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A regional near-surface high frequency spectral attenuation (kappa) model for northwestern Turkey

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ABSTRACT

One approach to model the high-frequency attenuation of spectral amplitudes of S-waves is to express the observed exponential decay in terms of Kappa (κ) factor [1]. Kappa is a significant parameter used for identifying the high-frequency attenuation behavior of ground motions as well as one of the key parameters for stochastic strong ground motion simulation method. As of now, there is not a systematic investigation of the Kappa parameter based on the recently-compiled Turkish ground motions. In this study, we examine a strong ground motion dataset from Northwestern Turkey with varying source properties, site classes and epicentral distances. We manually compute κ from the *S*-wave portion of each record and study both horizontal and vertical kappa values. We use traditional regression techniques to describe the (potential) relationships between kappa and selected independent variables such as the site class, distance from the source or magnitude of the event. A linear effect of magnitude on kappa is not found statistically significant for the database studied herein. We express the initial findings of a regional κ model for Northwestern Turkey as a function of site class and epicentral distances. Single station analyses at selected sites confirm the regional model. Finally, we present stochastic strong motion simulations of past events in the region using the proposed kappa model. Regardless of the magnitude, source-to-site distance and local site conditions at the stations, the high-frequency spectral decay is simulated effectively at all stations considered.

1. Introduction

One approach to model the high-frequency attenuation of spectral amplitudes of S-waves is to express the observed exponential decay in terms of Kappa (κ) factor [1]. Kappa is one of the key parameters for stochastic strong ground motion simulation method (e.g.: [2,3]). Recently, several authors studied the distance, magnitude, style of faulting and site class dependency of kappa based on data from various regions worldwide. (e.g.: [4–7]). The distance-dependency of κ is well-known, however there are alternating views on whether kappa is fundamentally a source property [8,9], a site effect or a combination of both [10]. Since kappa values computed at stations located at various distances from the sources include path attenuation, it is important to remove these effects in order to identify a physical parameter that is descriptive of the local site attenuation. For this purpose, the zero-distance kappa factor (κ_0) is defined [11] and used extensively in various applications. As recently outlined in Ktenidou et al. [12], in addition to being a key input in stochastic ground motion simulations, kappa has been employed in several applications lately ranging from site effects to ground motion prediction. A common application of kappa regarding the site effects is to adjust the site amplifications computed with the quarter-wavelength method of Boore and Joyner [13]. Another use of kappa in evaluation of local site conditions is the investigation of potential correlations between V_{S30} and κ (e.g.: [14–16]). Additionally, single station kappa values are used for correcting the acceleration spectra for site effects before source effects are studied (e.g.: [17–19]). Recently, kappa is also used in calibration of ground motion prediction equations from one region to another with different site conditions (e.g: [16,20,21]). It is important to note that different authors compute the kappa factor in alternative ways which could potentially yield incompatible values. Regarding this issue, Ktenidou et al. [12] recently performed an extensive study on the variability of kappa computations and recommended several remedies for more stable and homogeneous results.

Recently, regional kappa models have become particularly essential for their extensive use in stochastic ground motion simulations. As numerical experiments indicate (e.g.: [22]), the significant trade-off among the input parameters used in stochastic simulations can

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only be avoided with the use of well-defined regional estimates of all input parameters including κ_0. This observation is particularly valid for areas where it is crucial to use stochastically-simulated ground motions due to infrequent seismic activity; sparse seismic networks or lack of velocity models for use in alternative ground motion simulation techniques. Recently, several stochastic simulations of recent destructive earthquakes that occurred in Turkey are performed (e.g.: [22–25]) along with a limited number of attempts for estimating kappa from records of specific events ([25–28]). However, there is not yet a systematic investigation of the Kappa parameter using the recently-compiled Turkish ground motion dataset ([29]).

In this study, we examine a strong ground motion dataset from Northwestern Turkey with different source properties, site classes and epicentral distances. In Northwestern Turkey, the North Anatolian Fault Zone (NAFZ) is mostly strike-slip in character along with few normal mechanisms. The geology varies from hard Mesozoic bedrock to large sediment-filled, pull-apart basins formed by the NAFZ. The area is associated with significant seismic hazard and risk due to active faults in the vicinity of important industrial facilities of Turkey and dense residential building stock. This region had experienced major structural and economic losses during the 1999 Kocaeli (Mw=7.4) and 1999 Düzce (Mw=7.2) earthquakes. This study area is particularly selected due to the regional seismic activity yielding a large dataset.

