CHAPTER 1
INTRODUCTION

1.1 Introduction

The northeastern region (NER) of India has been classified as one of the most seismically active and vulnerable regions of the world owing to its high degree of complex geotectonic setup. The region extends from latitude 22° to 30° N and longitude 89° to 98° E. This region is encompassed by the eastern Himalaya collision belt to the north comprising the Main Boundary Thrust (MBT) and Main Central Thrust (MCT) and flanked by the Indo-Burman subduction zone on its eastern margin; the Shillong-Mikir Plateau and the Assam Valley are jawed between the Himalayan arc and the Indo-Burmese arc, forming the major tectonic entities of the region. The seismic activity of NER, India is well reflected by the two great earthquakes which visited the region on 12 June, 1897 (M ≥ 8.5) and August 15, 1950 (M = 8.7), infamously known as the Shillong Plateau earthquake and the great Assam earthquake respectively. Apart from this 20 large (M ≥ 7.0) earthquakes occurred during the last 100+ years. Thus, the region has been categorized under seismic zone V (the most seismically hazardous and vulnerable zone) by Bureau of Indian Standards (BIS 1893-2002) which is shown in the seismic zoning map of India (Refer Figure 1.1). The region has been reckoned as the sixth most seismically active regions of the world; the other five being Mexico, Taiwan, California, Japan and Turkey.

Thus, given the intense seismic history, the high seismic vulnerability of this region and the on-going intriguing tectonic processes, its geological complexity, the northeastern India have always drawn the attention of seismologists, geologists and earth scientists to comprehend the geotectonics of the region in a profound manner and come out with a robust seismic hazard model for this region which could be a significant contribution in an endeavour towards disaster mitigation. Thus this research problem is also an attempt in the same direction.
Figure 1.1: Seismic zoning map of India (Bureau of Indian Standards IS 1893: 2002)
1.2 Hypothesis of the Problem

In seismological research, so far significant progress have been made towards seismicity and seismotectonics of northeastern India, yet many issues concerning seismic velocity structure and seismic wave attenuation still remain unresolved. Towards the solution of this problem the region needs to determine the crustal and upper mantle velocity structures. Therefore, in such a complex region, it is very important to examine 3-D velocity structure.

Accurate determination of hypocentral parameters depends on precise picking of phases supplemented by a preliminary true crustal velocity model as the input to the hypocentral location programme. Any seismological research initiative pertains to accurate epicentre location which exclusively depends on velocity structure, and that remains a bigger challenge. Earlier studies on estimation of crustal velocity structure with analog data (De et al., 1990; Kayal et al., 1998., Bhattacharya et al., 2005) in northeastern India lacked in time accuracies and threw little light on the detailed 3-D velocity structure. With the advent of digital seismic network, excellent scope comes up to re-estimate the crustal velocity with higher accuracy in northeastern India.

Also, the region needs measures of elastic wave attenuations and scattering in the crust to understand the characteristics of source-receiver paths, like materials and physical properties of the earth’s interior (Aki, 1980). Lg waves (multiple reflected shear waves) are almost routinely used to study the crustal quality factor, \(Q_{Lg}\), which is a direct, most efficient measure of attenuation, (Sargeant and Ottemöller, 2009) and which has not been used so far for the seismically active northeastern part of India. Lg propagates with strong amplitudes over long regional distances in continental paths, with amplitudes least affected by the radiation pattern of the source (Hong, 2010). So the present study using crustally guided Lg waves recorded by broadband digital instruments will give better information on the crustal structure of northeastern region of India.
1.3 Objectives

Thus the present study utilizes the digital seismic database accrued from local seismic network with an attempt to obtain the following objectives:

a. To derive a 1-D velocity model by seismic inversion.

b. To obtain a 3-D velocity model for detailed seismic imaging of crustal structure beneath northeastern region of India.

c. To study the Lg wave propagation characteristics and its relation to the complex structure of NER of India.

Figure 1.2: Seismotectonic map of northeastern India (Sharma et al., 2017) The map shows recent seismicity (1990-2016) and major tectonic features of NER of India region. Seismic data are taken from the catalogue of broadband network of CSIR-NEIST-(Jorhat) and CSIR-NGRI-Hyderabad, and the tectonic features are from the GSI (2000). The two great (Mw ≥ 8.0) and some 17 large (Mw ≥ 7.0) earthquakes are shown with year of occurrence by stars respectively. Depth ranges are indicated by open circle: 0-30 km; light grey: 30-60 km; dark grey: > 60 km. Abbreviation used for different tectonic features are: MBT: Main Boundary Thrust; MCT: Main Central Thrust; DT: Dapsi Thrust; BS: Barapni Shear Zone; LT: Lohit Thrust; MT: Mishmi Thrust; SF: Sagaing Fault; OF: Oldham Fault; KF: Kopili Fault; VL: Volcanic Line. Scale: 1° = 111 Km
1.4 Scope of the Study

1.4.1 3-D Velocity Structure By Seismic Tomography In Northeastern India

Seismic tomography is an extensively used method for exploring the lateral heterogeneities in the earth’s crust by investigating the velocity anomalies of seismic waves. In this technique, a set of significant earthquakes which are locally recorded are characterized. These earthquakes are employed to delineate the earth’s interior and its associated complexity by using the arrival times of the waves at the seismic stations which are used to compute the wave velocities through the earth’s crust.

