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Scattering and intrinsic attenuation in Cairo metropolitan area using genetic algorithm

Mohamed F. Abdelwahed [a,c], Ali K. Abdel-Fattah [b,c,*]

[a] King Abdulaziz University, Geohazards Research Center, Jeddah, Saudi Arabia
[b] King Saud University, College of Science, Geology and Geophysics Department, Riyadh, Saudi Arabia
[c] National Research Institute of Astronomy and Geophysics (NRIAG), 11421 Cairo, Egypt

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ABSTRACT

A total number of 46 local earthquakes ($2.0 \le ML \le 4.0$) recorded in the period 2000–2011 by the Egyptian seismographic network (ENSN) were used to estimate the total (Q_t^{-1}), intrinsic (Q_i^{-1}) and scattering attenuation (Q_{sc}^{-1}) in Cairo metropolitan area, Egypt. The multiple lapse time window analysis (MLTWA) under the assumption of multiple isotropic scattering with uniform distribution of scatters was firstly applied to estimate the pair of L_e^{-1}, the extinction length inverse, and B_0, the seismic albedo, in the frequency range 3–24 Hz. To take into account the effect of a depth-dependent earth model, the obtained values of B_0 and L_e^{-1} were corrected for an earth structure characterized by a transparent upper mantle and a heterogeneous crust. The estimated values of Q_t^{-1}, Q_{sc}^{-1} and Q_i^{-1} exhibited frequency dependences. The average frequency-dependent relationships of attenuation characteristics estimated for the region are found to be: $Q_t^{-1}=(0.015\pm0.008)f^{(-1.02\pm0.02)}$, $Q_{sc}^{-1}=(0.006\pm0.001)f^{(-1.01\pm0.02)}$, and $Q_i^{-1}=(0.009\pm0.008)f^{(-1.03\pm0.02)}$; showing a predominance of intrinsic absorption over scattering attenuation. This finding implies that the pore-fluid contents may have great effect on the attenuation mechanism in the upper crust where the River Nile is passing through the study area. The obtained results are comparable with those obtained in other tectonic regions.

1. Introduction

The seismic wave attenuation, described by the quality factor Q, is one of the basic physical parameters used in seismological and earthquake engineering studies. It is a complex mechanism which depends on the intrinsic attenuation due to the medium an elasticity and the scattering attenuation associated with the heterogeneities. Because of the combination of both mechanisms, coda waves are generated on the seismic waves traveling through the Earth medium.

The knowledge of the relative contributions of intrinsic (Q_i^{-1}) and scattering (Q_{sc}^{-1}) attenuation is important for the appropriate subsurface structure, tectonic interpretations and quantification of the ground motion (e.g. [28,8,19,11,12]). Therefore, quantifying the relative contribution of scattering and intrinsic attenuation has been the subject of considerable interest among seismologists in the past few decades and different methods have been developed (e.g., [7,48,24,32,27,38,47]). The Multiple Lapse Time Window Analysis (MLTWA), as proposed by Hoshiba et al. [32], is the most common method used to separate intrinsic absorption from the scattering attenuation. The MLTWA method gives information about the temporal change of seismic energy during a wave's propagation by considering the integral of the signal energy calculated in three successive time windows along the coda waves of local earthquakes as a function of the hypocentral distance. The integrals of energy are evaluated on the basis of the radiative transfer theory applied to elastic waves [41]. The attenuation properties of (Q_{sc}^{-1}) and (Q_i^{-1}) affect the distribution of the energy within the seismic record. The wave scattering appears where the energy accumulates directly after the direct S-wave or in the coda waves based on the effect of scattering heterogeneities along the path between earthquake sources and recorded seismic stations. The intrinsic absorption (Q_i^{-1}), however, produces a linear decay on the logarithm of the seismic wave field energy with distance independent on the coordinates. Therefore, the study of the energy decay for each window versus hypocentral distance provides an ideal framework that allows separating the influence of each attenuation parameter [14]. The theoretical model of seismic energy propagation is proposed earlier by Hoshiba et al. [32]. The model describes the propagation of seismic waves in a half-space medium, heterogeneous, and isotropic. The MLTWA technique has been widely applied to several areas in the world (e.g. [35,28,8,40,9,12,44,13]).

