11	3	1	2	28.05	84.99	0	5.50	2
1962	2	20	22	2	42	26.10	97.00	35	6.30	2, 3
1962	9	16	19	6	3	16.67	93.86	42	5.00	2
1962	9	22	6	51	34	26.33	96.92	25	6.10	2, 3
1962	10	30	16	13	0	26.60	93.30		5.50	1
1963	2	22	1	32	2	27.00	88.00		5.20	2
1963	5	8	14	15	0	22.50	84.50		5.20	1
1963	6	19	10	47	26	25.00	92.03	45	6.20	2, 3
1963	6	21	0	0	0	24.80	90.90		6.20	1
1963	6	21	15	26	31	24.90	92.17	51	5.70	2, 3, 1
1963	6	21	0	0	0	24.80	92.10		6.40	5,10
1963	9	28	0	0	0	22.90	94.50		5.90	6
1963	9	28	6	0	2	23.00	94.00		5.60	2
1963	10	14	2	1	0	25.20	95.30		5.30	1
1964	1	22	15	58	44	22.33	93.58	60	6.20	2, 3
1964	2	18	3	48	34	27.40	91.18	22	5.30	2
1964	2	27	15	10	48	21.65	94.40	91	6.00	2, 3
1964	2	28	17	47	7	18.28	94.44	46	5.00	2
1964	3	20	19	0	53	23.47	94.39	94	5.10	2
1964	3	27	4	30	36	25.82	95.71	115	5.20	2
1964	3	27	23	3	41	27.13	89.36	29	5.00	2
1964	4	13	3	19	57	27.52	90.17	1	5.30	2
1964	4	15	16	35	53	21.60	88.07	6	5.20	2
1964	6	3	2	49	17	25.88	95.69	121	5.60	2, 3
1964	6	13	17	35	58	23.00	93.95	60	5.20	2
1964	7	12	20	15	59	24.88	95.31	152	5.60	2, 3
1964	7	13	10	58	4	23.51	94.67	110	5.40	2
1964	8	30	2	35	7	27.36	88.21	21	5.10	2
1964	9	1	13	22	37	27.12	92.26	33	5.80	2, 3
1964	10	21	23	9	1	28.04	93.75	37	6.80	2, 3
1964	11	9	16	12	52	29.53	86.04	33	5.10	2
1964	11	25	8	33	3	26.39	96.13	108	5.00	2
1965	1	12	13	32	24	27.40	87.84	23	5.90	2, 3
1965	1	12	13	55	18	27.31	87.68	18	5.20	2
1965	1	22	2	41	35	19.96	94.44	80	5.10	2
1965	2	18	4	26	35	24.97	94.21	45	5.60	2, 3
1965	2	25	10	34	7	23.63	94.64	94	5.10	2
1965	4	11	22	33	7	26.82	92.33	70	5.00	2
1965	5	30	8	48	20	25.93	95.80	101	5.30	2
1965	6	1	4	32	49	20.13	94.83	81	5.30	2
1965	6	1	4	33	5	19.90	94.70	33	5.10	2
1965	6	11	15	43	12	24.68	95.33	149	5.00	2
1965	6	15	7	59	20	29.67	95.51	30	5.30	2
1965	6	18	8	17	38	24.94	93.67	48	5.30	2
1965	10	16	19	33	26	17.54	94.79	44	5.10	2
1965	12	5	22	1	39	23.34	94.46	97	5.10	2
1965	12	9	20	26	1	27.43	92.51	4	5.20	2
1965	12	9	20	26	1	26.70	92.50	8	5.30	2
1965	12	15	4	43	47	22.00	94.47	109	5.20	2
1965	12	17	22	46	11	22.00	94.50	114	5.10	2
1966	6	26	10	56	1	26.14	92.84	74	5.00	2
1966	9	26	5	10	56	27.49	92.61	20	5.90	2, 3
1966	10	18	20	34	37	24.28	94.87	86	5.10	2
1966	10	22	3	3	24	23.04	94.28	72	5.10	2
1966	11	19	7	42	31	18.35	95.32	79	5.20	2
1966	12	15	2	8	3	21.51	94.43	84	5.70	2, 3
1966	12	28	3	59	0	28.00	89.00	33	5.20	2
1967	1	4	11	26	4	23.55	94.19	54	5.20	2
1967	1	5	20	19	0	30.00	86.00	33	5.20	2
1967	1	30	21	5	3	26.10	96.14	39	5.60	2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1967	2	8	17	17	4	23.13	93.80	51	5.10	2
1967	2	15	5	57	31	20.33	93.99	51	5.30	2
1967	3	2	11	47	1	28.70	86.38	20	5.20	2
1967	3	11	16	56	51	28.45	94.39	15	5.10	2
1967	3	14	6	58	4	28.41	94.29	20	5.70	2, 3
1967	9	13	19	37	0	27.00	87.00	33	5.20	2
1967	9	15	10	32	44	27.42	91.86	19	5.80	2, 3
1967	12	10	18	43	34	22.49	94.88	153	5.00	2
1968	1	31	11	45	1	29.80	92.20	25	5.10	2
1968	6	12	4	29	22	24.83	91.94	39	5.30	2
1968	8	18	14	18	5	26.42	90.62	22	5.10	2
1968	12	27	14	38	1	24.12	91.61	27	5.10	2
1969	1	25	23	34	28	22.98	92.40	49	5.20	2
1969	2	7	9	25	38	27.46	94.14	33	5.00	2
1969	2	11	22	8	5	41.42	79.24	3	5.80	2
1969	2	13	3	21	3	27.90	85.40	33	5.00	2
1969	2	24	10	37	2	27.90	85.60	33	5.20	2
1969	4	28	12	50	17	25.93	95.20	68	5.00	2
1969	6	30	8	51	5	26.93	92.71	44	5.00	2
1969	8	29	10	2	50	26.35	96.06	72	5.20	2
1969	10	17	1	25	12	23.09	94.70	124	6.30	2, 3
1969	11	5	20	25	14	27.66	90.24	13	5.00	2
1969	11	11	5	50	1	26.60	91.80	33	5.00	2
1970	2	19	7	10	2	27.40	93.96	12	5.40	2
1970	2	26	19	30	15	27.62	85.70	96	5.00	2
1970	3	10	5	20	0	26.83	96.98	24	5.20	2
1970	4	6	5	7	60	26.45	96.34	98	5.00	2
1970	5	29	10	33	59	23.96	94.06	49	5.10	2
1970	7	25	1	35	2	25.72	88.58	32	5.10	2
1970	7	29	10	16	20	26.02	95.37	68	7.00	2, 3
1970	7	29	10	30	47	26.04	95.33	33	5.00	2
1970	7	29	10	31	1	26.24	95.10	52	5.30	2
1970	7	31	6	47	1	26.16	95.61	47	5.10	2
1971	2	2	7	59	56	23.71	91.66	37	5.40	2
1971	3	12	5	25	18	28.72	94.90	35	5.00	2
1971	5	30	11	56	1	25.22	96.43	44	5.00	2
1971	5	30	15	44	20	25.20	96.41	40	6.30	2, 3
1971	5	31	5	13	59	25.22	96.51	22	6.10	2, 3
1971	6	26	2	16	37	24.60	94.78	74	5.00	2
1971	7	17	15	0	56	26.41	93.15	52	5.50	2, 3
1971	10	14	12	55	22	23.06	95.86	47	5.10	2
1971	11	11	4	40	58	21.44	93.88	55	5.00	2
1971	12	4	8	38	0	27.93	87.95	29	5.20	2
1971	12	29	22	27	4	25.17	94.73	46	5.70	2, 3
1972	4	28	11	30	17	16.99	94.85	28	5.30	2
1972	8	21	18	55	7	27.23	88.02	33	5.10	2
1972	11	1	21	53	46	26.44	96.37	94	5.20	2
1972	11	22	21	5	21	25.09	96.25	0	5.00	2
1972	12	18	11	20	32	21.25	94.35	76	5.00	2
1973	3	22	1	6	57	28.12	87.15	33	5.20	2, 3
1973	5	31	23	39	52	24.31	93.52	1	5.90	2, 3
1973	7	4	16	44	14	27.49	92.60	30	5.20	2, 3
1973	7	4	21	4	46	23.60	94.86	126	5.20	2, 3
1973	7	27	20	23	49	23.28	94.49	60	5.40	2, 3
1973	10	16	9	50	44	28.36	82.99	34	5.00	2
1973	12	26	1	42	20	22.43	93.38	31	5.10	2, 3
1974	3	24	14	16	1	27.66	86.00	20	5.70	2, 3
1974	4	5	3	46	30	21.33	93.68	47	5.00	2, 3
1974	9	7	11	40	28	25.82	96.43	30	5.20	2
1974	9	27	5	26	34	28.59	85.51	20	5.60	2, 3
1974	11	21	19	45	11	19.99	94.99	78	5.10	2, 3
1975	1	31	12	38	51	28.09	84.77	19	5.40	2, 3
1975	2	17	3	38	20	17.65	97.84	6	5.50	2