Travel time tomography of local earthquakes (LET) are used here to analyze the hypocentral parameters obtained from seismological data. In this method using only one dimensional (1-D) velocity model and local travel times of seismic waves, the inversion gives a picture of the 3-D structure consistent with independent geologic and geophysical information without any prior assumptions of the structure. LET is a great technique to get a clear picture about the tectonic processes, which might have occurred in the past within a crustal volume. Large earthquakes are supposed to have occurred favourably on pre-existing faults, but detection of these faults, especially when they are not exposed on the surface, is difficult. The earthquake data itself can be used right away to find the velocity structure beneath the subsurface of the earth through velocity inversion. The additional benefit of using earthquake data to solve for the structure is that one determines structure in the area, which is seismically active. The earthquake data also unveils the spatial distribution of active faulting and the types of fault ruptures occurring throughout the volume. Therefore, the velocity solution and the seismicity can be analyzed together to understand the active tectonic processes. The benefit of this method is that earthquakes are considered to be of
excellent quality, naturally occurring sources of both compressional and shear wave energy.

Some attempts have been made by some workers to understand the crustal velocity structure and the associated structural complexity of the lithosphere beneath northeastern region of India (NER) of India by employing the techniques of seismic tomography (Kayal and De, 1987; De and Kayal, 1990; Kayal and Zhao, 1998; Mukhopadhyay et al., 1997; Bhattacharya et al., 2008). But such studies had its own associated shortcomings with the seismic data used. These studies were based mostly on analog data which are lacking in timing accuracy which is of paramount importance in any seismological exercise, especially travel-time tomography. But with advent of digital instrumentation and broadband recording systems along with the creation of a robust local seismic network equipped with GPS timing system for NER of India, the magnitude of timing error has got drastically reduced. Moreover, good quality seismic data over large frequencies with better azimuthal coverage is available now having the facility to pick the phases with more clarity. This gives a fillip to carry out such tomographic studies with better control in the accuracy of the results and facilitates a more profound insight into the complex geotectonics of the region and also caters well towards the primary objective of realization of a more reliable seismic velocity model for the region.

1.4.2 Lg Wave Attenuation in Northeastern India

An earthquake is accompanied by release of strain energy which propagates in form of seismic waves which are elastic in nature and propagates throughout the body of the earth traversing the crust, mantle and the core. As the seismic waves travels away from the source of the earthquake negotiating diverse paths of propagation with its associated degree of variation in the tectonic, structural and lithologic
heterogeneities, they lose their energy content or in other words the seismic waves decay in their amplitudes with increasing distance from the source. This phenomenon of decay or loss of energy of seismic waves with increasing distance from the source defines the attenuating property of the medium of propagation. The rate of decay of the amplitudes of seismic waves is gauged by a dimensionless seismological parameter called the crustal quality factor “Q” which is again a function of the degree of heterogeneity of geologic material and structure traversed by the seismic waves and thus, plays a decisive role in correlation of crustal structure. There exist an inverse relationship between Q and attenuation of seismic waves; higher values of Q represent slower decay or a lesser attenuating medium. This quantification of attenuation of seismic waves can be further correlated to the tectonic complexity of a region and may be also extended to comprehend various other geological parameters like geothermal gradient, the saturation of rocks with fluids and partial melts, delineation of geological boundaries and discontinuities within the crust, material composition, thickness and heat flow etc (Haberland and Rietbrock, 2001; Sato and Sacks, 1990 & Ojeda and Ottemöler, 2002).

Notwithstanding the fact that many seismological studies have been carried out for NER of India (Gupta and Kumar, 2002; Manikchandra and Kumar, 2008; Hazarika et al., 2009; Baruah et al., 2010; Padhy and Subhadra, 2010), but a thorough investigation needs to be done in context of seismic wave attenuation. Albeit, for NER of India such studies in terms of attenuation of coda waves and high frequency seismic waves have been done by some workers (Gupta and Kumar, 2002; Manikchandra and Kumar, 2008; Hazarika et al., 2009; Baruah et al., 2010 ; Padhy and Subhadra, 2010) but investigation of attenuating property of the crust in terms of a strong regional phase like Lg is poorly understood in context of NER of India. Lg
waves are crustally-guided shear waves which propagate by multiple reflections or reverberation with strong amplitudes over large epicentral distances in the continental paths, thus Q can be reliably determined from the decay of Lg spectral amplitudes with distance (Campillo, 1987; Baumont et al., 1999).

