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Technical Note

Investigation on the stochastic simulation of strong ground motions for Bucharest area

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ABSTRACT

This short article evaluates the stochastic method of ground motion simulation for Bucharest area using both the single-corner frequency model and recently introduced double-corner frequency models. A dedicated Q model is derived using ground motions obtained during the largest Vrancea earthquakes from the past 30 years. The simulated ground motions are tested against the observed data from the Vrancea earthquakes of August 1986 and May 1990. Moreover, the observed data are also compared against simulations obtained using the Q model derived by Oth et al. (2008). Finally, the results of the simulations show that the derived Q model is better suited for larger magnitude events, while the Q model of Oth et al. (2008) provides better results for smaller earthquakes.

1. Introduction

The stochastic method [1] has been and is still very much used for the simulation of ground motions in many studies from the literature. A complete description of this method can be found in [1]. The Fourier amplitude spectrum (FAS) of the stochastic ground motion is obtained by combining the contribution of the earthquake source, propagation path and local site conditions. The most commonly used description of the source is done by using the Brune single-corner-frequency model [2]. Recently, Boore et al. [3] introduced two double-corner-frequency models, called multiplicative double-corner-frequency model (MDCF) and additive double-corner-frequency model (ADCF). Other source models are implemented in the software package SMSIM [4], used in this study.

In this short study a comparison between observed and generated ground motions for Bucharest area is illustrated. The observed data comprise of horizontal recordings from Bucharest area obtained during the three Vrancea seismic events of August 1986 ($M_w = 7.1$) and May 1990 ($M_w = 6.9$ and $M_w = 6.4$). The generated ground motions are obtained using both the single-corner-frequency (SCF) model and two recently introduced double-corner-frequency models – MDCF and ADCF [2]. A Q model is specifically derived from the compiled strong ground motion database and is used in the stochastic simulations along with the model derived for Vrancea by Oth et al. [5]. Moreover, kappa values are obtained for Bucharest area using the procedure described in [6,7]. Finally, the fit of the generated data with the observed data is evaluated through the distribution of residuals.

The stochastic method has already been applied for the Vrancea intermediate-depth seismic source in several studies. For instance, Pavel et al. [8] computed mean amplification factors for Bucharest using a single-corner-frequency model and strong ground motions from two Vrancea earthquakes. The stochastic method was employed by Benetatos and Kiratzi [9] to simulate ground motions for the Vrancea earthquake of May 30, 1990. In addition, source spectra for Vrancea intermediate-depth seismic events were also derived in several studies from the literature (e.g. Oth et al. [10], Sokolov et al. [11] or Gusev et al. [12]).

2. Earthquake and strong ground motion database

Two ground motion databases are compiled for the present study. The first one consists of the horizontal recordings (soil classes B and C according to EN1998-1 [13]) from three intermediate-depth Vrancea earthquakes which occurred in 1986 and 1990, respectively and it is used to derive a Q model using the procedure shown by Boore et al. [14] and to evaluate the spectral decay parameter kappa [6,7]. The geometrical spreading function is also checked using the Fourier amplitude spectra (FAS) of horizontal recordings from this first database. This database comprises of 59 recordings from soil class B conditions and 56 from soil class C conditions. The second database which is basically a subset of the first one, is composed only of horizontal recordings obtained in the Bucharest area during the same three earthquakes

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Table 1
Earthquake information (from the ROMPLUS catalogue).

Event no.	Date	Lat. (°)	Long. (°)	Magnitude, M_w	Depth (km)	No. of recordings
1	August 30, 1986	45.52	26.49	7.1	131	36
2	May 30, 1990	45.83	26.89	6.9	91	46
3	May 31, 1990	45.85	26.91	6.4	87	33

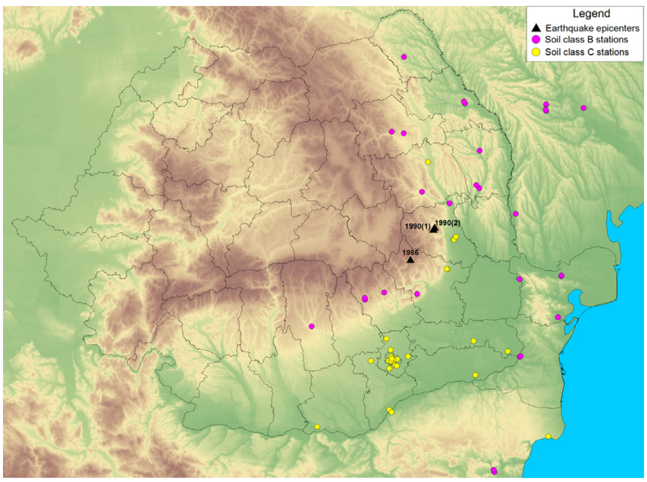

Fig. 1. Distribution of the seismic stations and of the earthquake epicenters.

of August 1986 (13 recordings) and May 1990 (12 recordings and 6 recordings). This second database is used to evaluate the stochastic ground motion simulations. The characteristics of the earthquakes and the number of corresponding recordings are given in Table 1. In the case of the first two events, the corresponding stress drops were taken from the article of Ganas et al. [15], while in the case of the last event a stress drop values of 60 bars was assumed.