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1975	3	3	19	24	23	24.11	93.50	42	5.00	2, 3
1975	3	29	10	8	32	19.69	93.97	0	5.20	2
1975	4	24	1	35	51	27.44	87.04	26	5.10	2, 3
1975	5	21	3	16	18	23.86	94.09	51	5.30	2, 3
1975	5	30	17	45	0	26.55	96.92	53	5.70	2
1975	6	3	0	37	43	26.59	96.91	43	5.20	2, 3
1975	6	3	3	23	35	26.59	96.95	10	5.40	2
1975	6	10	11	50	10	28.19	95.91	30	5.10	2, 3
1975	6	23	10	29	28	26.71	93.27	65	5.40	2
1975	6	24	15	38	28	27.74	87.50	33	5.20	2, 3
1975	6	28	6	7	52	29.06	95.56	48	5.00	2, 3
1975	6	28	21	32	3	22.64	94.89	137	5.10	2, 3
1975	7	8	12	4	3	21.42	94.62	112	6.50	2, 3
1975	7	23	3	3	11	26.58	96.36	22	5.20	2, 3
1975	9	29	13	42	41	18.24	96.40	11	5.20	2, 3
1975	11	4	19	27	59	24.09	95.11	98	5.20	2
1975	11	26	15	2	31	28.15	87.80	33	5.10	2, 3
1975	12	13	22	35	44	23.62	94.27	62	5.20	2, 3
1975	12	30	8	57	23	18.15	96.52	23	5.20	2, 3
1976	4	5	21	23	34	21.89	95.30	69	5.50	2, 3
1976	6	23	15	38	43	21.18	88.62	50	5.30	2, 3
1976	8	12	23	26	47	26.70	97.04	31	6.20	2
1976	9	14	6	43	52	29.81	89.57	75	5.50	2, 3
1976	10	23	16	9	21	28.63	86.24	81	5.10	2, 3
1976	12	15	4	35	12	23.10	94.61	103	5.00	2, 3
1977	1	6	21	50	8	31.25	87.98	25	5.00	2
1977	5	12	12	20	4	21.60	92.77	40	5.90	4, 2, 3
1977	10	13	11	32	14	23.27	93.16	61	5.40	4, 2, 3
1977	11	13	21	2	32	26.51	93.00	52	5.10	2, 3
1977	11	18	5	20	10	32.65	88.39	24	5.70	2
1977	12	23	21	0	27	23.71	92.31	33	5.10	2, 3
1978	1	8	6	32	59	24.73	95.20	98	5.10	2, 3
1978	2	3	23	46	42	23.02	94.70	92	5.10	2, 3
1978	2	10	17	29	47	28.03	84.70	0	5.30	2, 3
1978	2	22	9	7	31	23.30	94.13	83	5.00	2, 3
1978	2	23	23	18	37	23.16	94.93	122	5.10	4, 2, 3
1978	8	10	14	52	52	26.46	96.94	38	5.10	2, 3
1978	9	30	9	4	31	16.60	95.88	7	5.50	2
1978	10	4	13	53	51	27.82	85.93	19	5.20	2, 3
1978	10	24	13	38	44	14.58	96.43	3	5.00	2
1978	12	8	0	22	7	16.69	95.94	12	5.00	2
1979	1	1	18	51	15	20.51	93.59	95	5.30	4, 2, 3
1979	2	18	6	16	12	23.04	95.98	43	5.10	2, 3
1979	5	29	0	39	56	24.92	95.05	109	5.30	4, 2, 3
1979	6	19	16	29	12	26.29	87.57	24	5.20	4, 2, 3
1979	7	13	23	20	15	25.13	95.59	117	5.00	4, 2, 3
1979	8	11	20	32	8	24.20	94.93	113	5.00	2, 3
1979	9	29	11	32	44	29.04	95.80	35	5.10	2, 3
1979	10	3	11	35	17	18.11	94.94	54	5.60	4, 2, 3
1979	11	25	2	40	49	25.21	96.32	10	5.20	4, 2, 3
1979	12	6	9	48	54	30.05	95.48	12	5.20	2, 3
1980	2	2	12	29	15	27.83	101.24	22	5.10	2
1980	2	22	3	2	45	30.55	88.65	14	5.70	2
1980	4	4	8	19	23	21.30	93.76	64	5.20	2, 3
1980	6	22	14	38	53	30.13	81.77	29	5.10	2
1980	6	24	7	35	45	33.00	88.55	3	5.10	2
1980	8	12	16	44	2	24.81	94.62	52	5.10	2, 3
1980	10	8	16	19	58	31.43	87.72	34	5.00	2
1980	10	30	5	29	41	23.90	91.46	30	5.00	2, 3
1980	11	18	13	46	21	29.55	85.18	24	5.00	2, 3
1980	11	19	19	0	56	27.42	89.05	44	6.20	4, 2, 3
1980	11	20	18	14	16	22.69	94.49	20	5.30	4, 2, 3
1981	2	9	15	49	22	27.20	89.76	16	5.10	2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1981	4	25	11	32	27	24.99	95.52	153	5.70	4, 2, 3
1981	5	1	4	8	13	23.32	94.64	99	5.00	4, 2, 3
1981	5	13	2	7	52	32.58	82.36	18	5.00	2
1981	6	30	21	55	57	23.00	95.45	10	5.10	4, 2, 3
1981	7	7	2	29	8	25.13	97.90	42	5.00	2
1981	8	14	6	9	34	25.15	97.96	38	5.20	2
1981	8	16	18	55	42	25.52	96.63	38	5.10	2, 3
1981	8	23	15	56	14	26.70	96.06	82	5.20	2, 3
1981	10	23	23	44	45	29.89	94.93	0	5.10	2, 3
1982	1	22	4	29	56	30.89	89.87	3	5.30	2
1982	1	23	17	37	29	31.68	82.28	25	6.00	2
1982	1	23	17	48	2	31.56	82.21	31	5.30	2
1982	1	24	11	35	40	21.41	94.67	120	5.40	2, 3
1982	1	25	17	26	17	31.58	82.25	33	5.10	2
1982	3	30	13	19	52	23.56	95.58	42	5.00	2, 3
1982	4	5	2	19	41	27.38	88.84	9	5.10	2, 3
1982	4	8	2	41	19	18.01	85.84	32	5.50	4, 2, 3
1982	4	22	16	39	32	29.94	95.00	14	5.10	2, 3
1982	7	4	18	34	29	19.56	90.65	29	5.60	4, 2, 3
1982	7	6	6	13	32	25.88	90.31	8	5.10	2, 3
1982	8	31	10	42	45	25.38	91.46	32	5.00	2, 3
1982	9	14	6	1	28	25.93	95.31	88	5.00	2, 3
1982	11	26	13	26	29	27.78	94.87	29	5.10	2, 3
1982	12	28	7	30	4	22.40	100.99	7	5.20	2
1982	12	30	8	37	1	26.01	91.69	61	5.00	2, 3
1983	1	3	11	28	15	24.23	94.45	84	5.10	2, 3
1983	1	12	3	28	24	26.90	97.00	31	5.00	2
1983	1	13	23	0	12	24.67	95.03	109	5.40	2, 3
1983	1	31	3	26	4	24.72	95.04	70	5.00	2, 3
1983	2	2	20	44	7	26.90	92.87	42	5.20	2, 3
1983	3	1	13	22	32	28.63	96.05	40	5.10	2, 3
1983	4	17	23	16	39	21.86	94.19	112	5.10	4, 2, 3
1983	6	26	2	31	19	23.06	93.87	81	5.00	2, 3
1983	8	23	12	12	19	24.48	94.69	148	5.20	4, 2, 3
1983	8	30	10	39	34	25.34	94.90	69	5.70	4, 2, 3
1983	9	22	23	51	57	20.58	93.09	43	5.10	2, 3
1983	9	23	20	18	8	24.77	95.12	115	5.20	2, 3
1983	10	2	21	3	24	28.05	92.52	38	5.00	2, 3
1983	10	21	8	44	53	21.87	94.37	92	5.30	4, 2, 3
1983	11	16	0	54	18	26.58	96.38	144	5.40	4, 2, 3
1984	1	15	12	1	58	19.68	94.61	60	5.20	2, 3
1984	1	20	14	53	59	28.65	96.36	28	5.00	2, 3
1984	2	1	6	10	33	13.01	95.72	37	5.00	2
1984	2	19	9	29	51	24.99	94.79	51	5.00	2, 3
1984	3	5	21	26	50	24.85	95.49	96	5.50	4, 2, 3
1984	3	21	23	6	24	26.76	93.30	15	5.00	2, 3
1984	4	25	14	58	42	26.03	95.70	109	5.00	2, 3
1984	5	6	15	19	19	24.33	93.42	61	6.00	4, 2, 3
1984	5	18	4	28	52	29.52	81.79	0	5.60	2
1984	5	21	9	59	5	23.66	91.51	13	5.30	2, 3
1984	9	22	9	10	30	26.49	92.15	29	5.20	2, 3
1984	9	30	21	35	25	25.44	91.51	34	5.10	2, 3
1984	11	18	22	4	36	28.67	83.32	0	5.40	2, 3
1984	11	28	10	29	30	26.52	96.96	16	5.70	4
1984	12	3	4	17	48	27.41	96.84	84	5.30	2, 3
1984	12	30	23	33	45	24.75	92.99	102	6.00	4, 2, 3
1985	1	7	16	13	5	27.14	91.96	12	5.60	2, 3
1985	1	21	12	57	18	24.70	94.38	94	5.00	2, 3
1985	2	21	12	40	1	28.35	96.04	15	5.40	2, 3
1985	4	24	6	47	52	25.83	95.97	56	5.30	4, 2, 3
1985	7	1	2	23	57	18.40	87.43	10	5.50	4, 2, 3
1985	7	15	10	38	48	19.25	97.30	19	5.00	2
1985	8	1	12	13	52	29.24	95.53	40	5.70	4, 2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1985	8	25	18	42	19	25.45	97.68	14	5.00	2
1985	9	5	18	30	22	25.40	97.71	20	5.00	2
1985	10	12	18	22	37	27.11	92.52	14	5.30	2, 3
1985	12	26	18	4	26	27.09	92.07	11	5.00	2, 3
1986	1	7	20	20	0	27.38	88.43	42	5.00	2, 3
1986	1	10	3	46	44	28.60	87.09	81	5.50	4, 2, 3
1986	1	18	7	44	49	21.10	95.56	22	5.20	2, 3
1986	2	8	0	28	59	23.79	93.09	33	5.40	4, 2, 3
1986	2	19	17	34	30	24.89	91.18	18	5.30	4, 2, 3
1986	4	17	13	15	57	24.43	94.74	86	5.00	2, 3
1986	4	26	0	26	2	23.31	94.92	129	5.10	4, 2, 3
1986	6	20	17	12	47	31.22	86.82	33	5.90	2
1986	6	23	8	50	16	26.25	96.89	32	5.00	2, 3
1986	7	19	20	12	53	31.18	86.86	17	5.10	2
1986	7	23	5	18	40	26.75	95.54	68	5.40	2, 3
1986	7	26	20	24	56	23.86	94.19	65	5.50	4, 2, 3
1986	9	10	7	50	26	25.38	92.15	47	5.30	2, 3
1986	11	1	5	2	40	25.53	96.91	70	5.40	4, 2, 3
1986	11	20	13	5	6	32.61	92.84	33	5.10	2
1986	12	31	15	49	53	26.47	92.91	46	5.10	2, 3
1987	1	24	10	34	26	27.63	92.69	24	5.00	2, 3
1987	3	1	13	31	8	28.67	95.85	17	5.10	2, 3
1987	4	29	0	15	28	22.60	93.73	48	5.30	2, 3
1987	4	29	5	15	35	24.07	94.64	107	5.10	2, 3
1987	5	18	1	53	59	24.58	93.94	75	6.30	4, 2, 3
1987	8	9	21	15	3	29.47	83.74	74	5.50	2
1987	8	24	9	24	44	23.04	94.53	127	5.30	4, 2, 3
1987	9	6	23	38	54	26.64	93.41	58	5.20	2, 3
1987	9	17	1	34	44	30.35	94.83	4	5.00	2
1987	9	25	23	16	34	29.47	90.34	15	5.10	4, 2, 3
1987	10	6	22	18	17	29.90	90.42	10	5.00	2, 3
1988	1	1	22	14	43	20.33	96.01	26	5.20	2, 3
1988	1	25	1	12	27	29.80	94.87	33	5.40	4, 2
1988	2	6	14	50	44	24.05	91.66	31	5.90	4, 2, 3
1988	2	19	23	17	16	18.62	95.57	66	5.30	4, 2, 3
1988	4	20	6	40	26	27.02	86.72	55	5.40	2, 3
1988	5	9	16	3	37	29.02	94.77	20	5.10	2, 3
1988	5	10	20	51	40	29.04	94.78	23	5.00	2, 3
1988	7	3	8	19	21	22.22	94.36	86	5.20	4, 2, 3
1988	8	6	0	36	38	25.19	94.89	101	7.30	4, 2, 3
1988	8	13	19	59	53	24.94	95.24	126	5.10	4, 2, 3
1988	8	20	23	9	16	26.52	86.64	35	6.90	4, 2, 3
1988	8	21	13	16	24	24.94	95.89	94	5.20	4, 2, 3
1988	9	27	19	10	10	27.19	88.37	28	5.00	2, 3
1988	10	23	11	43	11	20.74	94.67	46	5.10	4, 2, 3
1988	10	29	9	11	1	27.39	85.73	18	5.50	4, 2, 3
1988	11	6	14	13	24	23.23	99.45	8	5.10	2
1988	11	27	7	12	42	23.52	93.72	33	5.20	2, 3
1988	12	20	9	45	44	27.66	91.12	39	5.00	2, 3
1988	12	27	18	15	53	23.25	94.74	124	5.10	2, 3
1989	1	18	18	22	47	30.18	100.21	28	5.10	2
1989	1	22	23	55	13	18.29	94.13	33	5.20	2, 3
1989	2	3	17	50	10	29.74	90.13	15	5.40	4
1989	2	12	7	55	56	26.18	96.83	33	5.30	4, 2, 3
1989	3	8	20	2	7	26.94	92.77	59	5.10	2, 3
1989	4	3	19	39	38	25.15	94.81	85	5.60	4, 2, 3
1989	4	9	2	31	43	28.74	89.94	15	5.20	4, 2, 3
1989	4	13	7	25	38	24.25	91.71	33	5.50	4, 2, 3
1989	5	3	15	41	30	30.04	99.53	1	5.80	2
1989	5	4	1	31	22	30.01	99.53	20	5.00	2
1989	5	7	0	38	19	23.54	99.54	33	5.40	2
1989	5	22	19	24	31	27.38	87.86	5	5.00	2, 3
1989	6	12	0	4	16	22.13	89.88	15	5.80	4, 2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni- tude	Refe- rence
1989	6	28	12	8	31	23.79	94.37	66	5.00	2, 3
1989	7	15	0	9	25	22.91	93.94	139	5.60	4, 2, 3
1989	8	9	16	1	25	24.51	94.55	80	5.20	2, 3
1989	9	24	10	55	26	20.22	94.75	144	5.40	4, 2, 3
1989	12	2	19	44	33	21.62	93.89	45	5.30	4, 2, 3
1989	12	8	0	4	33	21.54	93.78	15	5.60	4, 2, 3
1990	1	9	2	29	22	28.15	88.11	36	5.70	2, 3
1990	1	9	18	51	36	24.42	94.95	130	6.30	4, 2, 3
1990	1	10	6	37	55	24.46	94.63	87	5.30	2, 3
1990	2	22	13	33	17	29.14	90.02	54	5.00	2, 3
1990	2	22	22	7	0	24.95	93.13	52	5.10	2, 3
1990	2	26	6	20	14	23.02	94.01	93	5.00	2, 3
1990	3	8	18	57	5	25.11	96.61	57	5.20	4, 2, 3
1990	4	30	1	56	18	26.54	95.23	150	5.30	2, 3
1990	9	2	6	29	26	26.58	92.67	57	5.20	2, 3
1990	11	15	3	28	25	23.81	93.00	26	5.20	2, 3
1990	11	29	10	20	33	24.37	94.64	82	5.00	2, 3
1990	12	29	19	24	12	26.68	92.59	27	5.00	2, 3
1991	1	5	14	57	24	23.61	96.18	21	7.00	4, 2, 3
1991	1	5	16	4	15	23.97	96.04	43	5.20	2, 3
1991	1	23	6	7	9	24.72	95.22	118	5.40	2, 3
1991	1	28	22	24	43	26.08	95.39	0	5.00	2, 3
1991	2	2	0	15	40	25.51	91.17	26	5.00	2, 3
1991	3	11	10	24	39	25.81	94.74	33	5.00	2
1991	5	11	2	15	23	23.42	93.25	74	5.40	4, 2, 3
1991	6	23	10	4	2	26.59	93.19	46	5.40	2, 3
1991	6	25	20	34	58	21.52	94.02	58	5.00	2, 3
1991	8	7	11	36	29	25.27	88.66	10	5.00	2, 3
1991	12	4	3	27	31	24.19	93.83	70	5.50	4, 2, 3
1991	12	7	13	57	39	24.00	93.83	52	5.10	2, 3
1991	12	20	2	6	11	24.47	93.08	101	5.40	4, 2, 3
1992	2	6	3	35	15	29.61	95.64	15	5.60	2, 3
