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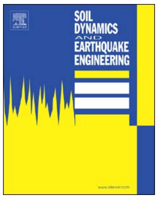

Seismological parameters derived from local earthquakes reported in Sri Lanka

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ABSTRACT

Attenuation characteristics of the bedrock beneath Sri Lanka were investigated analysing local seismic data recorded at the country's broadband seismic network. Digital high-gain records of 13 small to micro earthquakes, magnitude varying from M_L 3.6 to 1.5 in the local magnitude scale, were processed for estimating coda *Q*, Kappa (*K*) and H/V ratios. The standard single scattering model, which demands the decay rate of backscattered coda waves found at the tail part of seismograms, was applied at eight deferent frequency pass bands from 1 to 19 Hz. A parametric study by changing coda time window as 40, 50, 60 and 70 s, was carried out to examine the significance of time dependent behaviour in coda *Q*, if any. A clear trend of increasing *Q* with the length of time window at low frequencies, and a minor reversing trend at high frequencies were noted. The average variation of *Q* for all time window cases was in the form, $Q = (301 \pm 17)f^{(0.67 \pm 0.02)}$. The near-surface attenuation parameter, Kappa, was estimated by measuring the slope of displacement spectral amplitudes at frequencies below the corner frequency, and has shown to vary between 0.03 and 0.06 s for selected locations. The average Kappa for the region was 0.04 ± 0.02 s. H/V ratio was found to be close to unity as same as which found in the authors' previous study for the region, and this implies the country's upper crust has a negligible amplification in effect.

Since uncertainty in estimated parameters was plausible due to numerous reasons, a ground motion comparison between observed and stochastically predicted amplitudes was performed for the validation. Stochastic predictions with Brune's point source model for stress drops of about 2–4 MPa (20–40 bars), exhibited a good compliancy with observed records. Apparent source spectra of the events were also determined after correcting for due path attenuations. Finally, a scenario investigation in the local context was undertaken to identify expected ground motions which can be induced by a possible major event occurred at the capital city - Colombo.

1. Introduction

Attenuation characteristics of seismic waves during the propagation need to be essentially identified for a proper evaluation of the seismic hazard of a region. These region specific attenuation characteristics are often associated with inherent geotectonic features specific to the region. Thus, studying attenuation characteristics of a particular region may also be helpful to explore featuring tectonic attributes of the region.

Seismic wave attenuation that undergoes within a crust, in respect to the most dominating phases such as *S* and *Lg*, can generally be parameterized into three categories depending on the mode of attenuation and on local characteristics of the uppermost crust; (1) Geometric spreading (2) Anelastic whole path attenuation (3) Upper crustal attenuation. The geometric spreading or damping is commonly referred to as a frequency independent mode of attenuation in which the attenuation is primarily caused due to wave scattering (reflections and refractions) during the travel through the crustal waveguide. For instance, in the typical trilinear form, the rate of geometric damping of direct waves at near-source distances (hypocentral distances up to about 70 km) has been observed to be as R^{-1} (R is the hypocentral distance) [1,2]. At medium (between 70 to about 130 or 140 km) and far-source distances (hypocentral distances greater than 130 or 140 km), the rate has shown changing to R^{O} (because of compensatory effects of postcritical reflections and refractions at the Moho and Conrad discontinuities) and to $R^{-0.5}$ (because of multiple reflections and refractions of body waves dominating regional phases), respectively [1–3]. In some cases, a rapid near-source geometric attenuation

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rate than the above [4,5] and even frequency dependent attenuation rates [6] have also been indicated. The anelastic attenuation accounts for decay of wave amplitude due to the energy dissipation typically taking place along the whole travel path of propagation. This energy dissipation entails various modes of intrinsic attenuation including those such as heating of the heterogeneous medium, rearrangement or dislocation of particles during the vibration of the medium, etc., which are considered as permanent losses of energy. Studies have also claimed that the decay rate, which is parameterized by the wave transmission quality factor (Q), includes wave scattering effects as well depending on the heterogeneity of the medium [7]. Moreover, evidence is also there for the time dependent behaviour of Q which is resulted as a consequence of change in the effective volume sampled at a given particular time [8,9]. The whole path attenuation or seismic absorption depends on the wave frequency in a manner in which high frequency waves diminish more rapidly than that do low frequency waves. Importantly, this attenuation would be dominant for far-field or distant earthquakes where the amount of attenuation is largely governed by the quality of the travelled medium. If the quality of crust is high, the wave propagation becomes good and vice versa. The upper crustal attenuation is also similar to the anelastic attenuation in the way which the mechanism involved, although this attenuation type is primarily considered capturing effects at the uppermost crust, probably at upper 3–4 km, where younger formations like Sedimentary rocks are abundant. As a norm, attenuations at the uppermost crust are examined separately from other path modifications, mainly because of higher attenuation rates at the uppermost part, in comparison to that in mid and deeper parts. The above discussed seismic wave attenuation types are generally case sensitive, i.e., the dominance of a particular mode can be controlled by several other factors such as site-source distance, wave frequency, crustal properties, local site characteristics, etc.