* Corresponding author at: King Saud University, College of Science, Geology and Geophysics Department, Riyadh, Saudi Arabia.
E-mail addresses: aabdelfattah@ksu.edu.sa, ali_kamel@yahoo.co.uk (A.K. Abdel-Fattah).

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Under the assumptions of multiple and isotropic scattering and uniform distribution of scatters, two parameters are calculated to evaluate scattering and intrinsic attenuation in the medium: the seismic albedo (B_0), defined as the dimensionless ratio of the scattering loss to total attenuation ($B_0 = Q_{SC}^{-1}/Q_t^{-1}$), and the extinction length (L_e^{-1}) that is the inverse of the distance (in kilometers) over which the primary *S*-wave energy is decreased by e^{-1}. Several authors have solved the multi-parameterization problem by employing a systematic grid search scheme (e.g. [31,26,13,43,25]). B_0 ranges between 0 and 1 and was proposed by Wu [49] to describe the proportions of energy loss dominated by intrinsic attenuation ($B_0 < 0.5$) or scattering attenuation ($B_0 > 0.5$).

Estimates of the Q_i^{-1} and Q_{SC}^{-1} are biased when the realistic Earth structure is far from being uniform. To overcome the difficulty in analytical expressing the equations describing the seismic signal energy envelope for a realistic velocity model, Hoshiba [29,30], Hoshiba et al. [31] and Bianco et al. [13] used numerical simulations of the radiative transfer equation in realistic earth media with velocity increasing and scattering coefficient decreasing with depth. Their solutions implicitly show how large is the bias associated with the estimates obtained in the uniform model assumption. Recently, Del Pezzo and Bianco [17] calculated corrections to be applied to the estimates obtained on the uniform assumption to reduce these biases. These corrections have been obtained for a realistic earth model composed by an inhomogeneous crust overlying a transparent mantle, with the velocity increasing with depth. Applying these corrections, the scattering properties of the lithosphere in terms of separated Q_i^{-1} and Q_{SC}^{-1} can be routinely obtained in realistic assumptions, and many already existing data can be reinterpreted by applying this correction [18].

Due to the importance of the respective region from seismological point of view, detailed information related to the attenuation mechanism and its behavior is required. For this purpose, we applied the MLTWA technique [32] to accurately quantify the separate amount of scattering (Q_{sc}^{-1}) and intrinsic absorption (Q_i^{-1}) in different frequency ranges. This method gives information about the temporal change of seismic energy during a wave's propagation by considering the energy in multiple consecutive time windows as a function of the hypocentral distance. The present study of coda wave attenuation in Cairo zone will enhance our knowledge about the attenuation characterization of seismic waves which is an important component of seismic hazard assessment in the study region. So far, few studies have investigated the attenuation properties of the coda-Q and S-wave attenuation in the region of interest (e.g., [21,1]). El-Hadidy et al. [21] estimated the frequency dependant coda wave attenuation structure in the frequency band of 1.5–18 Hz for the shallow crust, in terms of coda wave Q and proposed a regional attenuation law as $Q_c = 85.66f^{0.79}$. Abdel-Fattah [1] studied the attenuation of body waves in the crust beneath the vicinity of Cairo Metropolitan area (Egypt), using the coda normalization technique to band passed filtered seismograms of frequencies ranging from 3.0 to 24 Hz, in which the analysis showed a strong frequency dependence for both body and shear waves. The estimated quality factor of P-wave Q_α^{-1} ranged from 10.7×10^{-4} to 72.9×10^{-4}, while the S-wave quality factor Q_β^{-1} ranged from 4.3×10^{-4} to 28.6×10^{-4}. These values follow the frequency-dependent attenuation; $Q_\alpha^{-1} = (19 \pm 2) \times 10^{-3} f^{-0.8 \pm 0.1}$ and $Q_\beta^{-1} = (7 \pm 1) \times 10^{-3} f^{-0.85 \pm 0.1}$. He also concluded that, the attenuation at higher frequencies is less pronounced than at lower frequencies and related this argument to the geological conditions of the studied area, which is tectonically complex with a high density of faults and pore fluids are also expected. The detailed properties of the scattering and intrinsic attenuation in this region are not well known. The aim of this paper is to estimate the scattering (Q_{sc}^{-1}) and intrinsic (Q_i^{-1}), attenuation mechanisms in greater Cairo using the MLTWA method by proposing an algorithm based on genetic algorithm method constrained with *F*-test distribution for the slandered division in the calculations.

