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INTERPRETATION OF RESONANCE FUNDAMENTAL FREQUENCY FOR MOLDAVIAN AND SCYTHIAN PLATFORMS

E. F. MANEA, A. PREDOIU, C. O. CIOFLAN, M. DIACONESCU

National Institute for Earth Physics, Calugareni, 12, RO-077125 Bucharest-Magurele, Ilfov, Romania
E-mails: *elena.manea@infp.ro*

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Abstract. In this study, we mapped the depth of the fundamental frequency of resonance for the Moldavian and Scythian Platforms using the available data at 18 seismic stations. Each site was investigated through the computation of H/V spectral ratios from three-component single station measurements of ambient vibrations. The observed resonance peaks were interpreted according with the available geological information.

Key words: site effects, ambient vibration, Moldavian Platform, bedrock depth, fundamental frequency of resonance.

1. INTRODUCTION

Strong intermediate-depth earthquakes originating in Vrancea seismic zone are affecting mainly the extra-Carpathian area of Romania. The effects of such earthquakes are prominent in Moldavia and often reach the level of VIII MSK as in the city of Iasi, during the 1977 event (M_w = 7.4) and even IX–X in Focsani and its neighborhood in November 10, 1940 (M_w = 7.7) [1–4].

This seismogenic zone is characterized by a high concentration of events in a well-defined volume at intermediate depth (60 to 180 km depth) and generates 2 to 3 events with magnitude M_w > 7.0 each century [5].

After the 1977 event, the efforts were concentrated on the analysis of seismological data in order to develop reliable velocity models which can be used in the seismic microzonation. To achieve this, a seismic network started to be developed for monitoring the seismic activity occurred on Romania and many projects were done in order to gather a high amount of data [6].

Assessment of the expected ground motion level to future earthquakes require the knowledge of seismic effects induced by the propagation path and local geological structure. An important phenomenon responsible for the amplification of seismic motion over soft sediments is the resonance of the trapped seismic waves due to the impedance contrast between sediments and underlying bedrock.

In the last decades, many methods were developed to investigate the local ground conditions at a site and to quantify the amplification for site-specific hazard purposes. One of the most commonly used is the horizontal-to-vertical (H/V) spectral ratio technique [7–12]. In the present study, this technique was used in order to extract valuable information about the geological structure under the Moldavian Platform. Spectral ratios of the ambient vibration records were computed for the online seismic stations of the National Seismic Network located within the Moldavian and Scythian Platforms. Additionally, the data recorded at some temporary stations deployed during CALIXTO project [13] have been used. At some CALIXTO stations, the ground motion amplification factor, computed from the spectral ratios for S and coda waves, varies from 2 to 6 in the frequency range of 0.5 to 12 Hz [7].

In this study, the resonance peaks observed in the noise spectral ratios were interpreted according with the available geological/geophysical information from the BIGSEES database (www.bigsees.ro) developed by the National Institute for Earth Physics.

The fundamental frequencies identified for each station in this study constitute the starting point in construction of a tri-dimensional (3D) geological model required in the estimation of the possible local effects occurred during strong earthquakes.

2. GEOLOGICAL SETTINGS

Moldavian platform is located in the North-East of Romania and is a part of the East European Platform (Fig. 1). To the West, it is delimited by the Eastern Carpathians and by Bistrita fault on the South [14]. Its basement is older than the Upper Rifean or at least the Vendian times and consolidated during the Carelian or Gothians times [15]. In the South of the East European platform is situated the Scythian platform, bounded to the North by Bistrita Fault, in the East by Sf. Gheorghe Fault and to the South-West by Trotus Fault. The latter two are separating the Scythian platform from the North Dobrogea promontory (Fig. 1).

Moldavian and Scythian Platforms have different type of basements but the sedimentary cover presents the same characteristics, because of their common evolution, started with Paleozoic [16]. Moldavian has a Precambrian basement instead of a Paleozoic one present on Scythian Platform. The geophysical data [16] suggests that the thickness of sediments increases from the East to West. The Moldavian Platform basement can be found between 800 and 3200 meters depth (*e.g.* 819 m at Batrânești, 859 m at Todireni, 1160 m at Iași, 1210 m at Popești, 3200 at Bacau). Its abrupted variation along the both platforms reflect the high level of fracturing in particular to the edges. This base was covered with sediments starting with the sedimentary cycles of Cambrian, Ordovician-Silurian, Devonian, Upper Jurassic-Cretaceous, Upper Cretaceous and locally with Paleogene and recent Neogene [17]. Some detrimental deposits (as quartz sand and clay) have accumulated during Cambrian and deposits of quartz sandstones during Ordovician. The largest extension is Silurian deposits, dominated by limestone and rich fossils. This layer surface reach 1200 m depth at Rădăuţi and 400 m to the east of part of Siret. The Mesozoic sedimentary layer is characterized by discontinuities but reaches up to 1000 m thickness. During the Lower Cretaceous, 350 m of limestone, dolomite and anhydrite, transgressive on Palaeozoic rocks or older, have accumulated on the western side of the platform.