1992	2	9	12	44	53	29.64	95.68	10	5.10	2, 3
1992	2	25	1	57	26	25.17	92.23	33	5.00	2, 3
1992	3	25	22	32	34	24.18	95.20	120	5.20	4, 2, 3
1992	3	27	0	5	25	21.12	94.52	86	5.60	4, 2, 3
1992	4	15	1	32	12	23.96	94.57	143	5.70	4, 2, 3
1992	4	23	15	32	49	22.43	98.88	10	5.70	2
1992	6	2	22	7	45	28.94	81.90	56	5.20	2
1992	6	15	2	49	3	23.95	96.03	23	6.30	4, 2, 3
1992	7	8	10	9	53	21.07	93.51	79	5.40	4, 2, 3
1992	7	9	21	34	4	20.96	90.20	30	5.30	4, 2, 3
1992	7	30	8	25	0	29.46	90.30	15	6.10	4, 2, 3
1992	8	16	20	16	40	30.12	92.09	30	5.00	2
1992	10	28	7	2	11	18.88	96.29	49	5.50	4, 2, 3
1992	11	22	11	42	48	20.43	94.51	71	5.30	4, 2, 3
1992	12	12	14	20	57	25.48	91.39	41	5.00	2, 3
1993	2	15	14	29	41	25.89	87.51	30	5.00	2, 3
1993	3	20	14	52	11	28.87	87.64	15	6.20	4, 2, 3
1993	3	20	21	26	49	29.03	87.35	27	5.20	4, 2, 3
1993	3	27	9	42	58	24.64	95.02	109	5.00	2, 3
1993	3	31	13	44	10	29.10	87.33	16	5.10	2, 3
1993	4	1	16	30	11	23.55	94.00	107	5.30	4, 2, 3
1993	5	24	5	2	30	28.91	96.18	43	5.00	2, 3
1994	4	6	7	3	24	26.16	96.84	9	5.90	2, 3
1994	4	9	11	19	32	24.63	94.81	102	5.10	2, 3
1994	4	14	17	32	45	24.98	95.58	192	5.00	2, 3
1994	5	5	10	43	1	24.78	94.44	60	5.00	2, 3
1994	5	19	3	46	29	25.62	95.30	108	5.10	2
1994	5	29	14	11	59	20.45	94.17	49	6.50	4, 2, 3
1994	8	3	14	59	58	21.51	93.98	34	5.80	3
1994	8	3	15	0	7	21.61	93.88	65	5.70	4, 2
1994	8	8	21	8	37	24.76	94.97	146	6.10	4, 2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
1994	8	19	21	2	48	17.96	96.58	15	5.80	4, 2, 3
1994	11	21	8	16	40	25.37	96.83	43	5.90	4, 2, 3
1995	1	23	9	27	13	19.26	96.08	3	5.10	2, 3
1995	1	30	22	2	11	18.61	93.80	21	5.00	2, 3
1995	2	17	2	44	32	27.48	92.62	35	5.50	4, 2, 3
1995	5	6	1	59	14	24.83	95.02	148	6.40	4, 2, 3
1995	5	9	9	54	22	25.00	94.94	124	5.20	4, 2, 3
1995	5	16	21	48	6	17.89	96.49	11	6.10	2, 3
1995	12	12	5	42	33	26.87	96.07	33	5.10	2, 3
1996	4	26	16	30	58	27.84	87.80	25	5.00	2, 3
1996	6	9	23	25	27	28.71	92.58	83	5.20	4, 2, 3
1996	7	3	6	44	52	29.77	88.32	15	5.60	4, 2
1996	7	3	10	10	42	29.92	88.19	33	5.00	4, 2, 3
1996	7	8	11	40	40	21.33	94.77	120	5.10	2, 3
1996	7	26	13	9	10	24.68	96.53	68	5.40	4, 2, 3
1996	7	27	8	45	20	20.80	94.85	129	5.20	4, 2, 3
1996	7	31	8	0	34	29.74	88.67	15	5.40	4, 2
1996	7	31	8	2	53	30.10	88.13	33	5.00	2
1996	9	25	17	41	18	27.60	88.80	32	5.00	2, 3
1996	11	11	9	22	30	19.27	95.05	86	6.00	4, 2, 3
1996	11	19	0	12	22	24.05	93.38	53	5.40	4, 2, 3
1996	11	20	23	27	7	28.86	95.95	29	5.00	2, 3
1996	12	30	11	8	19	27.49	86.77	33	5.00	2, 3
1997	1	31	20	2	14	27.99	85.21	7	5.20	2, 3
1997	4	14	17	53	38	22.55	94.18	110	5.30	4, 2, 3
1997	5	8	2	53	19	24.51	92.36	35	6.00	4, 2, 3
1997	7	11	14	54	53	21.41	94.64	150	5.40	4, 2, 3
1997	7	18	19	39	23	26.83	91.80	46	5.00	2, 3
1997	7	31	15	59	40	23.80	93.43	42	5.30	4, 2, 3
1997	10	30	2	2	53	29.54	89.73	45	5.30	2, 3
1997	11	3	2	29	57	28.60	85.39	33	5.50	4, 2, 3
1997	11	21	11	23	9	22.21	92.70	54	6.10	4, 2, 3
1997	11	27	16	11	57	27.56	87.31	33	5.10	2, 3
1997	12	8	2	3	56	27.50	87.27	33	5.00	2, 3
1997	12	30	13	43	24	25.01	96.52	54	5.80	4, 2, 3
1998	5	2	8	36	55	24.84	95.09	127	5.50	4, 2, 3
1998	7	8	3	44	59	27.32	91.07	33	5.20	2, 3
1998	7	20	1	6	7	29.83	88.47	15	5.70	4
1998	7	21	14	40	54	29.93	88.50	16	5.00	4, 2
1998	8	18	4	10	23	27.65	91.10	35	5.20	2, 3
1998	8	25	7	41	53	29.86	88.31	15	5.80	4
1998	9	3	18	15	52	27.86	86.95	3	5.60	2, 3
1998	9	26	18	27	14	27.87	93.60	33	5.50	4, 2, 3
1998	9	30	2	29	59	29.64	88.25	33	5.20	4, 2, 3
1998	10	5	10	24	57	29.89	88.60	33	5.20	4
1998	10	16	0	5	37	23.82	94.74	112	5.40	4, 2, 3
1998	11	6	22	52	9	11.06	92.49	33	5.10	2
1998	11	26	10	14	23	27.69	87.86	35	5.10	2, 3
1998	12	2	13	25	1	26.40	93.50	10	5.00	2, 3
1999	2	22	11	37	53	23.15	93.99	51	5.10	4, 2, 3
1999	4	5	22	32	57	24.50	93.96	65	5.60	4, 2, 3
1999	4	5	22	32	58	25.00	93.51	33	5.50	2
1999	7	22	10	42	12	21.53	92.02	10	5.20	2, 3
1999	7	22	10	42	12	21.62	91.90	10	5.20	2
1999	7	28	17	55	6	25.77	93.23	11	5.00	2
1999	8	1	8	24	51	28.37	86.79	40	5.20	2, 3
1999	8	1	8	24	52	28.55	86.75	87	5.00	2
1999	8	15	16	18	37	18.46	96.23	39	5.20	4, 2, 3
1999	8	15	16	18	40	18.38	96.38	47	5.00	2
1999	9	20	7	28	6	27.24	87.98	23	5.00	2
1999	10	5	17	4	51	25.88	91.89	33	5.20	4, 2, 3
1999	10	5	17	4	4	26.26	91.93	33	5.30	2
2000	1	2	10	23	55	27.60	92.57	6	5.10	2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
2000	1	25	12	7	45	27.68	88.36	32	5.00	2
2000	1	25	16	43	19	27.68	92.65	4	5.30	2, 3
2000	2	27	17	21	24	23.03	94.13	39	5.10	2, 3
2000	6	7	21	46	56	26.80	97.19	33	6.20	2
2000	7	2	4	27	58	24.45	94.67	103	5.20	4, 2, 3
2000	10	6	12	5	41	24.38	97.80	33	5.10	2
2000	10	11	9	42	11	23.58	94.63	122	5.60	4, 2, 3
2000	11	13	8	56	56	21.94	93.04	74	5.50	4, 2, 3
2001	3	3	22	56	5	23.99	93.43	64	5.30	4, 2, 3
2001	4	10	22	8	23	25.35	94.91	149	5.30	4, 2, 3
2001	4	28	10	37	55	28.77	87.13	25	5.20	2, 3
2001	7	10	20	57	41	22.60	93.32	33	5.00	2
2001	7	16	16	12	44	28.15	84.87	4	5.00	2, 3
2001	8	12	1	58	1	24.43	94.99	142	5.10	4, 2, 3
2001	10	4	21	50	52	18.93	92.28	10	5.30	2
2001	10	13	20	54	53	18.69	91.80	15	5.20	4, 2, 3
2001	10	13	22	18	15	18.95	92.30	8	5.40	2
2001	10	19	7	4	35	21.08	93.69	47	5.00	2, 3
2001	10	20	15	29	44	19.73	92.68	12	5.30	2
2001	11	1	13	20	32	19.06	92.44	10	5.20	2
2001	11	1	15	49	46	18.84	92.18	10	5.60	2
2001	11	6	14	9	24	27.39	91.97	21	5.20	2, 3
2001	11	19	12	49	11	23.89	92.88	10	5.00	2
2001	11	23	12	40	38	19.57	92.81	150	5.20	2
2001	11	23	13	33	35	19.65	92.62	10	5.30	2
2001	11	23	14	0	4	19.70	92.73	19	5.20	2
2001	11	25	20	7	0	19.02	92.31	21	5.10	2
2001	12	2	22	41	13	27.22	88.18	25	5.10	2, 3
2001	12	12	23	38	3	22.01	94.14	10	5.60	2
2001	12	20	22	47	9	20.76	93.35	10	5.30	2
2002	1	18	21	6	4	23.75	93.53	33	5.40	2
2002	1	29	21	56	1	21.54	92.27	145	5.00	2
2002	3	1	15	59	38	13.04	93.57	24	5.00	2
2002	3	10	13	15	39	21.21	94.24	87	5.30	2
2002	4	2	19	12	49	25.53	96.11	33	5.10	2
2002	4	6	7	41	9	20.97	94.35	99	5.20	2
2002	7	7	2	47	11	22.36	94.51	132	5.90	2
2002	8	31	12	40	33	29.88	88.06	16	5.00	2, 3
2002	10	5	12	14	39	24.85	95.27	159	5.90	2, 3
2002	10	16	1	31	21	21.16	93.16	46	5.10	4, 2, 3
2002	10	30	18	7	15	23.33	93.88	93	5.70	2
2002	11	10	21	54	1	17.26	93.56	42	5.10	4, 2, 3
2002	11	30	2	52	3	28.62	95.07	31	5.10	2, 3
2002	12	4	11	30	57	19.57	94.86	49	5.70	4, 2, 3
2002	12	12	10	55	19	23.52	93.66	69	6.00	2
2003	1	16	11	36	50	29.96	88.11	12	5.10	2, 3
2003	1	17	2	53	6	19.68	95.13	114	5.00	4, 2, 3
2003	3	25	18	51	31	26.92	89.82	56	5.50	4, 2, 3
2003	7	26	23	18	25	22.90	92.31	15	5.70	4, 2, 3
2003	7	27	12	7	33	22.83	92.34	15	5.50	4, 2, 3
2003	8	18	9	3	10	29.26	95.91	33	5.50	4, 2, 3
2003	9	21	18	16	23	19.86	95.72	16	6.60	4, 2, 3
2003	10	30	15	22	22	19.82	95.73	15	5.30	4, 2, 3
2003	12	7	20	20	55	19.85	95.91	10	5.10	2, 3
2003	12	19	0	12	2	19.65	95.80	15	5.50	4, 2, 3
2004	1	28	1	16	16	17.40	94.31	33	5.00	2, 3
2004	9	27	17	5	41	29.78	95.70	31	5.20	4, 2, 3
2004	12	9	8	49	5	24.66	92.72	39	5.40	4, 2, 3
2004	12	30	1	13	46	19.86	95.85	42	5.00	2, 3
2005	2	3	20	13	32	26.04	95.58	79	5.00	4, 2, 3
2005	2	8	7	20	60	19.61	96.05	16	5.10	4, 2, 3
2005	2	15	11	15	14	24.52	92.61	27	5.10	4, 2, 3
2005	2	15	13	5	54	24.40	94.62	60	5.20	4, 2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
2005	3	25	13	34	44	25.54	94.92	83	5.20	4, 2, 3
2005	6	1	20	6	45	28.81	94.72	19	5.90	4, 2, 3
2005	7	17	1	4	48	20.80	95.09	122	5.00	4, 2, 3
2005	9	18	7	26	2	24.48	94.71	105	5.70	4, 2, 3
2005	10	22	13	45	8	25.86	96.66	10	5.00	2, 3
2005	10	31	10	34	5	17.58	92.68	19	5.00	4, 2, 3
2005	10	31	21	47	60	28.38	84.88	23	5.00	4, 2, 3
2005	12	29	7	20	57	24.74	96.29	19	5.10	4, 2, 3
2006	2	14	0	55	29	27.22	88.64	19	5.30	4, 2, 3
2006	2	23	20	4	58	26.91	91.94	12	5.80	4, 2, 3
2006	2	23	20	7	25	26.90	91.62	1	5.20	2, 3
2006	3	3	1	36	8	21.15	94.44	121	5.20	2, 3
2006	3	25	20	13	37	23.33	93.91	46	5.10	4, 2, 3
2006	5	11	17	22	59	23.31	94.30	34	5.70	4, 2, 3
2006	8	12	20	46	13	24.59	92.86	33	5.00	4, 2, 3
2006	11	3	14	43	12	21.99	93.26	35	5.00	4, 2, 3
2007	1	9	5	27	25	19.13	95.35	98	5.10	4, 2, 3
2007	5	7	5	58	37	23.02	94.58	97	5.00	4, 2, 3
2007	6	29	23	23	58	25.40	96.79	14	5.20	4, 2, 3
2007	7	30	22	42	7	19.06	95.77	12	5.90	4, 2, 3
2007	7	31	8	43	43	19.05	95.79	14	5.20	4, 2, 3
2007	8	11	14	35	53	27.39	87.73	22	5.00	2, 3
2007	8	11	18	4	53	-22.24	-179.50	608	5.30	2
2007	9	18	9	1	51	19.95	93.64	35	5.10	2, 3
2007	9	26	17	33	43	23.94	94.54	42	5.10	2, 3
2007	11	7	7	10	25	22.15	92.50	25	5.50	4, 2, 3
2007	11	10	19	36	25	29.39	95.44	28	5.00	2, 3
2007	11	29	19	0	23	23.37	94.49	116	5.10	2, 3
2007	12	7	6	56	33	23.46	94.66	109	5.00	4, 2, 3
2008	3	20	13	15	52	23.89	90.04	49	5.10	2
2008	7	27	22	42	8	23.60	94.63	114	5.20	2, 3
2008	8	30	8	30	52	26.31	101.89	2	5.60	2
2008	10	6	8	30	52	29.66	90.50	12	6.30	4, 2, 3
2008	10	6	8	45	11	29.81	90.38	10	5.00	2, 3
2008	10	6	10	17	12	29.79	90.31	10	5.10	2, 3
2008	10	6	12	10	38	29.56	90.53	14	5.20	4, 2, 3
2008	10	8	14	7	22	29.76	90.57	15	5.50	4, 2, 3
2008	12	1	9	24	0	28.16	85.32	31	5.00	2
2008	12	2	5	11	42	27.32	87.97	24	5.20	2, 3
2008	12	8	8	59	9	29.99	82.09	15	5.30	2
2008	12	20	23	22	51	22.65	96.09	15	5.30	4, 2, 3
2009	3	26	4	44	11	22.41	85.87	10	5.10	2, 3
2009	7	24	3	11	57	31.17	85.96	13	5.80	2
2009	8	11	21	43	50	24.25	94.77	115	5.50	4, 2, 3
2009	8	19	10	45	18	26.51	92.45	46	5.00	2, 3
2009	8	30	19	27	51	25.13	95.06	78	5.30	4, 2, 3
2009	9	3	19	51	11	24.29	94.73	116	5.90	4, 2, 3
2009	9	14	14	2	58	19.61	95.03	10	5.00	2
2009	9	21	8	53	10	27.20	91.63	12	6.10	4, 2, 3
2009	9	21	19	38	44	20.14	94.87	74	5.70	4, 2, 3
2009	10	29	17	0	40	27.20	91.62	15	5.20	4, 2, 3
2009	11	7	20	8	55	29.31	86.28	19	5.60	4, 2, 3
2009	11	17	20	40	21	27.95	92.90	35	5.00	2
2009	12	13	14	41	57	21.87	91.74	12	5.10	4, 2, 3
2009	12	29	9	1	55	24.31	94.84	125	5.60	4, 2, 3
2009	12	31	9	57	31	27.33	91.48	19	5.50	2, 3
2010	2	26	4	42	42	28.41	86.77	85	5.50	4, 2, 3
2010	3	12	23	19	57	22.99	94.62	115	5.50	4, 2, 3
2010	4	28	18	1	23	19.18	93.01	31	5.30	4, 2, 3
2010	9	10	17	24	21	23.29	90.74	18	5.10	4, 2, 3
2010	11	30	8	40	0	29.78	90.53	21	5.40	4, 2, 3
2010	12	29	18	30	59	30.88	86.52	14	5.20	2
2011	2	4	13	53	49	24.46	94.68	104	6.40	4, 2, 3

