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Separation of Scattering Attenuation and Intrinsic Absorption using Multiple Lapse Time Window Analysis

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Abstract - **A large number of studies on the field of scattering caused by the heterogeneities in the earth are reported in literature. The study presented aims at determining the seismic wave attenuation factors namely, scattering attenuation and intrinsic absorption.Determination of the two factors require estimation of two parameters namely, seismic albedo and extinction length. The method of multiple lapse time window analysis is employed to estimate the two factors. Here, multiple finite lapse time windows of 0-15, 15-30 and 30-45 seconds are used for analysis. The mean square amplitudes of band pass filtered seismogram (1-2, 2-4, 4-8 Hz) data is averaged over the time windows to estimate the seismic energy. This energy is corrected for local site amplification and source effects. Coda normalization is employed for this purpose. The energy obtained is further corrected for geometrical spreading. Finally, the normalized energy is plotted with respect to the hypocentral distance. The synthetic energy distribution is obtained from Monte Carlo simulation.**

Keywords: Scattering Attenuation, Intrinsic Absorption, Seismic Albedo, Extinction Length, Normalized Energy.

INTRODUCTION

Redistribution of seismic energy is a function of impedance contrasts in the earth which is mainly responsible for reflection and refraction of seismic energy back to the surface. However, heterogeneities on a scale smaller than the prevailing wavelength are known to affect the characteristics of the incoming seismic waves [1]. Further, the scattering of energy caused by inhomogeneities in the earth is responsible for the attenuation of energy contained in the seismic wave. In addition to scattering the attenuation also occurs due to intrinsic absorption. In view of this, attempts have been made to separate the two from the measurements of earthquake waveforms. To quantify and separate scattering attenuation from the intrinsic absorption, several models are developed. The models given by Wu (1985), Wu & Aki (1985), Frankel and Wennerberg (1987), Gusev and Abubakirov (1987), Wu & Aki (1988), Hoshiba (1991) and Hoshiba (1993) have been used to study the intrinsic absorption and scattering attenuation and to infer the physical properties of the lithosphere.
Frankel and Wennerberg (1987) developed an “energy flux model”. This model assumed uniform distribution of coda wave energy in the space. They concluded that scattered waves spread rapidly over the space behind the direct wavefront. Frankel and Wennerberg’s model of the energy density distribution was consistent with observations that were recorded in the seismogram envelopes at different distances. The two distributions asymptotically approached a common decay curve[2].

Gusev and Abubakirov (1987) and Hoshiba (1991) were successfullysynthesized the space-time distribution of multiple scattered coda wave energy. This was done using Monte Carlo simulation method. The results given by their numerical simulation was coherent to the solution given by Zeng et al (1991). Assumption of isotropic forward scattering was taken scattering. The scattering was expressed in terms of a uniform probability per unit volume, which gave an exponential distribution of path lengths. In the simulation intrinsic attenuation was excluded. The results of this simulation was also compatible for the diffusion model for large lapse time [3].

Wu (1985) introduced his method for quantitatively separating the scattering attenuation and intrinsic absorption. Wu’s method was based on the radiative transfer theory that was given by Ishimaru (1978). His method was based on comparison of observed seismic energy with the theoretical distribution obtained from numerical simulation. Wu proposed estimation of seismic energy over an infinite time window. However, it was not practical to use an infinite time window. Investigators took a finite time window of 32 seconds to obtain the seismic energy distribution. Although, they could not compare it with the Wu’s model which was based on an infinite lapse time window.

Hoshiba (1991) found the inconsistency that existed in taking a finite lapse time window in observation and the infinite time window proposed by Wu. The finite time window resulted in underestimation of the value of seismic albedo (B_0) if it is large. To avoid this difficulty Fehler et al. (1992) revised this method and presented "multiple lapse time window analysis" whose numerical basis was explained by Hoshiba et al. (1991). In this method multiple lapse time windows were chosen unlike Wu's single infinite lapse time window. Multiple lapse time window analysis consisted of comparing the observed seismic energy integrals over different finite lapse time window with the synthetic energy integrals obtained from Monte Carlo simulation of multiple isotropic scattering.

Methodology

Multiple lapse time window analysis was established by Fehler in 1992 to generate the energy density distribution of multiple scattered S wave. This method was a refined version of Wu's method by eliminating the use of an infinite lapse time window and using multiple finite time windows. In 1992, Fehler et al. applied this method to the data in the Kanto-Tokai region, Japan. Later this method was applied to the data in Long Valley, central California, and Hawaii by Mayedaet a1.in 1992.

Estimation of Seismic Energy from Seismogram[3]

The mean square amplitudes of band pass filtered seismograms are obtained. They are measured as a function of lapse time t. It can be denoted as $F_{obs}(r_m, t)$ where r_m is the hypocentral distance and m refers to the number of stations. This function is integrated over three time windows of 0-15, 15-30 and 30-45 seconds. The time window is chosen from the onset of S-wave. After obtaining the energy, we have to apply correction for site amplification and source effect. Coda wave method can be used to apply site correction.

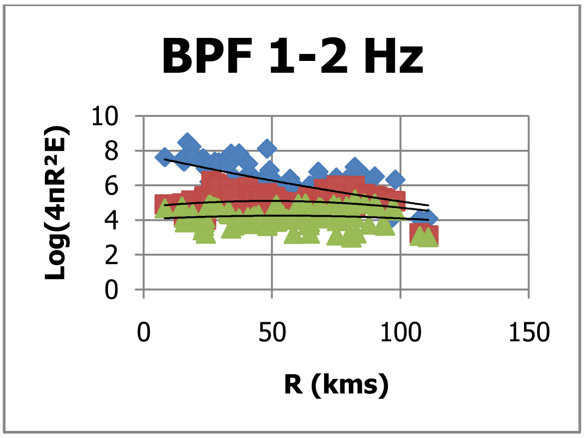
The corrected energy integrals are multiplied by the factor of $4\pi r^2$ to account for the correction of geometrical spreading. The values for energy vs corresponding hypocentral distances are plotted giving the energy density at various stations.