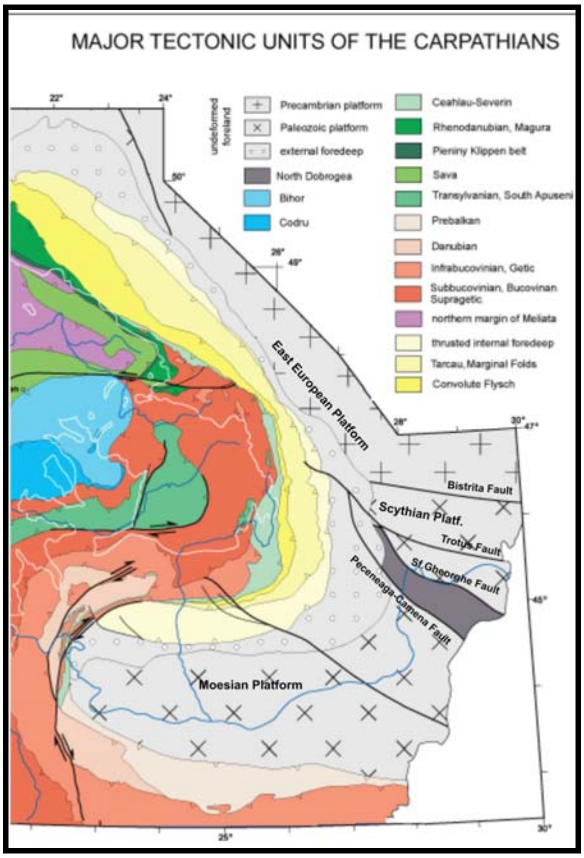

Fig. 1 – Major tectonic units of the Carpathians (after [14]).

The Paleocene and Eocene sediments settled transgressive over the Cretaceous ones, have about 150 m thick and consist of sandstone and limestone. They are present at the western edge of the platform at depths of 1225 m and 4690 m.

The Neogene deposits started to accumulate in the Upper Badenian. The Badenian deposits are detrimental and includes an evaporative episode. Their base is at shallow depth in the North-East part of the Platform, but it deeping to 1500 m in the West. During Sarmatian, clay, marl, silt and sands, limestone and impure limestone, have accumulated in the middle. The thickness of the Sarmatian sediments varies between 800 and 2600 m and is rising from east to west. In the Meotian, had been accumulated andesites, sands, sandstone, conglomerates and clays, reaching up to 180 m thick [18].

3. AVAILABLE DATA AND METHODS

The data from 10 online stations deployed by the National Institute for Earth Physics (NIEP) after 2004 and the ones deployed during CALIXTO Experiment on the Moldavian Platform were used (Fig. 2). The CALIXTO experiment was performed in 1999 the framework of the cooperation between National Institute of Earth Physics and University of Karlsruhe ("Strong Earthquakes: A Challenge for Geosciences and Civil Engineering" [13]). We use only 8 seismic stations for this experiment with a good quality data and with minimum 10 days continuum recordings. The data were processed using the horizontal-to-vertical (H/V) Fourier spectral ratios on single station three-component recordings.

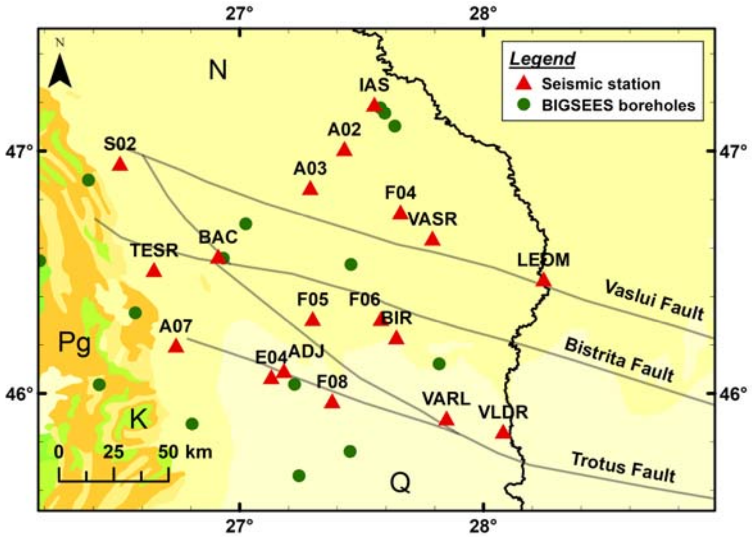

Fig. 2 – Location of the stations within Moldavian and Scythian Platform. Abbreviations used here for geological units: Q – Quaternary, N – Neogene, K – Cretaceous, Pg – Paleogene (modified from [19]).

