Bucharest geophysical model derived from complex interpretation of S-waves propagation

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Bucharest is one of the most exposed European capitals to the earthquake hazard. The major earthquakes affecting the city have their origin in the Vrancea intermediate depth source. Although Bucharest is situated away (at about 150 km) from the source zone of Vrancea, the city experienced significant damage during past earthquakes of magnitude greater than 7 (Marmureanu et al., 2010).

Ground motion recorded during these large Vrancea earthquakes are characterized by predominant long periods in Bucharest. This phenomenon has been interpreted as the combined effect of both seismic source properties and site response of the large sedimentary basin. The thickness of the unconsolidated deposits beneath the city is more than 150 m and the total depth of the Quaternary sediments is more than 500 m. The complex geological structure and the low seismic wave velocities of the sediments are the primary responsible for the large amplification and long duration experienced during earthquakes.

For a better understanding of the geological structure under Bucharest, non-invasive methods are used, as: H/V (Nogoshi and Igarashi, 1971; Nakamura, 1989) and three - components array analysis of ambient vibration (3C F-K, Fäh et al. 2008, Poggi and Fäh 2010), in order to retrieve the dispersion characteristics of surface waves.

In this study, detailed in Manea et al. (2016), we are using data from a 35-km diameter array (the URS experiment) installed by the National Institute for Earth Physics (NIEP) and by the Karlsruhe Institute of Technology during 10 months in the period 2003-2004. The array consisted of 32 three-component seismological stations, deployed in the urban area of Bucharest and adjacent zones (Fig. 1).

The available geological, geotechnical and geophysical information are taken into account (Fig. 1). These data were integrated in a GIS database during the BIGSEES national project ("Bridging the Gap between Seismology and Earthquake Engineering: from the seismicity of Romania towards a refined implementation of seismic action EN1998-1 in earthquake resistant design of buildings", 72/2012), led by NIEP.

Standard H/V spectral ratios of the ambient vibration recordings were computed on daily windows of 30 minutes for each URS station.

The consistence of the H/V curves over the entire array suggests that there are no significant lateral variations within the subsoil of the city. Two predominant peaks can be seen with relatively low amplitudes that may show the absence of large impedance contrasts (Fig. 2). The fundamental peak (f_0), between 0.14 - 0.3 Hz, is attributed to the geophysical bedrock, interpreted as the interface between Tertiary and Cretaceous (Mesozoic) geological units, whose distribution confirms that the bedrock is dipping to the North (Grecu et al 2003) at about 1.4 km depth (Manea et al., 2016).

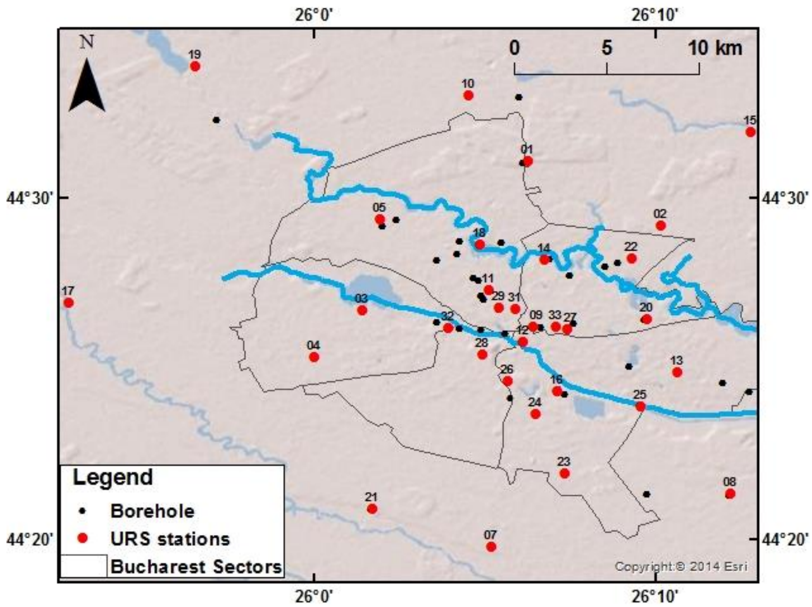

Figure 1. *Location of the URS stations in Bucharest and adjacent areas.*

The second peak that is not well defined in the range 0.6 - 0.9 Hz (Grecu et al., 2007), is correlated in the literature with the base of the Quaternary and was attributed to the engineering bedrock (Bala et al., 2013). In this study, this peak was interpreted as a mixture of the second higher mode of Rayleigh waves and other types of waves such as SH waves. This hypothesis has been verified by comparing the H/V curves with the SH-wave transfer function from the retrieved velocity structure. At higher frequencies, the curves are particularly flat and do not exhibit shallow resonances in general.

