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Shear wave attenuation characteristics over the Central India Tectonic Zone and its surroundings

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ABSTRACT

The study area lies between latitude 18–26°N and longitude 73–83°E, and mainly covers the Central India Tectonic Zone (CITZ). The frequency-dependent shear wave quality factor (Q_s) has been estimated over the CITZ and its surroundings using Double Spectral Ratio (DSR) method. We have considered 25 local earthquakes with magnitude (M_L) varies from 3.0 to 4.7 recorded at 11 stations running under national seismic network. The Fast Fourier Transformed (FFT) spectra were computed from the recorded waveform having time-window from onset of S-phase to 1.0 s and for a frequency-band of 0.1–10 Hz. Three different shear wave velocities (i.e., 3.87, 3.39 and 3.96 km/s) were obtained over the study area based on a pair of earthquakes recorded at a pair of stations. The low Q_s values of 51–96 at 1 Hz (i.e., $Q_s = 51f^{0.49}$; $Q_s = 90f^{0.488}$ and $Q_s = 96f^{0.53}$) were found in the area covering the Son–Narmada–Tapti (SONATA) lineament, CITZ, eastern part of the Satpura fold belt, Vindhyan and Gondwana basins, Godavari and Mahanadi grabens, and southern part of Gangetic plain. Intermediate Q_s values of the order of 204–277 (i.e., $Q_s = 204f^{0.56}$ and $Q_s = 277f^{0.55}$) were noted in the cartonic areas, namely, Bundelkhand, Dharwar-Bhandara and Bastar. While the higher Q_s values of 391–628 at 1 Hz (i.e., $Q_s = 391f^{0.49}$, $Q_s = 409f^{0.48}$, $Q_s = 417f^{0.48}$, $Q_s = 500f^{0.66}$, $Q_s = 585f^{0.65}$ and $Q_s = 628f^{0.69}$) were found in the eastern part of the SONATA, CITZ, and the northeastern part of the Satpura fold belt. The low Q_s values might be attributing to the more heterogeneous SONATA rift system. Low Q_s values further may presumably be associated with lower-level of seismicity and apparently account for higher tectonic stress accumulation over long duration. The long-term accumulated stress is generally released through occasional triggering of moderate magnitude earthquakes in the SONATA zone. Surrounding the SONATA region, the higher Q_s values possibly accounts for a more homogeneous subsurface structure along the SONATA zone.

1. Introduction

Elastic seismic wave during propagation suffers energy loss due to two distinct physical mechanisms, namely, intrinsic absorption from inelasticity of rocks and scattering under distributed heterogeneities in the subsurface. Intrinsic attenuation converts the seismic energy to heat due to inelastic absorption and scattering attenuation redistributes the energy at random heterogeneities present in the lithosphere. Therefore, the attenuation of seismic waves in the lithosphere is an important property for studying the regional earth structure in relation to seismicity. During propagation of seismic waves through the earth medium, its higher frequency components undergo more pronounced attenuation than low frequency components resulting in resolution loss in seismograms. The approximate linear behavior of attenuation with frequency (Barton, 2007) is commonly used for modeling of attenuation (Kjartansson, 1979; Kolsky, 1956). Absorption property of the medium can be described by a single parameter, namely, the quality factor (Q). Estimation of Q from seismic data has become an important area of discussion and understanding the degree of subsurface heterogeneities and rock types (Castagna et al., 2003; Silin et al., 2006). Hirsche et al. (1984) and Pramanik et al. (2000) stated that Q-parameter can improve the resolution of seismic data, and alternatively leads to a better understanding the stratrigraphy (Chopra and Marfurt, 2007). Brown (2004) stated that attenuation forms the basis of attribute classification together with time, amplitude and frequency. Dvorkin and Mavko (2006) and Odebeatu et al. (2006) proposed that Q-parameter is a direct indicator of hydrocarbon bearing zone of the deep sedimentary area. Many researchers estimated the Q_p^{-1}; Q_s^{-1} and Q_c^{-1} from the P, S and Coda waves of the observed seismic records for specific interest. Among these, the study on crustal seismic attenuation of S waves has been more advanced than P waves (Castro et al., 1990; Takemura et al., 1991; Kato et al., 1992; Kinoshita, 1994)

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because of increasing demand of the engineering seismology. Several studies involving frequency-dependent attenuation of shear wave over different part of the Japan (Aki, 1980; Sato and Matsumura, 1980; Bennett and Bankun, 1982; Masuda, 1988; Kato et al., 1992; Scherbaum and Sato, 1991; Takemura et al., 1991; Fehler et al., 1992; Yoshimoto et al., 1993 and Kinoshita, 1994) provided valuable informations irrespective of absence of strong motion recorder for estimation of ground motion at a site during incidences of future large earthquake from possible sources. Anderson et al. (1996) assessed quantitatively the influence of Q_s on strong motion parameters and suggested that Q_s along the entire path of the shear wave is more significant with increasing amplification at shallow-level sediments.