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
2011	4	15	17	21	10	27.90	87.31	50	5.40	2
2011	6	3	0	53	25	27.45	87.84	30	5.00	2, 3
2011	7	5	20	22	35	26.88	97.25	10	5.30	2
2011	9	18	12	40	60	27.44	88.35	46	6.90	4, 2, 3
2011	11	21	3	15	43	24.82	95.19	129	5.80	4, 2, 3
2011	11	28	15	6	48	25.17	97.57	10	5.10	2
2012	3	27	23	40	12	26.01	87.70	31	5.00	2, 3
2012	5	11	12	41	37	26.18	93.03	46	5.40	4, 2, 3
2012	7	1	4	13	55	25.60	94.73	50	5.60	4, 2, 3
2012	7	9	20	13	7	25.29	96.66	12	5.10	4, 2, 3
2012	7	14	19	55	19	25.40	94.45	41	5.30	4, 2, 3
2012	7	22	2	11	12	24.86	96.43	18	5.10	4, 2, 3
2012	7	22	16	44	22	29.93	88.32	25	5.00	4, 2, 3
2012	7	29	2	21	14	22.83	94.32	72	5.80	4, 2, 3
2012	8	2	19	6	11	26.13	96.24	35	5.10	2, 3
2012	10	2	18	37	39	26.78	92.95	36	5.20	4, 2, 3
2012	11	11	1	12	56	22.73	96.03	17	6.80	4, 2, 3
2012	11	11	10	54	43	22.60	96.05	12	5.90	4, 2, 3
2012	11	11	18	19	44	23.06	96.07	20	5.60	4, 2, 3
2012	11	13	18	28	13	22.83	95.98	16	5.00	4, 2, 3
2012	12	22	16	41	47	22.29	94.80	142	5.50	4, 2, 3
2012	12	26	13	59	46	22.77	95.87	27	5.00	4, 2, 3
2013	1	9	1	41	55	25.09	94.95	106	5.80	4, 2, 3
2013	3	2	1	30	43	24.56	92.28	45	5.50	4, 2, 3
2013	3	30	20	4	47	22.94	96.07	12	5.20	4, 2, 3
2013	4	3	16	35	48	19.13	95.79	12	5.80	4, 2, 3
2013	4	4	15	16	27	19.08	95.77	12	5.60	4, 2, 3
2013	4	11	3	47	3	19.04	95.83	12	5.50	4, 2, 3
2013	4	16	8	34	13	28.67	95.12	40	5.20	4, 2, 3
2013	8	2	12	4	33	23.74	94.82	93	5.00	4, 2, 3
2013	9	9	3	28	34	22.91	96.05	23	5.20	4, 2, 3
2013	9	20	11	53	28	22.81	96.04	12	5.00	4, 2, 3
2013	9	20	12	24	49	22.88	96.04	12	5.70	4, 2, 3
2013	9	20	12	24	5	22.91	95.74	74	5.60	2
2013	9	21	3	32	46	26.92	89.52	10	5.50	2
2013	10	3	6	12	44	27.17	88.79	27	5.30	4, 2, 3
2013	10	15	3	45	0	27.30	87.45	10	5.50	2
2013	10	21	2	25	33	26.56	94.51	15	5.90	2
2013	10	27	12	10	59	20.00	96.92	10	5.30	2
2013	11	1	6	11	25	20.17	95.04	10	6.10	2
2013	11	4	16	44	21	27.46	92.35	10	5.70	2
2013	11	6	4	16	20	26.39	93.74	36	5.40	4, 2, 3
2013	11	29	1	54	47	28.91	95.85	10	5.00	2, 3
2013	12	20	3	5	45	22.20	91.56	10	5.70	2
2014	1	26	12	38	37	22.78	96.01	20	5.20	4, 2, 3
2014	1	29	13	46	55	23.71	94.08	54	5.10	4, 2, 3
2014	3	9	16	2	56	19.24	95.69	0	5.10	2, 3
2014	4	11	2	33	15	29.79	91.62	10	5.10	2
2014	5	21	16	21	57	18.10	88.09	58	6.10	4, 2, 3
2014	5	30	1	20	17	25.03	97.78	10	6.00	2
2014	8	3	5	57	33	29.00	85.57	19	6.00	4, 2, 3
2014	8	3	5	57	3	29.30	85.54	31	5.30	2
2014	8	16	16	39	58	24.66	94.76	94	5.00	4, 2, 3
2014	9	9	9	28	23	21.98	93.14	16	5.40	4, 2, 3
2014	11	17	4	34	15	20.78	94.44	90	5.30	4, 2, 3
2014	11	20	18	14	40	23.49	93.46	35	5.70	4, 2, 3
2014	12	18	15	32	15	27.46	86.56	30	5.00	4, 2, 3
2014	12	21	5	37	43	24.30	94.76	93	5.10	4, 2, 3
2015	2	12	14	33	10	23.97	93.93	96	5.00	4, 2, 3
2015	4	9	22	51	48	22.76	88.39	33	5.60	2
2015	4	25	6	11	59	27.91	85.33	12	7.90	4, 2, 3
2015	4	25	6	15	3	27.44	85.07	0	6.10	2, 3
2015	4	25	6	15	20	28.18	84.82	30	6.00	2