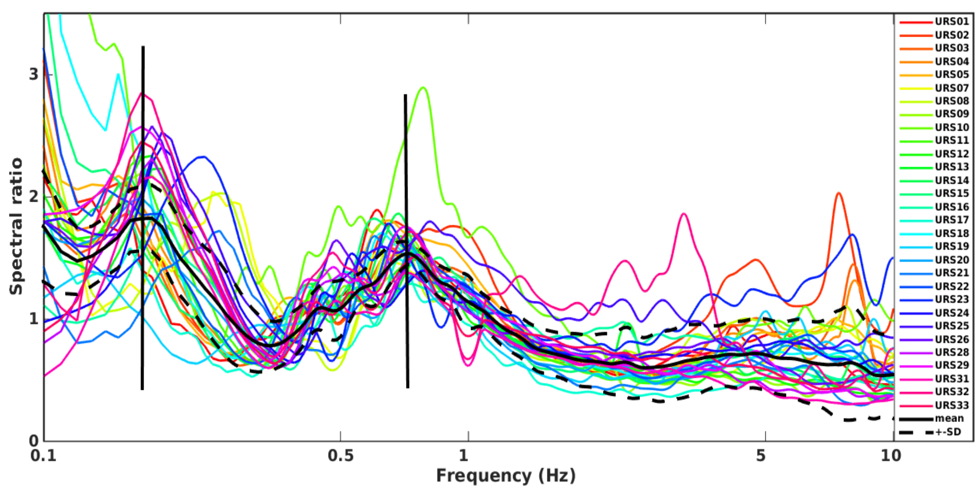

Figure 4. *H/V spectral ratios of ambient vibrations at each URS station in Bucharest. The mean and standard deviation are represented in black. The two identified peaks are designated with a vertical black line.*

The 3C F-K analysis of ambient vibrations was used in order to retrieve information about the propagation of Love and Rayleigh waves (dispersion and ellipticity). The large size of the array and the broadband nature of the available sensors gave us the possibility to characterize the surface wave dispersion at very low frequencies (0.05-1Hz). This is essential to explore and resolve the deeper portions of the basin. A large number of data sets were analyzed and the final interpretation of the Love and Rayleigh dispersion curves were achieved on the radial, vertical and transverse direction of propagation.

The comparison of the Love dispersion curves obtained using the 3C F-K analysis and the ones proposed by Sèbe et al (2009) obtained with earthquakes show a good match. Using the three - component frequency - wavenumber analysis of ambient vibrations, we could in addition retrieve the dispersion curves of Rayleigh fundamental mode and the higher mode of Rayleigh and Love.

A joint inversion was performed successfully using the surface wave dispersion curves, their ellipticity and the fundamental resonance frequency of the site. The superficial structural model (depth < 300m) is constrained by existing borehole data. Due to the size of the URS array, a good approximation of the deep velocity structure (<8km) under the city was achieved. Our velocity profiles agree with the ones obtained from refraction by Raileanu al. (2005) and are locally constrained by the geological data from BIGSEES project.

The comparison between the retrieved velocity profile and the model proposed by Marmureanu et al. (2010) from numerical simulation is made in Fig 3. The model of Marmureanu et al. (2010) does not show any impedance contrast at the interface between Tertiary and Cretaceous (Mesozoic) units. Moreover, it overestimates the shear-wave velocity above this interface and underestimates the velocity in the bedrock. This model does not explain the observed dispersion curves neither the observed fundamental frequency.

