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Separation of intrinsic and scattering attenuation in the crust of central and eastern Alborz region, Iran

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ABSTRACT

In this study, more than 380 local earthquakes ($2 < M_L < 4.5$) have been used to estimate the direct-shear waves (Q_d), coda (Q_c), intrinsic (Q_i) and scattering quality factor (Q_{Sc}) in the crust of central and eastern Alborz region. The events were recorded by one temporary and two permanent networks. The quality factors of shear and coda waves have been individually estimated at different frequency bands by using coda normalization (CNM) method and single backscattering (SBS) method, respectively. Average frequency-dependent relationships have been estimated for Q_d and Q_c as $111 \pm 4f^{0.85\pm0.04}$ and $112 \pm 8f^{1.02\pm0.06}$, respectively. The intrinsic quality factor, Q_i, has been separated from the scattering quality factor Q_{Sc} by using individually estimated Q_c and Q_d values. The average frequency-dependent relationships of Q_i and Q_{Sc} have been calculated in the form of $108f^{1.00}$ and $784f^{0.56}$, respectively. The results of this study suggest that S-wave's attenuation (Q_d^{-1}) is dominated by the intrinsic attenuation. The attenuation of coda waves has been observed similar to the intrinsic attenuation, which indicates, the coda decay is mostly caused by the intrinsic attenuation. It has been observed that the scattering mean free path is frequency independent at frequencies greater than 6 Hz. The results of this study are similar to the tectonically active regions.

1. Introduction

Attenuation of seismic waves is one of the important issues in seismology which has great impact on determination of source mechanism, waveform modeling, strong ground motion seismology and seismic hazard assessment. Seismic waves attenuate due to elastic and anelastic properties of media. Attenuation due to the anelastic properties of media (intrinsic attenuation) is related to the dissipation of seismic wave's kinematic energy and its conversion into heat (Jackson and Anderson, 1974). The attenuation due to the elastic properties of media is related to the scattering, reflection and refraction and the geometrical spreading effect. The scattering effects cause the seismic wave's kinematic energy redistribute due to the existing inhomogeneities within the media. The attenuation of seismic waves except the geometrical spreading effect can be expressed as the inverse of quality factor (Q_d^{-1}), which is the combination of the effects of scattering attenuation (Q_{Sc}^{-1}) and intrinsic absorption (Q_i^{-1}): $Q_d^{-1} = Q_{Sc}^{-1} + Q_i^{-1}$.

Seismic wave's scattering due to the existing inhomogeneities within the earth is responsible for generation of coda waves, which follows direct P and S-waves (Aki, 1969; Aki and Chouet, 1975; Sato, 1977; Sato et al., 2012). Scattering procedure can cause decrease in the amplitude of direct waves as well as broadening the duration of the oscillation with increasing distance (Sato et al., 2012). Aki (1969) mentioned that coda waves are a composition of incoherent waves scattered by randomly distributed heterogeneities in the lithosphere. Single scattering model has been introduced to model the envelope of coda waves for mean free paths much longer than the source to receiver distance (Aki, 1969; Aki and Chouet, 1975; Sato, 1977). It provides good description of the propagation characteristics at small hypocentral distances and short lapse times from the origin time. The multiple scattering dominates over single scattering as travel distance or lapse time increases (Sato et al., 2012). Some mathematical models have been proposed to interpret the coda waves, for example; the diffusion model (Wesley, 1965), multiple scattering theory (Gao et al., 1983; Kopnichev, 1977), energy flux theory (Frankel and Wennerberg, 1987) and radiative transfer theory (RTT). The RTT considers single and multiple scattering procedures and can be used to simulate full envelope of seismogram with good precisions (Wu, 1985; Wu and Aki, 1988; Zeng et al., 1991). An exact solution of RTT has been introduced in three dimensions, which named Radiative Transfer or Boltzmann Equation (RTE), by Zeng et al.

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(1991). The envelope of high frequency seismograms can be synthesized by using RTE. Because of the complexities and time consuming procedure of solving RTE, two approximate solutions have been proposed for the case of isotropic scattering (Paasschens, 1997; Zeng, 1991).

It is physically accepted that coda waves at shorter and latter lapse times are mostly composed of single and multiple scattering, respectively. The amplitude of coda waves mostly decreases due to the intrinsic attenuation at latter lapse times, but at shorter lapse times it decreases due to the combined effects of Q_i^{-1} and Q_{Sc}^{-1}. The intrinsic and scattering attenuation can be separated by analyzing the spatiotemporal distribution of coda wave's energy. For this purpose, two methods have been generally used: multiple lapse time windows (MLTW) method (Fehler et al., 1992; Hoshiba, 1991; Sato et al., 2012) and Wennerberg method (Wennerberg, 1993).