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Depth	Magni-tude	Refe-rence
2015	4	25	6	17	57	27.64	85.76	0	5.60	2, 3
2015	4	25	6	18	13	27.85	86.10	0	5.40	2
2015	4	25	6	20	20	28.02	84.41	0	5.40	2, 3
2015	4	25	6	20	48	28.08	85.03	10	5.80	2
2015	4	25	6	22	3	27.81	85.13	10	5.20	2, 3
2015	4	25	6	22	12	27.76	85.08	0	5.00	2
2015	4	25	6	22	20	27.80	85.44	0	5.10	2
2015	4	25	6	25	33	27.32	85.34	0	5.00	2, 3
2015	4	25	6	36	23	27.81	85.11	0	5.10	2, 3
2015	4	25	6	45	29	27.86	84.93	21	6.70	4, 2, 3
2015	4	25	6	45	22	28.39	84.83		7.10	2, 3
2015	4	25	6	53	42	27.70	85.31	10	5.00	2, 3
2015	4	25	6	56	0	27.72	84.91	0	5.50	2, 3
2015	4	25	6	56	32	27.74	85.78	0	5.20	2
2015	4	25	6	58	26	27.68	86.00	0	5.10	2, 3
2015	4	25	7	46	60	27.82	85.64	0	5.00	2, 3
2015	4	25	8	17	1	27.77	85.81	12	5.00	2, 3
2015	4	25	8	29	26	28.05	84.73	11	5.10	2, 3
2015	4	25	8	36	5	27.75	85.24	10	5.20	2, 3
2015	4	25	8	55	53	27.46	85.67	0	5.30	2, 3
2015	4	25	9	17	3	28.44	87.35	10	5.70	2, 3
2015	4	25	9	21	18	27.68	85.98	10	5.00	2, 3
2015	4	25	9	30	30	27.97	85.47	10	5.10	2, 3
2015	4	25	11	5	2	27.90	85.53	10	5.20	2, 3
2015	4	25	11	23	53	28.10	85.44	10	5.00	2, 3
2015	4	25	12	17	54	28.04	85.41	10	5.00	2
2015	4	25	12	44	4	28.06	84.67	0	5.20	2, 3
2015	4	25	16	27	24	27.89	85.66	19	5.00	2, 3
2015	4	25	17	42	53	28.06	85.89	21	5.30	4, 2, 3
2015	4	25	17	46	14	28.26	85.88	10	5.00	2, 3
2015	4	25	23	16	18	27.61	84.96	15	5.50	4, 2, 3
2015	4	26	7	9	20	27.56	85.95	21	6.80	4, 2, 3
2015	4	26	7	18	28	27.78	85.96	10	5.00	2
2015	4	26	7	19	54	27.81	85.98	10	5.10	2
2015	4	26	7	26	5	27.66	85.90	10	5.00	2, 3
2015	4	26	16	26	10	27.56	85.90	20	5.20	4, 2, 3
2015	4	27	12	35	53	26.66	88.27	27	5.10	4, 2, 3
2015	5	3	11	35	12	27.80	85.11	10	5.00	2, 3
2015	5	12	7	5	28	27.67	86.08	12	7.30	4, 2, 3
2015	5	12	7	10	19	27.74	86.26	25	5.70	2
2015	5	12	7	16	39	27.32	86.16	0	5.50	2, 3
2015	5	12	7	17	22	27.82	86.16	10	5.70	2
2015	5	12	7	22	27	27.62	86.33	0	5.00	2, 3
2015	5	12	7	33	9	27.70	86.01	0	5.40	2, 3
2015	5	12	7	36	60	27.37	86.35	20	6.30	4, 2, 3
2015	5	12	8	6	5	27.63	86.09	0	5.00	2, 3
2015	5	12	8	13	55	27.91	85.83	10	5.20	2, 3
2015	5	12	8	21	11	27.79	86.16	10	5.20	2, 3
2015	5	12	21	25	10	27.78	84.70	0	5.20	2, 3
2015	5	13	21	38	4	27.61	86.11	0	5.00	2, 3
2015	5	16	11	34	13	27.37	86.26	12	5.50	4, 2, 3
2015	5	25	11	5	2	27.91	85.50	10	5.30	2
2015	6	28	1	5	30	26.38	90.59	40	5.30	4, 2, 3
2015	7	21	1	27	9	19.15	96.25	19	5.00	4, 2, 3
2015	8	23	9	2	3	27.75	86.15	0	5.00	2, 3
2015	11	19	4	15	50	27.76	85.64	0	5.00	2, 3
2015	11	27	8	34	2	22.38	94.99	17	5.40	4, 2, 3