The data used for H/V spectral ratios of the ambient vibration were pre-processed by removing any offset and linear trend using a high-pass filter of 10 Hz. For this processing, the signals were split in sub-windows of 100s length and each sub-window tapered with a 5% cosine taper before performing the spectral ratios. The Fourier spectra computed for each component were subsequently smoothed using the Konno and Ohmachi algorithm [20] with a bandwidth of 60. Finally, the ratio between the horizontal (geometrical mean of the two components) and vertical Fourier spectra of the seismic noise recordings on one-hour window was computed. The results from all time windows were averaged for each seismic station separately.

As the fundamental frequency of resonance is connected with the velocity structure of the sediments, this value is used mainly to obtain information about the bedrock depth through simplified approaches (*e.g.*, [21]).

In order to approximate the variability of geophysical bedrock, the Rayleigh-wave fundamental frequency was computed using a generic velocity profile [22, 23]. The velocity profiles (V_p and V_s) representative for this region are the ones proposed by [24]. This simple model is designed as a linear gradient velocity model with 5 horizontal layers on top of the bedrock interface. The P-wave velocities are varying from 600 to 1900 m/s and the S-wave velocities from 260 to 1100 m/s. At the interface, the V_p is settled as 2700 m/s and V_s as 1500 m/s. This model was used in the past for site response evaluation in densely populated cities of Moldavia ([25] and references therein).

To interpret the corresponding depth of the fundamental frequency observed in the *H*/*V* curve, all the available geological, geotechnical and geophysical information from a GIS database are taken into account. This database was developed 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, www.bigsees.ro), led by NIEP. This one incorporates all the available geological, geotechnical and geophysical information collected from previous projects or contracts performed by NIEP, as stratigraphy, densities, seismic velocities from downhole measurements (for P waves, in some cases also S-wave velocities are available). The authors also reviewed all the existing published information recognized at the international level (*e.g.* [24, 7]).

4. RESULTS

The horizontal-to-vertical spectral ratio was successfully applied on 18 three-component single station measurements of ambient vibrations in order to assess the variability of the fundamental frequency of resonance over the entire area and to retrieve reliable information about the geological structure.

The computed *H*/*V* curves suggest the existence of multiple interfaces within the geological structure below this area. Two predominant peaks can be well identified and varies between 0.2 – 0.45 Hz and 0.4 and 7 Hz (Fig. 3). At two seismic stations, an additional peak can be identified at very low frequencies around 0.1 Hz (Fig. 3).

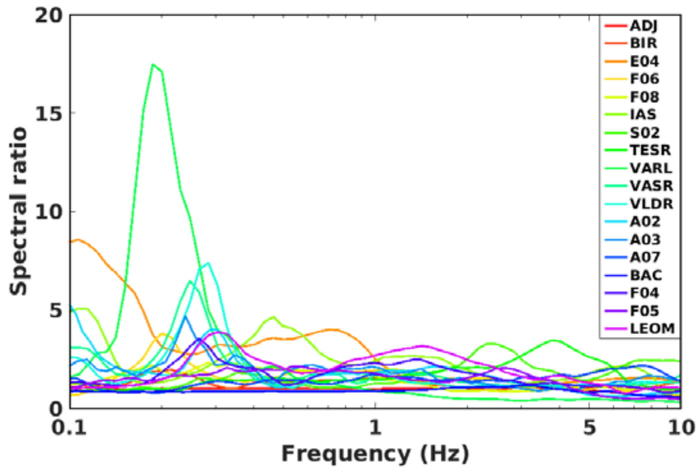

Fig. 3 – *H*/*V* spectral ratios of ambient vibrations at each station in the Moldavian and Scythian Platforms.

We interpret the peak around 0.2–0.45 Hz as the signature of the fundamental frequency of resonance for this area. In this frequency interval, the performance of the sensors installed at some stations doesn't allow the retrieval of this peak due to their frequency limitations. Using a geographic information system (ArcGis tool (www.arcgis.com)) the data are spatially interpolated by Natural Neighbor method (http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/natural-neighbor.htm).