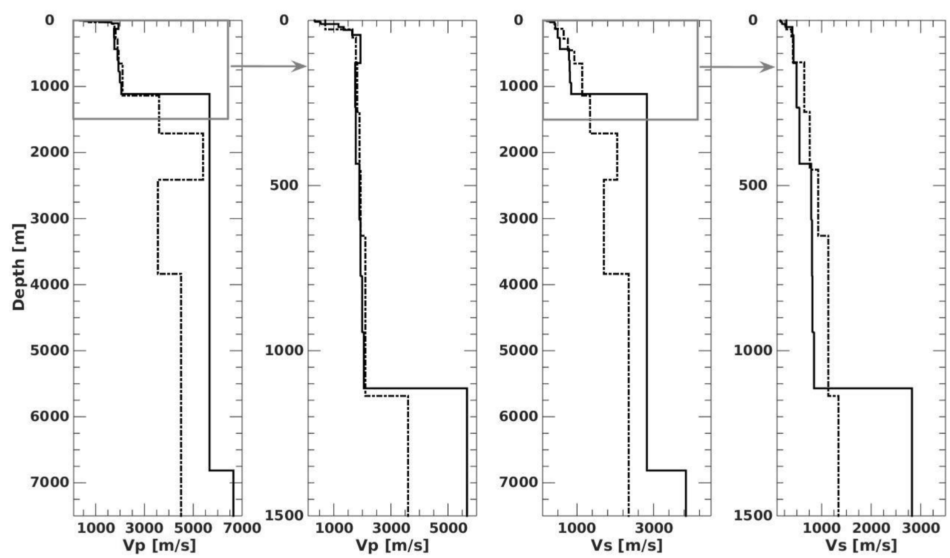

Figure 3. *Comparison between the regional 1D velocity model (solid line) and the model of Marmureanu et al. (2010) (dashed line).*

Our results are therefore bridging the gap between shallow and deep data. The variability of the Cretaceous bedrock (Figure 4) over the entire city was retrieved and is fitting with the ones from drilling and geological studies proposed by Mandrescu et al. (2008).

This model will be used for ground-motion numerical modelling and allow future studies focusing on the characterization and interpretation of the wave field and on numerical 3D wave-propagation modeling for hazard assessment.

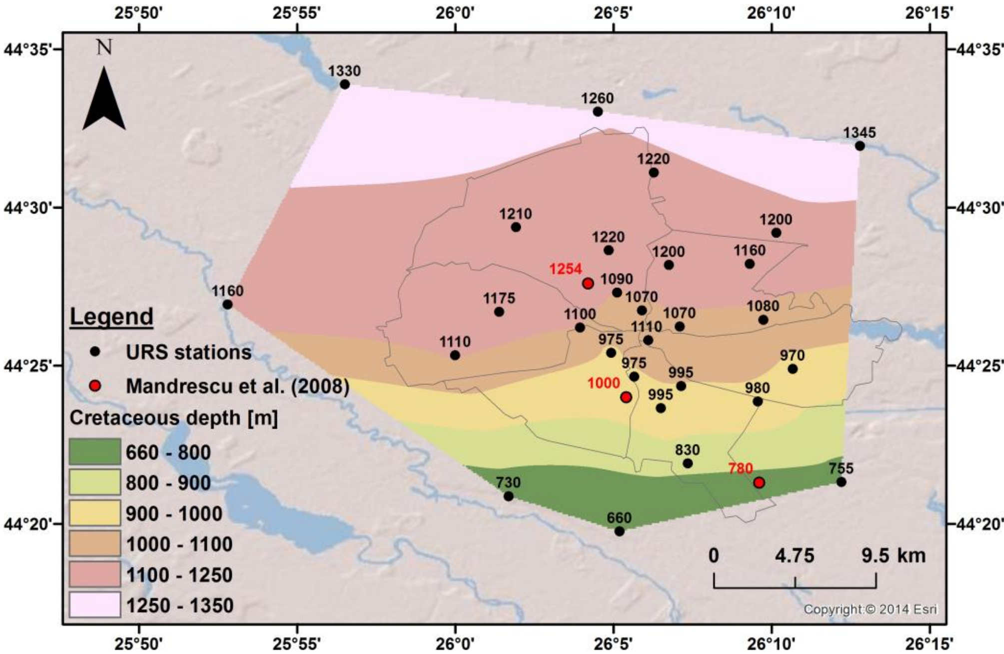

Figure 4. *Bedrock depth obtained from the inversion of the fundamental frequency and its comparison with the geological bedrock proposed by Mandrescu et al. 2008) under Bucharest).*

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