*List of Reference:

1 – NDMA: National Disaster Management Authority, India

2 – ISC: International Seismological Centre

3 – NEIC: National Earthquake Information Center, USA

4 – GlobalCMT: Global Centroid-Moment-Tensor Project

5 – BNBC: Bangladesh National Building Code

6 – ISET: Indian Society of Earthquake Technology

7 – ISS: International Seismological Summary

8 – IMD: India Meteorological Department

APPENDIX B Focal Mechanism

Year	Month	Day	Latitude	Longitude	Depth	Magnitude	Fault Plane Solution 1			Fault Plane Solution 2		
							Strike	Dip	Rake	Strike	Dip	Rake
1977	5	12	21.60	92.77	40	5.9	216	72	3	125	87	162
1977	10	13	23.27	93.16	60.8	5.4	145	41	-171	48	84	-49
1978	2	23	23.16	94.93	122.2	5.1	331	31	44	201	69	113
1979	1	1	20.51	93.59	95	5.3	93	32	62	305	62	106
1979	5	29	24.92	95.05	108.5	5.3	109	30	134	241	69	68
1979	6	19	26.29	87.57	24	5.0	179	34	-82	350	57	-95
1979	7	13	25.13	95.59	117.1	5.0	44	28	99	215	62	85
1979	10	3	18.11	94.94	54.4	5.6	181	16	-64	334	76	-97
1979	11	25	25.21	96.32	10	5.2	357	79	-175	266	85	-11
1980	11	19	27.42	89.05	44.1	6.2	209	51	-2	301	89	-141
1980	11	20	22.69	94.49	20	5.2	208	19	131	345	76	78
1981	4	25	24.99	95.52	152.9	5.7	135	44	80	329	47	99
1981	5	1	23.32	94.64	99.1	4.9	247	22	21	137	82	111
1981	6	30	23.00	95.45	10	4.9	7	40	142	128	67	57
1982	4	8	18.01	85.84	31.7	5.2	325	51	131	91	54	51
1982	7	4	19.56	90.65	29.4	5.6	240	73	0	330	90	-163
1983	4	17	21.86	94.19	112.3	5.0	236	26	-22	345	81	-115
1983	8	23	24.48	94.69	147.9	5.2	297	44	58	158	54	118
1983	8	30	25.34	94.90	68.9	5.7	161	65	159	260	71	26
1983	10	21	21.87	94.37	92	5.2	109	5	-151	350	87	-85
1983	11	16	26.58	96.38	144.4	5.4	177	58	147	286	62	37
1984	3	5	24.85	95.49	95.8	5.4	114	21	144	238	78	72
1984	5	6	24.33	93.42	61.3	6.0	157	69	161	254	73	22
1984	11	28	26.52	96.96	16	5.7	311	49	17	210	77	138
1984	12	30	24.75	92.99	101.8	6.0	352	46	123	129	53	61
1985	4	24	25.83	95.97	56.4	5.2	324	38	58	182	58	113
1985	7	1	18.40	87.43	10	5.4	60	58	1	330	89	148
1985	8	1	29.24	95.53	40	5.7	176	15	153	292	83	76
1986	1	10	28.60	87.09	81.4	5.1	140	46	-163	38	78	-45
1986	2	8	23.79	93.09	33	5.4	224	62	-15	321	77	-152
1986	2	19	24.89	91.18	18	5.3	340	50	180	70	90	40
1986	4	26	23.31	94.92	129.2	5.1	87	30	136	217	69	67
1986	7	26	23.86	94.19	64.9	5.4	130	72	15	36	76	162
1986	11	1	25.53	96.91	69.8	5.2	28	45	132	157	58	56
1987	5	18	24.58	93.94	75.3	6.2	67	68	-14	163	77	-158
1987	8	24	23.04	94.53	126.5	5.3	135	42	144	254	67	54
1987	9	25	29.47	90.34	15	5.0	201	45	-90	21	45	-90
1988	1	25	29.80	94.87	33	5.2	37	69	159	135	71	23
1988	2	6	24.05	91.66	31	5.8	239	76	9	147	82	166
1988	2	19	18.62	95.57	66	5.2	114	14	-124	329	78	-82
1988	7	3	22.22	94.36	86	5.0	133	18	-104	327	72	-85
1988	8	6	25.19	94.89	100.5	7.2	284	45	55	148	54	120
1988	8	13	24.94	95.24	126	5.0	307	35	69	152	58	104
1988	8	20	26.52	86.64	34.7	6.8	230	23	2	137	89	113
1988	8	21	24.94	95.89	93.8	5.2	67	49	28	318	69	136
1988	10	23	20.74	94.67	45.6	5.1	168	27	-58	313	68	-105
1988	10	29	27.39	85.73	18	5.2	309	30	109	106	62	79
1989	2	3	29.74	90.13	15	5.4	221	77	-9	313	82	-166
1989	2	12	26.18	96.83	33	5.3	295	60	24	193	69	148
1989	4	3	25.15	94.81	85.3	5.6	71	81	-8	163	82	-171
1989	4	9	28.74	89.94	15	5.1	330	43	-119	187	53	-65