Sri Lanka is located in the northern Indian Ocean more than thousand kilometres away from major plate boundaries. Although the country's seismotectonic location is widely regarded as aseismic, in many cases, the surrounding oceanic crust especially towards south southeast directions has been identified of posing active intraplate seismicity [10–12]. As evidenced in the historical reports, Sri Lanka has indicated no major/frequent local seismic activities in the past, but a few including a devastating one at the capital city-Colombo, which was on 14th of April 1615 with an estimated magnitude of the order of 6.4 in the Moment magnitude scale (M_w). The event has incurred damage of 200 houses and caused over 2000 casualties [13]. The apparent sparse seismicity of Sri Lanka in the local context is noticed concentrating at areas where active local lineaments/faults and bedrock fractures are being present [14–16]. Gamage and Venkatesan [17] have given efforts to identify such active areas in the country, by correlating reported events with local seismo-tectonic structures such as mega lineaments and shear zones particularly located at geological boundaries. However, attenuation characteristics of the crust underlain have not been explicitly parameterized partly owing to the lack of recorded data available for local events. Absence of a reliable seismic network and scarcity of good quality records were main barriers to be overcome for such a study. With the availability of recently completed broadband network that comprises of 3 digital broadband stations, and sufficient amount of data of small magnitude shallow crustal events at near to medium-source distances, the authors were able to undertake a study to examine coda Q, Kappa (K) and H/V ratios for the crustal structure of Sri Lanka. A possible geometric attenuation function to characterize attenuations at local distances, was also approximated. Digital high-gain records of 13 small to micro earthquakes, magnitude varying from M_L 3.6 to 1.5 in the local magnitude scale, were processed for the analysis. The standard single scattering model, which demands the decay rates of backscattered coda waves available at the tail part of seismograms, was used to estimate coda Q. The near-surface attenuation parameter, Kappa, was determined by measuring the slope of displacement spectral amplitudes at frequencies below the corner frequency. A ground motion comparison between observed and stochastically predicted amplitudes has been performed for the validation of estimated parameters. Source spectra were also derived to compare with Brune's classical point source model. Finally, a scenario investigation was carried out in one of identified seismically active local areas to evaluate ground motions that can be expected due to a possible major event.

2. The *Q* value and coda *Q* method

Q value alias "the wave transmission quality factor" is considered merely as a region specific property, which may highly be dependent on regional crustal characteristics such as age and composition of the crust, degree of heterogeneity, amount of asperities and irregularities, etc. There are several well established methods available in determining Q value for a region, out of which coda Q methods and spectral analysis methods are being popular in the current seismological practice. However, selection of a method to be applied in a region would depend on fundamental assumptions associated with the each method. For example, the single backscattering coda Q method proposed by Aki [18], postulates coda waves as a derivative of surface waves which are singly scattered at acute angles in a heterogeneous medium, and the scattering is isotropic. The isotropic scattering means the medium considered itself is isotropic as well as the scattering taking place at a given heterogeneity is uniform in all directions despite the direction of the wave travel prior to the scattering. Furthermore, the method omits station-source distances during the calculation, given the epicentral paths are short enough to neglect. Hence, the method would be best to use in a less complex medium that it can be hypothesized as isotropic, at short site-source distances, otherwise due modifications need to be addressed. On the other hand, spectral analysis techniques in which empirical attenuation equations are fitted with observed Fourier spectral amplitudes, have shown becoming increasingly popular amongst seismologists and engineers to adopt in regional studies that handle large amount of data at teleseismic distances. Although, the method is advantageous to determine the actual shape of Q which directly relates to the strong motion part (shear window) of a seismogram, one must be careful to apply the proper attenuation relationship that encompasses all possible means of attenuation for the subject region.

Aki and Chouet [19] introduce following formulae to interpret the shape of coda amplitude decay with the lapse time;

$$P(\omega|t)=St^{-1}e^{-\omega t/Q}\text{(Surface waves)} \tag{1}$$

$$P(\omega|t) = St^{-2}e^{-\omega t/Q} \quad \text{(Body waves)} \tag{2}$$

Here, $P(\omega|t)$ is the power spectral density of coda wave at time t. S is the source factor and ω is the circular frequency which is equal to $2\pi f$, where f is the wave frequency. Q is the frequency dependent wave transmission quality factor. During the derivation, coda waves are assumed to be singly backscattered (scattered at acute angles) at discrete heterogeneities which are uniformly distributed in the isotropic medium. Energy loss in direct waves that are not subjected to scattering and any effect due to downward scattering (into the upper mantle), have been neglected. Furthermore, the above equations are theoretically valid for collocated source-receiver condition, yet modified relationships to account for distance effect in long-distant events are also available in the literature [9,20–22]. Energy contribution from the multiple scattering is considered minimal in effect, and hence is ignored for the coda decay rate. Wu and Aki [7] suggest Q value estimated in this way by coda decay rates represents both attenuation effects, i.e., intrinsic attenuation and scattering effects, however effect of scattering on the decay rate would depend on amount of scattering taking place within the medium. When the scattering is weak the decay rate depends on both (intrinsic and scattering), while when it is strong (as in a defuse medium) the rate would depend only on intrinsic