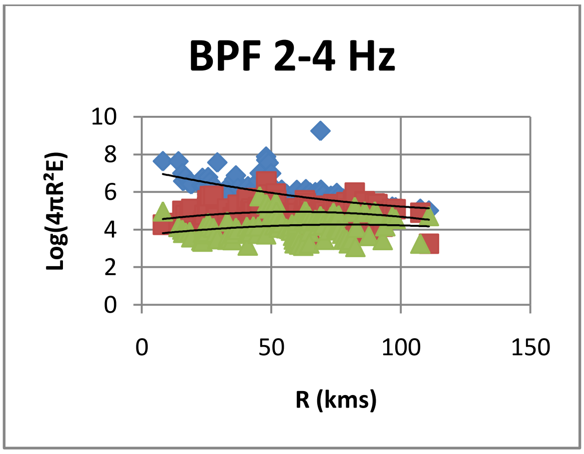
Numerical Simulation of Scattering[4]

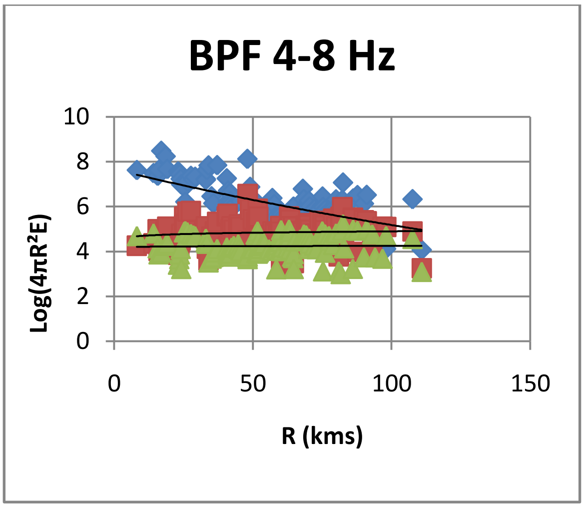
The next step is to obtain the synthesized energy integrals from numerical simulation. The space time distribution of scattered wave is created by using the Monte Carlo simulation method under the condition of isotropic scattering. The Monte Carlo simulation isimplementedtoacquiretheenergydistribution of amultiple scattered seismicwave. Pathof several random particlesdenotes the propagationof S waveenergy. Initially, the energy densityforeachorderof scattered waveis estimated separately. Later these energydensitiesare addedtoachieve the energydensity thereby incorporating the effects of multiple scattering.The theoretical curves obtained from simulations are compared with those obtained from the digital seismic data. The curve which fits best with the observed seismic date curve thereby gives the required value of L_e^{-1} and B_0.

Data Set and Analysis

11 events have been selected for the analysis around MCT (Main Central Thrust). The local magnitude of all the selected events is 2 and above. Time of origin of events is provided in the bulletin of seismological network and hypocentral distances from each station to the source are estimated with help of epicentral distance and focal depth.
The filtered seismograms obtained in terms of ASCII codes are used to determine the observational energy integrals. The root mean square amplitude at various stations is derived from this seismogram data. There is a decay of energy with respect to time.
The energy distribution for the observed normalized energy is plotted below for the three frequency bands.







120 seismograms are analyzed from 11 local events to obtain the normalized energy distribution plots shown above.

From the numerical simulation value for two attenuation parameters is obtained namely, seismic albedo (B_0) and the extinction length (L_e). These two parameters are used to obtain the attenuation factors and total attenuation.

Table 1.0 Estimation of Central Frequencies

FREQUENCY BAND	CENTRAL FREQUENCY(f_c) (Hz)
1-2	1.5
2-4	3
4-8	6

These values are used to determine angular frequency ω. The total energy Q_t is obtained from the above energy distribution curves. The inverse of $Q_t$gives total attenuation for the area (Q_t^{-1}). With help of total attenuation and the values for B_0, intrinsic absorption (Q_i^{-1}) is obtained and then the scattering attenuation (Q_s^{-1}) is obtained.

$Q_t^{-1} = Q_s^{-1} + Q_i^{-1}$

$B_0 = Q_s^{-1} / Q_t^{-1}$

$L_e^{-1} = g / B_0$

Where g is the scattering coefficient whose value is taken to be 0.01 [5].

The value of g can also be estimated depending upon the frequency at which the attenuation is studied.

These values are based on analysis of 11 local events (local magnitude 2.0 and above).

Table 2.0 Estimation of Seismic Wave Attenuation Factors

ω	Q_t^{-1}	Q_i^{-1}	Q_s^{-1}	B_0	L_e^{-1}
9.42	0.063	0.008	0.054	0.87	0.017
18.84	0.059	0.002	0.056	0.95	0.013
37.68	0.063	0.002	0.060	0.97	0.011

CONCLUSION

From the analysis of 120 digital seismograms from 15 local events along the MCT that occurred in the Garhwal Himalaya estimates of intrinsic absorption and scattering attenuation in the three frequency bands, viz.,1-2, 2-4 and 4-8Hz have been carried out. The results show that scattering is more dominant in this area.

In conclusion, the study shows that the crust in the Garhwal Himalaya region is heterogeneous. This explains the reason why scattering chiefly dominates the attenuation in this region.

The geological studies of the area reveal presence of a number of fractures in the area. The region is seismically active and collision between the plates is taking place, thereby producing fractures.This explains the large amount of scattering attenuation which takes place in this region.

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