The geographical distribution of the seismic stations and earthquake epicenters is shown in Fig. 1.

All the recordings were obtained on analog SMA-1 instruments. No processing was performed due to the fact that the raw waveforms are not available. The original processing was performed using an Ormsby band pass filter with cut-off frequencies of 0.15–0.25 Hz and 25–28 Hz, respectively.

3. Evaluation of the input data

As already stated, the Fourier amplitude spectrum (FAS) of the stochastically simulated ground motion is a combination of contributions from the earthquake source, propagation path and local site conditions. Guidance values for the input parameters of the stochastic method can be found for instance, in [1] and [3]. However, these values were specifically derived for crustal earthquakes. In the case of the Vrancea intermediate-depth seismic source, the input data have to be collected from several sources or have to be specifically derived using the available ground motion database. Since the number of available recordings for each earthquake is limited, it was decided to combine the recordings from soil classes B and C into a single class, termed as soil and to perform all the preliminary calculations on this combined database.

Fourier amplitude spectra (FAS) were computed for the horizontal components of all the ground motions in the database. The smoothing of the FAS was done using the parameters shown in Boore et al. [14] – a Konno and Ohmachi filter [16] with a width of 0.4.

The geometric means of the FAS for three spectral periods are plotted for each earthquake in Fig. 2 versus the hypocentral distance. The data are represented with different symbols for each earthquake (circle, triangle and square) and the fitted trendline has the same symbol as the corresponding earthquake data. In addition, a line corresponding to $1/R^{0.5}$ slope is also shown for comparison.

There are several observations to be made with regard to Fig. 2. The first observation is related to the significant spread of the data, both overall and within each earthquake separately. Moreover, the slopes of the fitted trendlines appear quite different, especially for the medium-period range. The slopes decrease with the decreasing of the spectral period. One can also notice that at small periods, the fitted trendlines are almost similar with the lines corresponding to a $1/R^{0.5}$ slope. As such, the wave scattering appears proportional with $1/R^{0.5}$ only for small and medium periods.

4. Regression model for FAS

A regression analysis for FAS is performed using the functional form shown in the article of Dhakal et al. [17], which is almost similar to the form given by Boore et al. [14]. The final functional form is given in eq. (1) below:

$$\log\ FAS = a + b \cdot M_w + c \cdot h + d\ \log\ R + e \cdot R \qquad (1)$$

In Eq. (1) the logarithms are base 10 and a, b, c and e are the regression coefficients, M_w is the earthquake moment magnitude from Table 1, h is the event depth (also from Table 1) and R is the hypocentral distance. Several values were assigned to the coefficient d corresponding to different geometrical spreading functions: -0.5, -0.7 and -1.0. The geometrical mean of the observed FAS was fitted to the functional form given in eq. (1) using standard regression methods. Finally, the Q values were obtained with the relation given in [14]. A number of values for the regression coefficients and for the model standard deviations obtained using a geometrical spreading of $1/R^{0.5}$ are given in Table 2.

Fig. 3 shows the results for several geometrical spreading functions (the results are only for Q). Several Q models from the literature for Vrancea [5], [9] and [11], as well as for other seismic sources [17] and [18] are plotted for comparison purposes. The Q values for all the models were corrected to a reference shear-wave velocity of 4.5 km/s. For some frequencies, the regression has yielded negative Q values. The reason for these values [5] can be due to the assumptions in the geometrical spreading function or to the fact that the seismic attenuation can't be represented accurately using simple functional forms. Negative Q values were also obtained through regression in other studies: (e.g. Castro et al. [19]). A $Q(f)$ function was also obtained through regression and is also plotted for comparison in Fig. 3. The functional form is $Q(f) = 165 * f^{1.20}$. The final geometrical spreading function is of the type $(1/R)^{0.5}$.

Fig. 4 shows the standard deviation of log FAS from the regression analysis for three functional forms corresponding to the different geometrical spreading functions. It is noteworthy the fact that the different geometrical spreading functions lead to similar standard deviations, but to different Q values. This observation is similar with the one made by Boore et al. [14].

5. Evaluation of kappa

The parameter kappa, also called spectral decay parameter, models the shape of the acceleration response spectrum in the high frequency