The separation of Q_i^{-1} and Q_{Sc}^{-1} will be evaluated by comparison of the normalized integral of signal energy in three time windows with the values theoretically calculated by using RTE, in MLTW method (Sato et al., 2012). Three time windows are mostly composed of direct S-wave, early coda waves (single scattering origin) and latter coda waves (multiple scattering origin), respectively. In Wennerberg method (1993), the Q_i^{-1} and Q_{Sc}^{-1} can be separated by using difference between direct shear wave's (Q_d^{-1}) and coda wave's (Q_c^{-1}) attenuation. It was confirmed based on the laboratory measurements (Matsunami, 1991) as well as observational studies (Farrokhi et al., 2015; Sato and Fehler, 2008; Sato et al., 2012) that Q_i^{-1} approaches coda attenuation (Q_c^{-1}). Therefore, coda waves mostly attenuate due to the intrinsic attenuation at long lapse times. The direct shear wave's amplitudes decrease as a results of combination of Q_i^{-1} and Q_{Sc}^{-1}. Wennerberg (1993) proposed a new approach to separate Q_i^{-1} and Q_{Sc}^{-1}, based on the theory of single scattering (Aki and Chouet, 1975) and hybrid approximation of RTE (Zeng, 1991).

A moderate earthquake with magnitude of M_L 4.0 occurred on the 17 October 2009 in the vicinity of Tehran (Fig. 1). This region is known with its high seismic hazard (BHRC, 2007). The city has experienced several destructive earthquakes in the past six centuries (Ambraseys and Melville, 1982; Tchalenko, 1975). This region is seismically active and needs to be studied in order to have correct attenuation laws for seismic engineering purposes. The effects of intrinsic and scattering attenuation within the central and eastern Alborz have been also investigated. We have estimated the Q_c, Q_d, Q_i and Q_{-Sc} attenuation parameters in the crust of the studied area by using 380 local earthquake, which recorded by one temporary and two permanent seismic networks. We have used single backscattering method (SBS; Aki and Chouet, 1975) and coda normalized method (CNM; Aki, 1980) to explore Q_c and Q_d parameters, respectively. Finally, in the next step, the Q_i^{-1} and Q_{Sc}^{-1} has been separated by using the Wennerberg approach (1993). The results of this study have been compared with tectonically active regions of the world.

2. Tectonic setting and seismic activity

Alborz region is a V-shape folded and faulted area, which located at north of Iran Plateau. It is bounded to South Caspian Basin from the north and to the Central-Iran micro-plateau from the south. The active tectonic has been developed due to different types of forces composed of collision between Central-Iran micro plateau and Eurasia starting in the late Triassic (Jackson and McKenzie, 1984; Stöcklin, 1974). The shortening stage due to collision (Allen et al., 2003; Guest et al., 2006), had been followed by extension forces (Davidson et al., 2004; Vincent et al., 2005), which caused andesitic eruption. Damavand volcano provides evidence of extension phase and andesitic eruption (Davidson et al., 2004). The third tectonic event is the middle Miocene-to-recent collision-related compression, which affects northern Iran and the Caspian block (Guest et al., 2007). This collision related compression due to the convergence between Arabian Plateau and Central-Iran micro Plateau caused the present tectonomorphological development of this region (Berberian and Berberian, 1981). New GPS study of the region estimate the northwestward motion of South Caspian Basin and indicate its rotation relative to Eurasia, which is accounting for the left lateral motion along Alborz range faults (Djamour et al., 2010; Vernant et al., 2004). Because of the left lateral motion of this region and the dominant fault mecha-

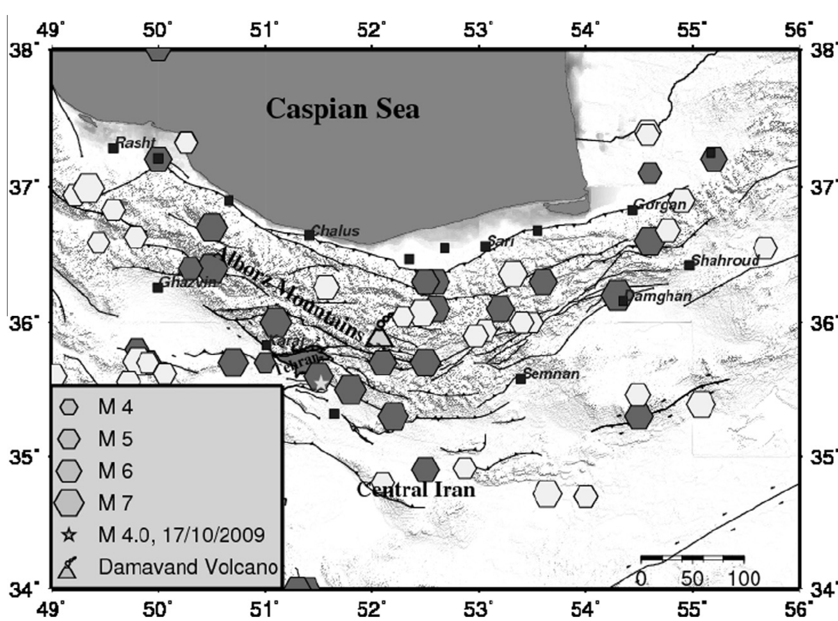

Fig. 1. The active faults and seismicity in central and eastern Alborz. Dark gray and gray hexagonal shows the earthquakes occurred before and after 1900 AD, respectively. Black squares show the existing cities.