Lg waves are almost routinely used to study the crustal quality factor, \( Q_{Lg} \), which is a direct, most efficient measure of attenuation, estimation of magnitude and in devising a ground motion model for its strong amplitude (Sargeant & Ottemoller, 2009). Thus, Lg wave attenuation is strongly correlated with the age of the crust, variation in crustal thickness, the nature of the crust-mantle transition, sediment thickness and crustal complexity (Sargeant & Ottemöler, 2009). Therefore, it is imperative to study the attenuation of Lg phase, so as to augment the understanding of Lg propagation and how it relates to the crustal structure of a region. Such an exercise is of paramount importance to decipher the actual crustal behaviour beneath NER of India in the wake of an impending large earthquake in the region (Hazarika et al., 2009) which would throw more light on the strong ground motion aspect as well. Thus, Lg wave attenuation study is of utmost necessity and plays a pivotal role to substantiate for a more robust seismic hazard risk evaluation exercise of a region.

This study has been designed in form of six chapters which are outlined in the succeeding sections.

1.5 Chapter Layout:

1.5.1 Chapter 1: Introduction

This chapter gives an introduction on the importance of seismic waves and the seismic hazard scenario of northeastern India. The applicability of seismic waves in the investigation of crustal heterogeneity and structure of a region has also been laid down in this chapter along with an overview of the scope of Lg waves in attenuation
studies in northeastern India. The chapter also focuses on the hypothesis of the problem and objectives of this study. Finally, the chapter concludes on the characterization of the thesis.

1.5.2 Chapter 2: Seismic Instrumentation

This chapter deals with the seismic instrumentation employed to generate the seismic data used in this study. The chapter details about the development of seismic instrumentation in NER of India along with a brief description on the seismic equipments used. For example the recorders and seismometers used in analogue and digital seismic stations of local seismic network have been outlined. Digital waveform data have been used in this study but prior to using the data, amplitude frequency response curve for each station needs to be determined with respective digitizer parameter and poles and zeros for obtaining true ground motion at a particular frequency, which is a primary input for earthquake signal processing. This aspect has been explained with an example.

1.5.3 Chapter 3: Geology and Tectonics of northeastern India

The chapter deals with the geology and tectonics of the study area which is delimited by latitude 22°N to 30°N and longitude 89°E to 98°E, covering the considerable portion of NER India. An overview on the geology and tectonic setting of northeastern India emphasizing on the major tectonic domains of Eastern Himalaya and Mishmi Massif, Indo-Burman Ranges, Shillong Plateau and Assam Valley and the Bengal Basin and Tripura Fold Belt has been laid down in this section. These tectonic domains have been illustrated well by a representative Geographical Information System (GIS) based tectonic map of northeastern India after Nandy, 2001; Murthy et al.(1969) and Kayal et al.(1998) in correlation with satellite imagery.
(Baruah and Hazarika, 2008). In addition the seismicity and the seismotectonics of NER of India have been presented in this section.

1.5.4 Chapter 4: Study of 3-D Velocity Structure in Northeastern India by Seismic Tomography

This chapter details on the 3-D velocity structure of northeastern India obtained by SIMULPLUS seismic tomographic algorithm given by Thurber (1983) and later modified by Eberhart-Phillips (1993) followed by seismic imaging using tomoDD programe. This chapter begins with an introduction of seismic tomography, followed by literature review on similar works carried for northeastern India, a review on the methodologies available, description of the data used and the procedure of data analysis. The chapter also showcases the 1-D velocity model obtained for NER of India, followed by an interpretation of the results in light of the geology and tectonics of northeastern India vis-a-vis detailed discussion on the 3-D velocity structure.

1.5.5 Chapter 5: Lg Wave Attenuation in Northeastern India

This chapter begins with a description on the attenuation mechanisms of seismic waves. A detailed characteristic of Lg waves and its importance in attenuation studies have been laid down in this chapter. Later it is followed by the importance of such studies pertinent to northeastern India. A review of literatures on similar studies were carried out in northeastern India followed by a review of the methodologies available to carry out attenuation studies have been detailed in this chapter. The chapter finally leads to the analysis of displacement spectra of Lg and finally the Lg attenuation models for the three major tectonic domains of northeastern India viz. the Indo-Burman ranges, the Shillong-Mikir plateau and the Eastern Himalaya and the Mishmi Massif with an average Lg attenuation model for northeastern India have been presented. Interpretation of the models and correlation with the tectonics and
geology of northeastern India followed by a detailed discussion have also been presented in this chapter.

1.5.6 Chapter 6: Summary and Conclusion

This chapter is a summary of the results obtained and the discussion presented in chapter 4 & 5 and the conclusion drawn out of this study. This chapter is concluded by a short guide to future researchers on scope available for extending such studies and the research gap available to formulate research problems in the future.

1.5.7 References

The references used while carrying out this study have been listed here alphabetically and then chronologically for an easy consultation of the background literatures in order to have a thorough understanding of the research work carried out.