For this end, the estimates will be discussed and compared with previous results obtained in the different tectonic areas over the world which would suggest a broader knowledge for further researches on the attenuation properties in Cairo metropolitan region.

2. Geologic and tectonic settings

Geographically, Cairo is situated on the Nile upstream of the River's Delta, about 250 km from the Mediterranean coastline and downstream of the Aswan dam. From the viewpoint of geology, the area under study is located in the alluvial valley of the Nile. The Nile Valley is underlain by alluvial deposits consisting mainly of sand and gravel silt with interbedded silt and clay sediments which cover the whole area of thevalley as well as the northern parts of the cultivated lands of northern Egypt. However, the crustal structure is rather heterogeneous and changes abruptly from area to area, especially near the Nile Valley. Within the Nile Valley graben, loose water-saturated sedimentsoccupy the Nile flood plain region, including Cairo, and the desert fringes. However, its thickness and water saturation decreases rapidly in both directions away from the graben ([22]). Consequently, the geological and morphological settingsof the upper crustin the region could bring a remarkable increasein the intrinsic effects on the propagation of seismic waves.

Tectonically, the present-day seismic deformation in northern Egypt, where the study area is located, is attributed to the collision between the African and Eurasian plates and the rifting along the Red Sea (Fig. 1). In addition, the Sinai sub-plate, local tectonic structures of the Gulf of Suez and the Nile River has a key role in the deformation process affecting the main tectonic regime in the study area. The recent geodetic data and GPS measurements imply that the African plate is moving NW with respect to Eurasia with a velocity of 6 mm/year [36] and the spreading rates along the Red Sea decrease from 14 mm/year at 15°N to 5.6 mm/year at 27°N. Along the southernmost segment of Aqaba-Dead Sea fault, motion is a left-lateral strike-slip of 5.6 mm/year [37]. This left-lateral motion shows a rate of about 2.8 mm/year at the northern segment of the Dead Sea with slight spreading of the Suez rift [46]. Owing to the complex tectonic, the region of northern Egypt and its surroundings are geologically characterized by lateral heterogeneities in crustal structures. For instance, the crustal thickness beneath the Eastern Mediterranean varies from oceanic to continental. In the vicinity of the study area, the shear wave velocity, sediment thickness and Moho depth derived from the dispersion curves of surface waves [20] showed lateral crustal heterogeneities. The authors concluded that the observed low velocities in the upper mantle of the Northern Africa that spanned to Crete might be an indication of serpentinized mantle from the subducting African lithosphere. On the other hand, the stretching and opening of the Red Sea could be the cause of the crustal faults and fractures widespread along the study area. The crustal structure studies show the presence of oceanic crust in the northern part of the Red Sea along the Egyptian coastline ([34]). Meshref [39] reported that the crust towards the respective area is continental, with a relatively simple structure consisting of a sedimentary layer of 3 km with velocity of 3.5 km/s, overlying a 30 km thickness of crust having moderate velocity changes from 6.0 to 6.35 km/s. The regional attenuation tomography results [10] are also showing a lateral variation east of the study area, indicating a possible change in the crustal characteristics that are consistent with the residual gravity anomalies obtained by Seber et al. [42].