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Attenuation of short-period body waves in Northwestern Himalayan Region, India

Priyamvada Singh[a,*], Sushil Kumar[b], Pitam Singh[c]

[a] Department of Earth and Planetary Sciences, University of Allahabad, India
[b] Wadia Institute of Himalayan Geology, Dehradun, India
[c] Department of Mathematics, Motilal Nehru National Institute of Technology Allahabad, India

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ABSTRACT

The attenuation of seismic wave is one of the basic physical parameters which is closely related to the seismicity and regional tectonics activity of a particular area. This is also important for seismic hazard measurement. Seismic wave attenuation for local earthquakes is determined from the analysis of direct body waves and coda waves. The dimensionless parameter, Q, is studied in the present work, which is defined as a measure of the rate of decay of the coda waves or body waves within a specific frequency band. Digital seismogram data of 75 earthquakes that occurred in Garhwal Himalaya region during 2004–2006 and recorded at 20 different stations have been analyzed to study the seismic body and coda wave attenuation. Seismic body wave attenuation characteristics are examined by estimating the frequency dependent relationship of quality factors for P-waves, Q_α and for S-waves, Q_β in the frequency range 1.5–28 Hz, using 95 seismic observations with hypo central distance less than 100 km. The extended coda normalization method was applied. The average value of Q_α is found to be varied from 45.10 at 1.5 Hz to 1400.0 at 28 Hz, while it varies from 109.02 at 1.5 Hz to 3987.0 at 28 Hz for Q_s. The estimated frequency dependent relation for quality factors are $Q_\alpha = (29.077 \pm 8.5)f^{(1.16\pm0.01)}$ and $Q_\beta = (67.84 \pm 13.5)f^{(1.18\pm0.02)}$ for P and S-waves, respectively. The rate of increase of $Q(f)$ for P and S waves in this region is comparable with the other regions of the Himalayas. The ratio $\frac{Q_\beta}{Q_\alpha}$ is greater than unity in the entire analyzed frequency range. It indicates that scattering is an important factor contributing to the attenuation of body wave in the region. The low $Q_{\alpha,\beta}$ values or high, attenuation at lower frequencies and high $Q_{\alpha,\beta}$ values or low attenuation at higher frequency may indicate that the heterogeneity decreases with increasing depth in the study region.

1. Introduction

Seismic waves provide valuable information about the earth's interior and makes it possible to obtain models of some internal properties. Generally, a high resolution model is a simplified mathematical representation of the actual material property variation within the earth. All different seismic wave types have been analyzed to reveal that how material properties vary in the interior of the earth. The amplitude of a seismic signal is modified during propagation, the longer the wave travel the greater the variety of heterogeneities they encounter. Therefore, this modification or decay may be considered as a result of averaging over many samples of heterogeneities. Some statistical treatment is required in which a small number of parameters characterized the average properties of the medium. Seismic wave attenuation is one of the fundamental properties of seismic waves from which the physical properties of material and heterogeneities in the earth's interior can be inferred [1,2]. The results of the seismic attenuation study provide important inside into the ground motion characterization that are required for appropriate seismic hazard assessment. These also have a practical relevance for a suite of applications, such as the calibration of ground motion prediction equations or the correction for sight amplification in earthquake early warning or rapid calculation of shake map for seismic emergencies or advance applications in engineering seismology [3].

In last forty years, a large number of studies are carried out by the various seismologists of the world, for estimation of attenuation characteristics of various parts of the crust using tail part of the seismogram i.e. coda waves.

The decay of coda waves with time or distance provides the average attenuation characteristics of the medium. These waves are the result of

* Corresponding author.
E-mail addresses: priyameps@allduniv.ac.in (P. Singh), sushilk@wihg.res.in (S. Kumar), pitams@mnnit.ac.in (P. Singh).

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numerous heterogeneities distributed randomly in the earth crust and upper mental. These can be explained by applying the statistical model in which a small number of parameters is sufficient to describe the properties of coda waves. Aki [4] and Aki and Chouet [1] are pioneers in this field and they proposed a single back scattering model to use coda waves of local earthquake, for the estimation of seismic coda wave attenuation. Coda is normally taken from the part of the seismogram coming after lapse time about twice the S- wave travel time. The attenuation properties of a medium are expressed by dimensionless quantity called quality factor Q and reciprocal of quality factor Q^{-1} is normally known as attenuation. The quality factor represents the decay of wave amplitude, during its propagation in the medium, caused by heterogeneities due to presence of cracks, faults, folds, moisture or an elasticity or sharp velocity anomaly or presence of interstitial fluid in shallow crust and upper mental (Herraiz and Espinosa [43]). The anelasticity causes dispersion, change pulse shape and affect amplitude of the wave. Normally quality factor is estimated by using coda waves and known as Q_C. The quality factor can also be estimated by the decay rate of direct P-wave; Q_{α}^{-1}, direct S-wave; Q_{β}^{-1} and amplitude. All seismic wave measurements are made near the free surface and both incident and refracted wave simultaneously coexist and total motion involves some of their respective amplitude. The study on the attenuation of S-waves has been more advanced than that of P-waves in the crust, being an important input for the design of earthquake resistant structures, disaster planning and other problems of engineering. Estimation of seismic wave attenuation is not perfectly a science but up to some extent an art of measuring the absence of something from tail part of the seismogram [5]. Certain amplitude is expected for a body or surface wave at a distant station. The difference between observed and expected amplitude is generally attributed to attenuation. The amplitude may be taken from their Fourier transform in the frequency domain or directly from the seismograms. A model must be predicted with varying parameters to fit the observe amplitude, to estimate attenuation. Initially the attenuation factors of S-wave in a certain part of crust was usually calculated by means of joint inversion of source spectra, propagation path and site response [5–10]. In 1980, Aki firstly obtain the frequency dependent direct S-wave attenuation, Q_{β}^{-1} in Kanto area of Japan by the coda normalization method. Later in 1980 coda normalization method was applied by Sato to a data set of deep borehole observation in the same area; the obtained results were similar to Aki [11]. Based on the coda normalization method, Aki [11] and Yoshimoto et al. [12] proposed a new method for the simultaneous measurement of P& S-wave attenuation by extending the conventional coda normalization method to P-wave.