Tonn (1991) has made a comprehensive comparison for ten methods available at that time for estimation of Q using VSP data, and inferred that no method is generally superior and their performance is constrained by the true amplitude of the signal with ~zero noise. Bath (1974) proposed that one of the most common approaches is the spectral ratio (SR) method when true amplitude data is not available. Since the extensive comparison by Tonn (1991), at least two additional methods have been proposed to estimate Q by Quan and Harris (1997) and Zhang and Ulrych (2002). These two methods basically involve the shift towards lower frequency of the amplitude spectrum due to attenuation. Further, the two methods differ in the choice of the parameter used to measure the shift: one for frequency centroid shift (FCS) (Quan and Harris, 1997) and the other for frequency peak shift (FPS) (Zhang and Ulrych, 2002). Performances of spectral ratio (SR), FCS and FPS methods for estimation of Q were also compared by Nunes et al. (2011) using a simple layer-cake isotropic model and noted that there is a plethora of possible variants for each method. Deighton and Vigner (2010) found two kinds of hurdles in SR method: one involves the choice of the usable frequency bandwidth and the other for estimating the gradient from Fast Fourier spectrum. In FCS method, the centric estimation is biased towards overestimating the Q because of contribution of the noise amplitude at the tail end of the amplitude spectrum, and for FPS method, peak identification is unstable due to local noise perturbation in the amplitude spectrum around the peak frequency. If one decides to use FPS method in a routine work-flow because of its easiness of automation, he has to deal with the problem of noise sensitivity. Possibly, previous noise filtering and/or some kind of interpolation process in the amplitude spectrum could overcome this problem. On the other hand, if one chooses FCS method, the bias towards overestimating Q in the presence of moderate-to-high noise level might be solved by previous noise filtering and/or automatically testing different upper limits to the integral. Finally, if one chooses SR method, the automatic selection of the usable frequency bandwidth is the key point as pointed out by Haase and Stewart (2003).

To overcome the shortcoming of the SR and other methods, Izutani (2000) carried out the determination of Q_s in southern Kyushu, Japan using the Double Spectral Ratio (DSR) method. This method considers two earthquakes those were recorded at two minimum observation sites on the ground surface. Therefore, four recording traces can be used to compute the Q_s using the DSR method. Izutani and Ikegaya (2003) using same procedure also determined the lateral variation of Q_s over Median Tectonic Line in Japan and observed the spatial variation of frequency-dependent shear wave quality factor with a minimum Q_s value of 20 at the center of the Median Tectonic line where shallow to deep fractures/faults pass and more than 100 at frequency 1.0 Hz were noted on both sides of it. Mandal and Yokoi (2006) reported frequency-dependent spatial variation of shear wave quality factor (Q_s) over Ohchigata graben and adjacent areas in Japan. The result obtained by this technique was further compared with the result obtained in the other parts of Japan which is well agreed. In the present study, we focus to estimate S-wave attenuation characteristic using DSR method in the Central India Tectonic Zone (CITZ) and its surrounding areas in the central part of India (Fig. 1). The study area lies between latitude 18–26°N and longitude 73–83°E comprises of Indian provinces of Madhya Pradesh, a part of Maharashtra, Gujarat, Uttar Pradesh and Chhattisgarh of Central India (CI). The major developing cities, namely, Bhopal (BHPL), Bhusawal, Nagpur (NGP), Rewa, Jabalpur (JBP), Indoor, Bharuch and Raipur which have large population and high degree of vulnerability to earthquake disasters. Further, the area is also tectonically more complex and located on both sides of the Son–Narmada–Tapti (SONATA) lineament, an active zone of crustal discontinuity between the Gangetic Plain and the Peninsular India (PI). Detailed Q study over the area was not carried out so far because of non-availability of network stations in a close spacing with observed earthquakes. However, after the incidence of 1993 Latur earthquake, Government of India took decision to strengthen and upgrade the seismic network in the Peninsular India. Presently there are 11 seismic stations (Fig. 1) over the study area. Most of the stations are maintained by the India Meteorological department (IMD) and few by the Geological Survey of India (GSI) (Table 1). The seismic wave forms earthquake data ($3.0 < M < 4.7$) recorded at different stations over the study area were used for assessing the variation of frequency-dependent shear wave quality factor (Q_s) in the Central part of India, particularly along the CITZ/SONATA zone and its surroundings.

2. Tectonic setup

The area of investigation encompasses an important part of the Central Indian Tectonic Zone (CITZ) with its diverse lithotectonic units of Phanerozoic, Proterozoic, and Archaean age. The area consists of Purna graben, Mahakoshal rift belt including Son–Narmada–Tapti (SONATA) lineament, Satpura mobile belt, cratonic blocks (Bundelkhand and Bastar craton), and Vindhyans, etc. (Fig. 1). The CITZ, passing all along the SONATA, is characterized by a suture between the northern Bundelkhand craton and the southern Dharwar–Bhandara cratons (Radhakrishna and Naqvi, 1986). The CITZ is regionally bounded by Narmada North Fault (NNF) in the north (Nair et al., 1995) and the Narmada South Fault (NSF) in the south (Yedekar et al., 1990), forming about ~120–150 km wide distinct tectonic segment. Besides, the NNF and NSF, the CITZ has other several deep-seated faults; prominent among them are the Purna, Gavligarh, Tapti, respectively. Deep crustal seismic velocity and other geophysical signatures across this zone (Kaila et al., 1985, 1989; Mall et al., 2008; Naganjaneyulu et al., 2010) delineated several deep-seated faults reaching up to Moho depths, occasionally penetrating more into the uppermost part of the mantle. These deep-seated faults mark the boundaries of various blocks e.g. the NSF and NNF those limit the boundary of the volcanosedimentary Mahakoshal fold belt, a lithological sequence evolved in an intracratonic rift (Acharya, 2003). Mahakoshal groups belong to different geological ages (Roy and Bandopadhyay, 1998) along with granite and gneisses. West (1962) reported that this linear feature is an ancient line of weakness, and the land to the north (e.g., Vindhyans) and south (e.g., Gondwanas) of the line undergone vertical movements in geological times. There are geological evidences that the NSF was again partially re-activated during Deccan volcanism in the area. Faulting activity continued in post-trappean times offsetting the Quaternary sediment cover. One such example exhibited by block faulting is noticed southeast of Jabalpur area (Srivastava et al., 1999).

Kaila et al. (1989) reported based on deep seismic study that the Vindhyan province experienced vertical block tectonics through-