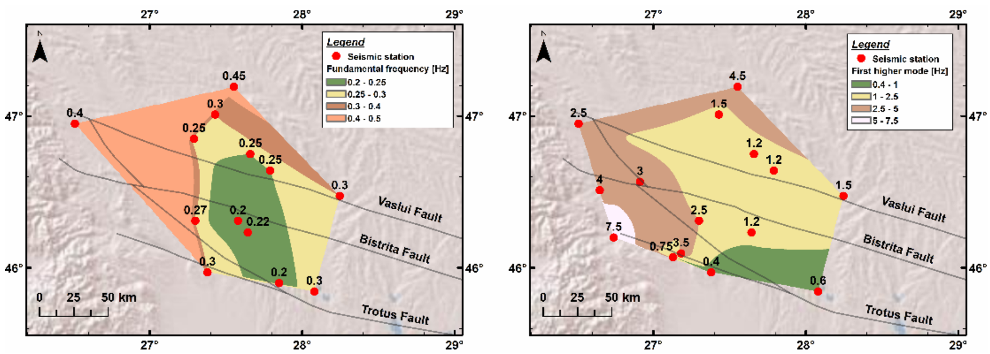

Fig. 4 – Variation of fundamental frequency (left) and the first higher peak (right) over the area under investigation.

In order to determine the depth attributed to each retrieved frequency, the Rayleigh wave ellipticity was computed using the generic velocity profile proposed by [25]. The depth of this model was varied until the fundamental frequency of the computed ellipticity is equal with the one observed from *H*/*V* ratio. The final depth obtained from this simple procedure was compared with the geophysical/geological available data from BIGSEES database (see Fig. 5).

At the IAS station the surface of Cretaceous starts at 1160 meters depth and the very low frequency around 0.1 Hz can be attributed to the interface between Neogene and Cretaceous. The depth of the fundamental peak (0.2 – 0.45 Hz) was computed using the simplified approach of inverting the bedrock depth alone with respect to the fundamental frequency of resonance from the *H*/*V* curve at each site/seismic station. Its corresponding depth can be observed in Fig. 5 and the comparison with the available geological/geophysical information from the BIGSEES database, shows that this interface corresponds to a velocity change within the deeper Neogene layers, possible due to the different type of sediments of Meotian and Sarmatian age.

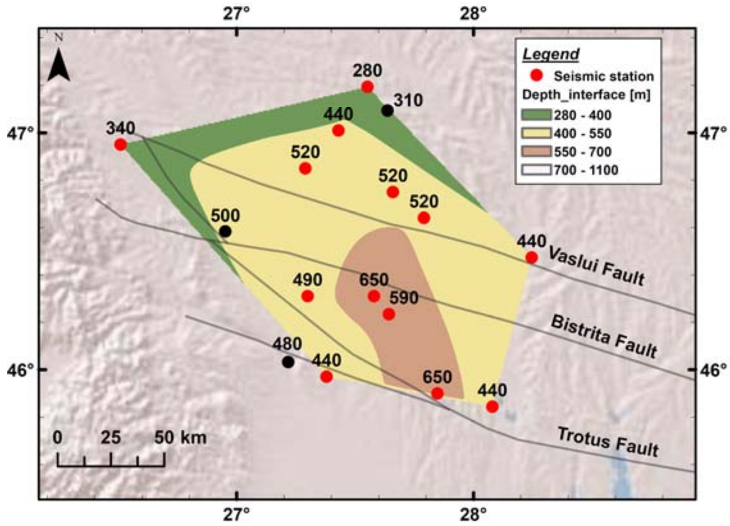

Fig. 5 – Variation of geophysical bedrock depth over the Moldavian and Scythian Platforms.

The secondary peak in *H*/*V* ratios observed at frequencies varying between 0.4 and 4.5 Hz correspond to depths between 300 and 100 m and is associated to the velocity change between the last cycles of sedimentation within Neogene layer above Trotus fault and to the Quaternary/Neogene interface below this fault.

5. CONCLUSIONS

In this study, we performed a step forward toward in the understanding of the seismic ground motion and its amplification over the Moldavian and Scythian Platforms by improving the mapping of the local geological and geophysical structure.

Single-station seismic measurements were used in order to compute the H/V spectral ratios and to retrieve the variation of the fundamental frequency of resonance along this area.

The computed H/V curves shows consistency and two predominant peaks are observed.

The fundamental frequency of resonance varies from 0.2 to 0.45 Hz and is corresponding to the succession of different sedimentation cycles within Neogene, as most probably Meotian and Sarmatian. A second peak in the H/V ratios of ambient vibrations observed between 0.4 and 7 Hz was attributed to the velocity change between the last sedimentation cycles within Neogene, above Trotus fault and to the Quaternary/Neogene interface below this fault. Another peak of very low frequency (around 0.1 Hz) was identified at a few stations and the available geological information display the presence of a deeper interface around 1100 m that can be interpreted as the interface between Neogene and Cretaceous.

With these new results, we performed a step forward toward the understanding of ground motion propagation in the Moldavian and Scythian Platforms as the geophysical bedrock is a major interface to take into account for ground motion modelling. Future studies will be done to refine the 3D velocity structure and to build a capable model for seismic waves propagation in this region.

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