Yoshimoto (1988) and Chung and Sato [13] estimated Q_{β}^{-1} and Q_{α}^{-1} in south east of South Korea and Nagano of Japan respectively using extended coda normalization method. After these studies, this method is successfully applied in different part of the crust to obtain both P & S-wave attenuation such as, South Korea central [14], Koyana India [15], Cairo Egypt [16], east central Iran [17], Bhuj, India [18], Chamoli, India [19], Northeast India [20], Cairo region, Egypt [21], Kumaun Himalaya [22], Northeast Himalaya (Parvez et al., 2012), Garhwal Himalaya [23].

Recently, for the present study region, frequency and lapse time dependent coda attenuation has been studied for different coda window lengths by Kumar et al. [24]. For the purpose of extending our knowledge on the seismic wave attenuation in this region P & S-wave attenuation is estimated using coda normalization method. A frequency dependent relationship is also established and compared with the other global studies. The ratio of P-wave attenuation and S-wave attenuation is also observed and its probable correlation with tectonic activities have also be investigated. Estimated values of body wave attenuation provide some information about mechanism of seismic attenuation. Comparison of our results with the other reported results of different parts of the world and adjacent parts of Himalayas extended our knowledge and understanding of the physical state of the medium.

2. Tectonic setting of the region and data

The convergence of the northward dipping Indian plate under the Eurasian plate formed, Himalayan originic belt, the most seismically active continental-continental collision zone of the crust. The major tectonic units are separated from each other by the main boundary thrust (MBT) and the main central thrust (MCT) and Himalayan frontal crust (MFT). These are major thrust faults striking parallel to the Himalayan arc. There are large numbers of local geological structure presents. India still continues to move northward and the Himalayas are one of the youngest mountain chain and tectonically very active part of the crust. The Himalayas form a 2500 km long arcuate shaped chain of hills and mountain that extent from the Kashmir to Arunachal Pradesh in the west to the east. Himalayas can be divided into three basic units as, higher, lower and outer Himalayas. The Higher and Lower Himalayas are separated from each other by the main central thrusts. The Lower is separated from the outer Himalayas by the main boundary thrusts. The outer Himalayas are separated from the Indo-Gangetic and Brahmaputra alluvial plains by the Himalayan Frontal thrusts. Some parts of Garhwal Himalayas approximately 700 km long is a seismic gap where a magnitude 8 or greater earthquake has not happened in recorded history [25,26]. However, the Garhwal Himalayas was recently rocked by two damaging earthquakes, the 20th October 1991, Uttarkashi earthquake (mb 6.6) and the 28th March 1999, Chamoli earthquake (mb 6.3). Some great earthquakes that occurred during the last 100 years in different parts of Himalayan region are, Shillong earthquake (M 8.0), 1897; Kangra earthquake (M 7.8), 1905; Bihar earthquake (M 8.0), 1934 and Assam earthquake (M 8.6), 1950 (Fig. 1).

2.1. Data

Events recorded during 2004–2006 in northwestern Himalayas, India are used for estimation of body wave attenuation. The digital waveforms are recorded on CMG 40T tri-axial broad band seismometers at 20 different stations in northwestern Himalayas. The data was acquired for two horizontal components and one vertical component in

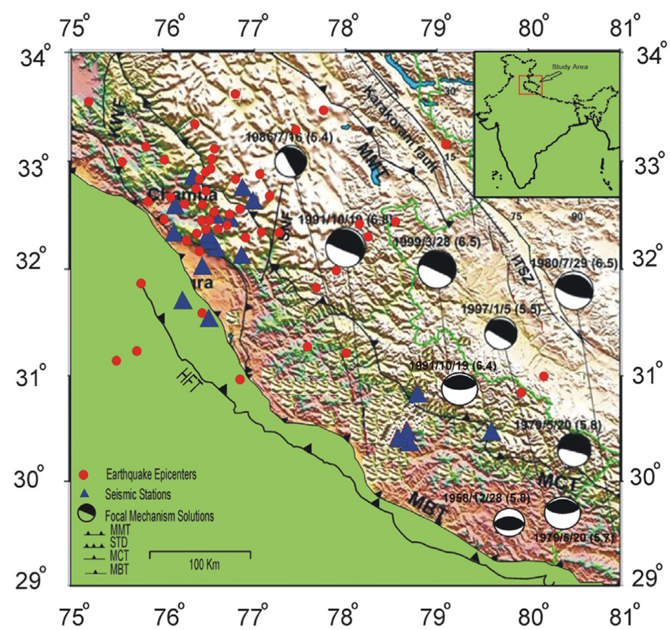

Fig. 1. Red circles show the event recorded and station locations are shown with blue triangles. HFT, MBT,MCT,STD and MMT are abbreviations for the Himalayan Frontal Thrust, Main Boundary Thrust, Main Central Thrust, South Tibetan Detachment and the Main Mantle Thrust, respectively. Date, magnitude and the focal mechanisms (beach ball) of some strong earthquakes are shown in figure.