Year	Month	Day	Lati-tude	Longi-tude	Depth	Magni-tude	Fault Plane Solution1			Fault Plane Solution2		
							Strike	Dip	Rake	Strike	Dip	Rake
1989	4	13	24.25	91.71	33	5.4	291	6	20	181	88	96
1989	6	12	22.13	89.88	15	5.8	354	67	164	90	75	24
1989	7	15	22.91	93.94	139.4	5.5	111	44	159	217	75	48
1989	9	24	20.22	94.75	144	5.3	83	59	145	192	61	36
1989	12	2	21.62	93.89	44.6	5.3	196	42	-50	328	59	-120
1989	12	8	21.54	93.78	15	5.4	213	38	-31	328	71	-124
1990	1	9	24.42	94.95	129.6	6.3	140	32	139	267	69	64
1990	3	8	25.11	96.61	56.5	5.2	32	73	173	124	84	18
1991	1	5	23.61	96.18	20.9	6.9	2	68	166	97	77	23
1991	5	11	23.42	93.25	73.6	5.4	159	77	171	251	81	13
1991	12	4	24.19	93.83	70	5.5	245	68	11	151	79	157
1991	12	20	24.47	93.08	100.8	5.3	258	54	30	150	66	140
1992	3	25	24.18	95.20	119.7	5.1	272	30	43	143	70	113
1992	3	27	21.12	94.52	86.2	5.6	159	12	-85	334	78	-91
1992	4	15	23.96	94.57	142.5	5.7	281	45	56	145	54	120
1992	6	15	23.95	96.03	22.9	6.3	8	69	-173	275	83	-21
1992	7	8	21.07	93.51	79	5.2	191	33	-75	353	58	-100
1992	7	9	20.96	90.20	30	5.3	79	59	13	342	79	148
1992	7	30	29.46	90.30	15	6.1	10	42	-94	196	49	-86
1992	10	28	18.88	96.29	48.9	5.4	68	65	7	335	84	155
1992	11	22	20.43	94.51	71.4	5.2	187	29	-43	317	71	-112
1993	3	20	28.87	87.64	15	6.2	161	46	-121	22	52	-62
1993	3	20	29.03	87.35	26.6	5.1	160	16	-106	357	75	-86
1993	4	1	23.55	94.00	107	5.1	99	44	-169	1	83	-46
1994	5	29	20.45	94.17	49.1	6.5	220	32	-8	316	86	-122
1994	8	3	21.61	93.88	64.5	5.7	216	73	0	306	90	-163
1994	8	8	24.76	94.97	145.6	6.1	111	34	120	257	61	71
1994	8	19	17.96	96.58	15	5.7	83	73	-5	175	85	-163
1994	11	21	25.37	96.83	42.7	5.9	34	76	179	124	89	14
1995	2	17	27.48	92.62	35	5.4	322	46	-172	226	84	-44
1995	5	6	24.83	95.02	147.7	6.4	278	39	60	135	57	112
1995	5	9	25.00	94.94	123.9	5.2	142	33	118	289	62	73
1996	6	9	28.71	92.58	83	5.2	12	23	-117	221	69	-79
1996	7	3	29.77	88.32	15	5.6	172	45	-102	8	46	-78
1996	7	3	29.92	88.19	33	5.0	175	27	-83	347	63	-94
1996	7	26	24.68	96.53	67.6	5.3	93	70	11	359	80	159
1996	7	27	20.80	94.85	128.9	5.2	204	60	33	96	62	146
1996	7	31	29.74	88.67	15	5.4	23	32	-41	150	70	-115
1996	11	11	19.27	95.05	85.6	6.0	191	68	20	93	71	157
1996	11	19	24.05	93.38	53	5.3	102	34	59	317	61	109
1997	4	14	22.55	94.18	110.1	5.2	150	61	165	247	77	30
1997	5	8	24.51	92.36	35	5.9	78	68	4	347	86	158
1997	7	11	21.41	94.64	150.4	5.3	208	37	24	98	76	124
1997	7	31	23.80	93.43	41.8	5.2	330	16	40	201	80	103
1997	11	3	28.60	85.39	33	5.5	21	31	-70	178	61	-102
1997	11	21	22.21	92.70	54.4	6.1	163	37	168	263	83	54
1997	12	30	25.01	96.52	54.4	5.7	122	84	5	32	85	174
1998	5	2	24.84	95.09	127.4	5.5	132	68	156	232	68	24
1998	7	20	29.83	88.47	15	5.7	16	32	-83	187	59	-95
1998	7	21	29.93	88.50	15.7	5.0	34	43	-90	214	47	-90
1998	8	25	29.86	88.31	15	5.8	14	46	-67	162	48	-112
1998	9	26	27.87	93.60	33	5.0	233	26	118	22	67	77
1998	9	30	29.64	88.25	33	5.1	139	32	-112	345	60	-76
1998	10	5	29.89	88.60	33	5.2	26	29	-77	191	62	-97

Year	Month	Day	Lati-tude	Longi-tude	Depth	Magni-tude	Fault Plane Solution1			Fault Plane Solution2		
							Strike	Dip	Rake	Strike	Dip	Rake
1998	10	16	23.82	94.74	112.1	5.3	86	12	180	177	90	78
1999	2	22	23.15	93.99	51	5.0	47	35	-103	242	56	-81
1999	4	5	24.50	93.96	65.1	5.5	86	62	16	348	76	151
1999	8	15	18.46	96.23	38.9	5.2	265	83	-2	356	88	-173
1999	10	5	25.88	91.89	33	5.2	244	68	12	149	79	158
2000	7	2	24.45	94.67	103.2	5.2	133	37	155	244	75	56
2000	10	11	23.58	94.63	122.3	5.5	343	14	98	155	77	88
2000	11	13	21.94	93.04	74	5.4	216	83	-5	307	85	-173
2001	3	3	23.99	93.43	64.1	5.2	140	40	-141	19	66	-57
2001	4	10	25.35	94.91	148.7	5.2	8	34	28	254	75	121
2001	8	12	24.43	94.99	142	5.0	285	40	48	155	61	119
2001	10	13	18.69	91.80	15	5.1	93	33	-80	261	58	-97
2002	10	16	21.16	93.16	45.9	5.1	310	43	-128	177	57	-60
2002	11	10	17.26	93.56	41.9	5.0	284	44	-90	104	46	-90
2002	12	4	19.57	94.86	48.6	5.5	160	15	-89	339	75	-90
2003	1	17	19.68	95.13	114.2	5.0	38	31	159	146	80	61
2003	3	25	26.92	89.82	55.8	5.4	40	70	-21	137	71	-159
2003	7	26	22.90	92.31	15	5.6	338	32	82	168	59	95
2003	7	27	22.83	92.34	15	5.4	2	16	88	184	74	91
2003	8	18	29.26	95.91	33	5.5	65	77	-6	156	84	-167
2003	9	21	19.86	95.72	15.8	6.6	8	71	172	100	83	20
2003	10	30	19.82	95.73	15	5.3	121	42	63	336	54	112
2003	12	19	19.65	95.80	15	5.2	136	39	66	346	55	108
2004	9	27	29.78	95.70	31.1	4.9	126	79	-176	35	86	-11
2004	10	8	24.34	94.35	77.5	4.8	139	46	147	252	67	48
2004	12	9	24.66	92.72	39.4	5.3	243	42	32	128	69	128
2005	1	18	22.73	94.52	88.7	4.8	271	28	31	153	76	115
2005	2	3	26.04	95.58	78.6	4.9	286	24	-26	40	80	-112
2005	2	8	19.61	96.05	16	4.7	129	46	53	356	55	122
2005	2	15	24.52	92.61	27.2	5.0	145	52	-174	52	86	-38
2005	2	15	24.40	94.62	60.4	5.2	276	61	28	171	65	147
2005	3	23	26.17	95.43	79	4.9	132	42	177	225	88	48
2005	3	25	25.54	94.92	83	5.2	151	65	176	243	86	25
2005	3	26	28.08	87.95	69.6	4.7	109	62	179	200	89	28
2005	6	1	28.81	94.72	19	5.8	209	6	26	93	87	95
2005	7	17	20.80	95.09	121.6	5.0	241	36	53	105	62	114
2005	9	18	24.48	94.71	105.4	5.7	271	54	38	156	60	138
2005	10	31	17.58	92.68	19.1	4.7	5	50	-127	234	52	-54
2005	10	31	28.38	84.88	22.5	4.7	120	42	97	291	48	84
2005	12	29	24.74	96.29	18.5	5.1	104	72	-1	195	89	-162
2006	2	3	26.94	86.70	30.9	4.7	279	30	91	98	60	90
2006	2	14	27.22	88.64	19.2	5.3	287	27	126	68	68	73
2006	2	23	26.91	91.94	12	5.4	321	73	-173	229	84	-18
2006	3	2	24.22	94.42	69.3	4.9	251	70	5	159	85	160
2006	3	25	23.33	93.91	46	5.1	142	76	-176	51	86	-14
2006	5	11	23.31	94.30	33.7	5.6	15	42	102	180	49	80
2006	5	30	20.54	92.04	21	4.9	63	85	-2	153	88	-175
2006	8	2	19.08	95.74	20.7	4.7	4	87	-178	274	88	-3
2006	8	12	24.59	92.86	32.7	5.0	255	61	20	156	73	149
2006	11	3	21.99	93.26	34.5	5.0	216	70	2	126	88	160
2006	11	10	24.61	92.61	31.8	4.9	141	46	154	249	72	47
2007	1	9	19.13	95.35	97.6	4.9	174	48	18	72	77	136
2007	5	7	23.02	94.58	97.3	5.0	229	69	13	134	77	159
2007	5	20	27.23	88.56	13.6	4.9	204	58	-4	296	86	-148