The fundamental objective of this study is to develop an initial kappa model and to estimate κ_0 values in Northwestern Turkey for future use in ground motions simulations and ground motion prediction equation (GMPE) adjustments. For this purpose, based on our initial observations on the regional dataset, we propose a practical kappa model that considers distance and site class as the model parameters. We also investigate magnitude-dependency of the computed kappa values. Next, we present single station kappa analyses to compare with the regional model. Finally, we perform stochastic strong ground motion simulations of selected past events in the region using the proposed kappa model.

The kappa values in this study are manually computed from the *S*-wave portion of both horizontal and vertical kappa components for each record. We use multivariate linear regressions to describe the (potential) relationships between horizontal and vertical kappa and the selected independent variables.

2. Data

The dataset consists of 174 records (522 components) measured at 15 different strong motion stations from 142 earthquakes with magnitudes $3.0 < Mw < 6.0$ in Northwestern Turkey. These records are extracted from the recently compiled Turkish strong ground motion dataset [29] and (the raw versions) are available at the web page of Turkish National Strong Ground Motion Network (via http://daphne.deprem.gov.tr). Events with magnitudes lower than Mw=3.0 are rejected for corner frequency issues that could complicate the kappa computations. The near-field datasets from the 1999 Kocaeli (Mw=7.4) and Düzce (Mw=7.2) earthquakes are also not included here due to the local site amplification effects and possible nonlinearity at the soft soil sites which both could lead to bias in kappa estimations.

Due to space limitations, it is not possible to display information regarding all 142 events used; however, Table 1 gives a summary in terms of three magnitude bins and shows the number of events and records per each magnitude bin. The major mechanism in the region is right lateral strike slip-faulting. The focal mechanisms of the 142 events used in this study can be found at the web page of Turkish Disaster and Emergency Management Presidency via www.deprem.gov.tr. Fig. 1 shows the epicenters of the events and locations of the strong ground motion stations used in this study. Fig. 2 displays the magnitude-epicentral distance and magnitude-hypocentral depth distributions of the records analyzed herein. Also shown in Fig. 2 is the epicentral distance range of the records at each station. Table 2 displays further information on the locations and NEHRP-site classes of the strong motion stations and the number of records per station. For these stations, both *P*- and *S*-wave velocity profiles down to a depth of 32 m along with geotechnical parameters are available at the webpage of the Strong Ground Database of Turkey (via http://daphne.deprem.gov.tr). The velocity profiles are obtained with Multichannel Analysis of Surface Waves (MASW) method. Further details on site characterization of these stations can be found in Sandikkaya et al. [30].

Table 1
Magnitude ranges of the earthquakes used in this study with the number of events and records per each magnitude bin.

Magnitude bins (Mw)	Number of events	Number of records (number of components) from these events
3.0–4.0	60	70 (210)
4.0–5.0	61	74 (222)
5.0–6.0	21	30 (90)
Total	**142**	**174** (**522**)

We note that the regional database we gathered originally had slightly more data than those employed herein however, for reliable kappa calculations; we selected only the records with clear S-wave arrivals and no signal-to-noise problems. Particularly, we checked that signal-to-noise ratio of the each record was mostly greater than an order of 3 in the frequency range of 0.25–25 Hz. We did not use the records with lower single-to-noise ratios in our analyses. We note that the entire dataset used in this study come from digital accelerographs located at the strong motion stations. The sampling rate for majority of the records is 100 Hz with a Nyquist frequency of 50 Hz while a small number of the records are sampled at 200 Hz. Finally, we use the epicentral distance as the distance metric to study the distance-dependency of kappa and we only employ the records within 200 km epicentral distance.

3. Analyses for kappa calculations

To compute the κ values, we follow the procedure introduced by Anderson and Hough [1] where the high-frequency spectral decay is modeled as:

$$A(f) = A_0 e^{\pi \kappa f} \quad f > f_e \tag{1}$$

where amplitude A_0 depends on source and path properties and f_e is the frequency over which the spectrum is approximated with a linear decay on a log(Amplitude) versus frequency plot.

To compute kappa from each component, we initially baseline correct the time series and apply 5% Hann windows tapering. We then pick the *S*-wave arrivals manually. Concerning the length of *S*-wave windows, we examined various lengths and observed that as long as only *S*-waves are picked, the length of the windows does not yield significant differences in kappa values. Finally we choose a constant value of 5 s for the length of the *S*-wave windows. Fourier amplitude spectrum of the selected *S*-wave portion is then smoothed between 0.25 Hz and 50 Hz and plotted in log-lin space. Through a comparison of the kappa values computed with smoothed and unsmoothed spectra, despite the small differences, we observed that the smoothing step was necessary for stable values of kappa for some records. Next, the frequencies where linear decay of log(Amplitudes) starts (f_e) and