Year	Month	Day	Latitude	Longitude	Depth	Magnitude	Fault Plane Solution1			Fault Plane Solution2		
							Strike	Dip	Rake	Strike	Dip	Rake
2007	6	29	25.40	96.79	14.1	5.2	105	82	-4	196	86	-172
2007	7	30	19.06	95.77	12	5.6	322	44	101	127	47	79
2007	7	31	19.05	95.79	13.5	5.0	313	43	86	138	47	94
2007	11	7	22.15	92.50	25	5.5	251	81	-7	343	83	-171
2007	12	7	23.46	94.66	108.7	5.0	135	42	120	277	54	65
2008	1	12	22.65	92.36	17.7	4.9	353	35	104	157	56	81
2008	7	7	25.95	95.34	70	4.9	137	45	135	262	60	55
2008	10	6	29.66	90.50	12	6.3	44	48	-55	178	53	-122
2008	10	6	29.56	90.53	13.6	5.2	173	43	-121	33	54	-64
2008	10	8	29.76	90.57	14.7	5.5	69	62	-25	171	68	-150
2008	12	20	22.65	96.09	14.8	5.3	359	79	172	90	82	11
2009	8	11	24.25	94.77	115	5.5	119	45	139	241	62	53
2009	8	30	25.13	95.06	78	5.3	261	52	32	150	65	138
2009	9	3	24.29	94.73	115.5	5.9	144	46	152	255	70	48
2009	9	21	27.20	91.63	12	6.1	281	6	94	97	84	90
2009	9	21	20.14	94.87	74.2	5.7	227	33	2	136	89	123
2009	10	29	27.20	91.62	15.1	5.1	293	7	107	96	83	88
2009	11	7	29.31	86.28	18.8	5.5	178	43	-92	0	47	-88
2009	12	13	21.87	91.74	12	4.9	345	40	94	160	51	87
2009	12	29	24.31	94.84	125.1	5.6	124	41	143	244	66	55
2010	2	20	23.14	94.63	104.8	4.8	231	46	67	83	49	112
2010	2	26	28.41	86.77	84.5	5.1	12	69	-16	108	75	-158
2010	3	12	22.99	94.62	114.7	5.5	103	32	142	227	71	64
2010	4	28	19.18	93.01	31.2	5.2	313	32	-131	179	66	-67
2010	9	10	23.29	90.74	18.4	5.1	149	77	171	241	82	13
2010	11	30	29.78	90.53	20.8	5.3	199	49	-59	336	50	-121
2011	2	4	24.46	94.68	103.5	6.3	256	52	36	142	62	136
2011	9	18	27.44	88.35	46	6.9	216	72	-12	310	79	-162
2011	11	21	24.82	95.19	129.2	5.8	143	48	118	284	49	62
2012	5	11	26.18	93.03	46.1	5.4	67	83	7	336	84	173
2012	7	1	25.60	94.73	49.6	5.6	147	78	176	238	86	12
2012	7	3	29.84	88.30	21.6	4.9	179	40	-84	351	50	-95
2012	7	9	25.29	96.66	12	5.1	220	82	-173	129	84	-8
2012	7	14	25.40	94.45	41.1	5.3	253	69	11	159	80	158
2012	7	22	24.86	96.43	17.9	5.1	95	77	-7	187	83	-167
2012	7	22	29.93	88.32	24.8	5.0	200	31	-47	332	68	-112
2012	7	29	22.83	94.32	71.9	5.8	174	65	-175	82	85	-25
2012	9	22	25.49	96.89	15	4.7	218	61	-166	122	78	-30
2012	10	2	26.78	92.95	35.5	4.9	89	53	44	329	56	134
2012	11	11	22.73	96.03	16.8	6.8	0	55	178	91	88	35
2012	11	11	22.60	96.05	12	5.9	91	75	14	358	77	164
2012	11	11	23.06	96.07	20.1	5.6	358	71	167	93	78	20
2012	11	13	22.83	95.98	16.4	4.9	0	60	174	93	85	30
2012	11	19	22.94	96.10	19.9	4.8	0	72	174	92	84	18
2012	12	3	23.09	96.06	20.4	4.8	360	67	-174	268	84	-23
2012	12	22	22.29	94.80	142.2	5.5	149	37	159	256	78	55
2012	12	26	22.77	95.87	26.8	5.0	1	60	171	95	82	30
2013	1	9	25.09	94.95	105.9	5.8	288	41	67	137	53	109
2013	3	2	24.56	92.28	45.1	5.2	332	37	147	89	71	58
2013	3	30	22.94	96.07	12	5.2	3	75	-180	273	90	-15
2013	4	3	19.13	95.79	12	5.3	152	36	102	318	55	82
2013	4	4	19.08	95.77	12	5.1	311	46	77	150	46	103
2013	4	11	19.04	95.83	12	5.1	125	39	70	330	53	105
2013	4	16	28.67	95.12	39.6	4.9	300	39	90	120	51	90

Year	Month	Day	Latitude	Longitude	Depth	Magnitude	Fault Plane Solution1			Fault Plane Solution2		
							Strike	Dip	Rake	Strike	Dip	Rake
2013	7	20	21.89	94.30	99.7	4.8	283	47	39	164	63	130
2013	8	2	23.74	94.82	92.9	4.9	235	36	40	111	68	119
2013	9	9	22.91	96.05	22.6	4.9	3	68	179	93	90	22
2013	9	20	22.81	96.04	12	5.0	360	77	175	91	85	13
2013	9	20	22.88	96.04	12	5.7	95	74	14	1	77	164
2013	10	3	27.17	88.79	27	4.9	304	37	123	85	59	67
2013	11	6	26.39	93.74	35.5	5.3	66	56	20	324	73	145
2014	1	26	22.78	96.01	20.1	5.1	1	70	-174	269	85	-20
2014	1	29	23.71	94.08	53.8	5.1	249	60	0	339	90	-150
2014	5	21	18.10	88.09	57.6	6.1	322	83	178	52	88	7
2014	8	3	29.00	85.57	19.4	5.2	202	42	-62	346	54	-113
2014	8	16	24.66	94.76	94	4.9	141	61	155	243	69	32
2014	9	9	21.98	93.14	16.1	5.4	118	81	6	27	84	171
2014	11	17	20.78	94.44	90.3	5.3	97	23	-156	345	81	-69
2014	11	20	23.49	93.46	35.2	5.7	157	56	-150	49	66	-37
2014	12	18	27.46	86.56	30.3	5.0	248	26	44	117	72	110
2014	12	21	24.30	94.76	92.6	5.1	152	68	157	252	68	24
2015	1	24	25.01	95.21	113.7	4.8	251	54	36	138	61	138
2015	2	12	23.97	93.93	96.4	5.0	170	75	-174	78	84	-15
2015	4	25	27.91	85.33	12	7.9	287	6	96	101	84	89
2015	4	25	27.86	84.93	21	6.7	308	23	131	85	73	74
2015	4	25	28.06	85.89	20.8	5.3	339	40	-105	178	52	-78
2015	4	25	27.61	84.96	15	5.1	201	40	-20	306	77	-129
2015	4	26	27.56	85.95	20.6	6.7	289	14	98	101	76	88
2015	4	26	27.56	85.90	19.8	5.2	305	26	115	98	66	78
2015	4	27	26.66	88.27	26.5	5.1	154	57	-157	52	71	-35
2015	5	12	27.67	86.08	12	7.2	307	11	117	99	81	85
2015	5	12	27.37	86.35	20.1	6.1	299	28	116	90	65	77
2015	5	16	27.37	86.26	12	5.3	324	34	138	91	68	63
2015	6	28	26.38	90.59	39.5	5.3	234	78	11	142	79	167
2015	7	21	19.15	96.25	18.9	4.8	166	40	118	312	55	69
2015	11	27	22.38	94.99	16.6	5.4	92	37	38	330	69	121
2016	1	3	24.70	93.46	54.1	6.7	339	51	168	77	81	39
2016	4	13	23.03	94.79	150.6	6.9	130	39	125	268	59	66

- All the values are taken from GlobalCMT catalogue (www.globalcmt.org)

Appendix C Attenuation Equations

Al-Hussaini and Islam 2014:

$$I = 1.0249 + 1.4863 * (M) - 0.0042 * (R) - 2.4518 * log(R) + 1.001P$$

where,

I = Intensity of earthquake on site
M = Moment magnitude
R = Epicentral distance
P = Probability of exceedance

Trifunac and Brady, 1975:

$$log\ (PGA) = 0.14 + 0.300I$$

where,

PGA = Peak ground acceleration on site

PGA is divided by 1.5 to get the PGA on bedrock.

Zare et al. 1999:

$$\log A = a.Mw - b.X - logX + c_i.S_i + \sigma.P$$

where,

A = Ground motion parameter
Mw = Moment magnitude
X = Hypocentral distance
a = Co-efficient of magnitude
b = Co-efficient of distance
$c_i S_i$ = Co-efficient of site effects
σ = 84.1% standard deviation
P = Probability of exceedance

Abrahamson and Silva 1997:

$$
\begin{aligned}
\ln \mathrm{Sa} &= f_1 + F f_3 + HW f_{HW}(M) f_{HW}(R_{\mathrm{rup}}) + S f_5 \\
f_1 &= \begin{cases} a_1 + a_2(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)] \ln R \\ \hfill \text{for} \quad M \leq c_1 \\ a_1 + a_4(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)] \ln R \\ \hfill \text{for} \quad M > c_1 \end{cases} \\
\text{where } R &= \sqrt{r_{\mathrm{rup}} + c_4^2} \\
f_3 &= \begin{cases} a_5 & \text{for} \quad M \leq 5.8 \\ a_5 + \frac{a_6 - a_5}{c_1 - 5.8} & \text{for} \quad 5.8 < M < c_1 \\ a_6 & \text{for} \quad M \geq c_1 \end{cases} \\
f_{HW}(M) &= \begin{cases} 0 & \text{for} \quad M \leq 5.5 \\ M - 5.5 & \text{for} \quad 5.5 < M < 6.5 \\ 1 & \text{for} \quad M \geq 6.5 \end{cases} \\
f_{HW}(r_{\mathrm{rup}}) &= \begin{cases} 0 & \text{for} \quad r_{\mathrm{rup}} < 4 \\ a_9 \frac{r_{\mathrm{rup}} - 4}{4} & \text{for} \quad 4 < r_{\mathrm{rup}} < 8 \\ a_9 & \text{for} \quad 8 < r_{\mathrm{rup}} < 18 \\ a_9 \left(1 - \frac{r_{\mathrm{rup}} - 18}{7}\right) & \text{for} \quad 18 < r_{\mathrm{rup}} < 24 \\ 0 & \text{for} \quad r_{\mathrm{rup}} > 25 \end{cases} \\
f_5 &= a_{10} + a_{11} \ln(\widehat{\mathrm{PGA}} + c_5)
\end{aligned}
$$

where,

S_a = Spectral acceleration
M = Moment magnitude
S = Site category (= 0 for rock)
F = Source mechanism
HW = Hanging wall effect
a, c, f = Co-efficients
PGA = Peak ground acceleration on rock

Appendix D Coordinates of the Locations

The nearest coordinates used for the locations in Chapter 3 are presented below:

Location	Latitude	Longitude
Alikadam	21.60	92.20
Bandarban	22.20	92.20
Bogra	24.80	89.40
Brahmanbaria	24.00	91.20
Chittagong	22.40	91.80
Comilla	23.40	91.20
Cox's Bazar	21.40	92.00
Dhaka	23.80	90.40
Faridpur	23.60	89.80
Jhalokathi	22.60	90.20
Khulna	22.80	89.60
Kurigram	25.80	89.80
Meherpur	23.80	88.60
Mongla	22.40	89.60
Mymensingh	24.80	90.40
Pabna	24.00	89.20
Rajshahi	24.40	88.60
Rangamati	22.80	92.00
Rangpur	25.80	89.20
Shaistaganj	24.20	91.40
Srimangal	24.40	91.60
Sylhet	24.80	91.80
Takerhat	25.20	91.20
Thakurgaon	26.00	88.40