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Resonance Frequencies of Soil and Buildings – Some Measurements in Sofia and Its Vicinity

S. Castellaro[1], **R.B. Raykova**[2], **M. Tsekov**[2]

[1]Department of Physics and Astronomy, University of Bologna, Bologna, Italy

[2]Faculty of Physics, St. Kliment Ohridski University of Sofia, Sofia, Bulgaria

Abstract. We present a first attempt to investigate site effects in Sofia and its vicinity using microtremor H/V ratio survey method. We found a completely flat H/V curve for measurements in Vitosha seismic station, indicating stiff bedrock. The resonance frequencies in geological systems are proportional to the shear-wave velocity and thickness of the resonating layer. We obtained a resonance peak of the soil in the Lozenets district of Sofia indicating a thick sediment layer, in agreement with other regional geological data. Buildings also have a natural frequency of vibration. We found that nearby buildings of the Faculty of Physics of Sofia University have resonance frequencies that differ significantly from the resonance frequency of the subsoil at the site, thus preventing resonance amplification of vibration during earthquakes.

1 Introduction

Local geology and soil properties have significant effect on the intensity of ground motions during earthquakes. Study of this effect is of great importance for seismic risk assessment and reduction. One of the most important properties determining ground response during earthquakes is the resonance frequency of the subsoil.

Here we present measurements of resonance frequencies of soil and structures, performed at two local sites in Sofia and near Sofia with a portable instrument, specifically designed for microtremor acquisitions. The structure of the paper is as follows. In Section 2 we briefly present the H/V method used in this study. In Section 3 we present and discuss the results. In Section 4 we summarize our findings and we outline possible future work.

2 Method

Sedimentary layers (subsoil) are usually modelled as oscillators (e.g. spring-mass systems) vibrating at specific frequencies (resonance frequencies). The resonance frequencies in geological systems are proportional to the stiffness (according to the theory of elasticity stiffness depends on shear-wave velocity V_S) and thickness H of the resonating layer. In the simple model of a single resonating layer, above stiff bedrock, the resonance frequency is $f_0 = (2n-1)V_S/4H$, where n is the mode number. Assessing the amplification (resonance) frequencies of subsoil and structures is a key parameter for seismic engineering.

The H/V method was originally developed to assess the so called 'site effects' of the soft sediment cover layer influencing local amplification of ground vibration during earthquakes. Due to the specific geology of Sofia Valley, characterized by deep sedimentary cover layer, site effect are very important in seismic hazard and seismic risk assessment. Sofia, with its growing population and concentration of economic activity, is located in an earthquake prone region. Thus earthquake hazard studies for Sofia, inevitably including site effects characterization, are of significant social importance.

At present, the H/V method [1, 2] is the most common technique to experimentally assess the subsoil resonance frequencies. The ratio of the horizontal (H) and the vertical (V) components of a microtremor eliminates the source effects and enhances the effects induced by the wave path. Usually H/V ratio remains essentially unchanged with time at the same site and provides a good estimate of the fundamental frequency of soft subsoil. A peak with specific frequency in the H/V curve indicates the presence of a stiff layer, whose depth can be assessed knowing V_S of the sedimentary layers above. Space variations of H/V peak frequency are linked to lateral heterogeneities of the sedimentary structure.

3 Results and Discussion

First, we measured the resonance properties of the concrete platforms and underlying materials at Vitosha seismic station, located in the homonymous mountain near Sofia. Vitosha seismic station is one of the quietest Balkan Peninsula seismic stations in respect to seismic noise. The seismometers are placed on concrete platforms in two chambers at the end of a long tunnel dug in syenite rocks [3].

We found a completely flat H/V curve which is characteristic of stiff bedrocks (Figure 1). We observed that at frequencies greater than 8 Hz the H/V ratio drops slightly below 1. This suggests a shallow velocity inversion induced by the large concrete platform built over syenite bedrock, where the seismic instruments are set [4].

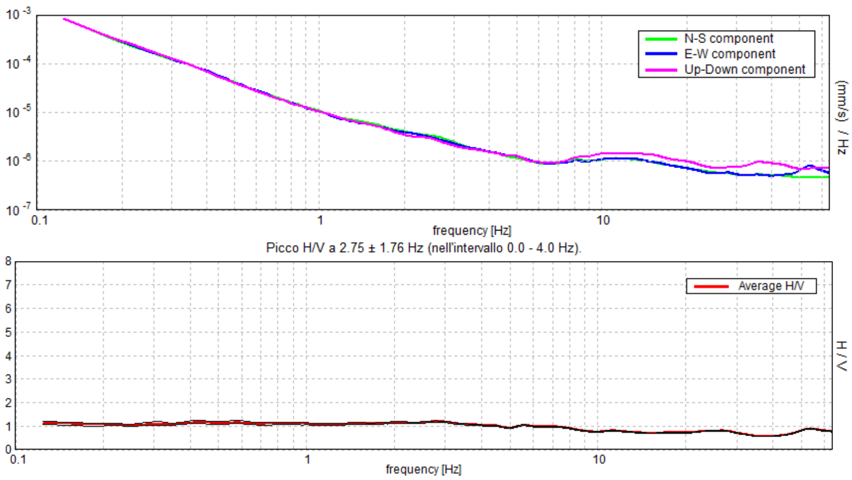

Figure 1: Top: single components (N-S, E-W, U-D) spectra at Vitosha seismic station. Bottom: H/V (average $\pm$ standard deviation) curves at the same location.

Next, we measured the vibration modes of the subsoil in the space between buildings A and V of the Faculty of Physics (FPh) of Sofia University, located in the Lozenets district of Sofia (Figure 2). The H/V

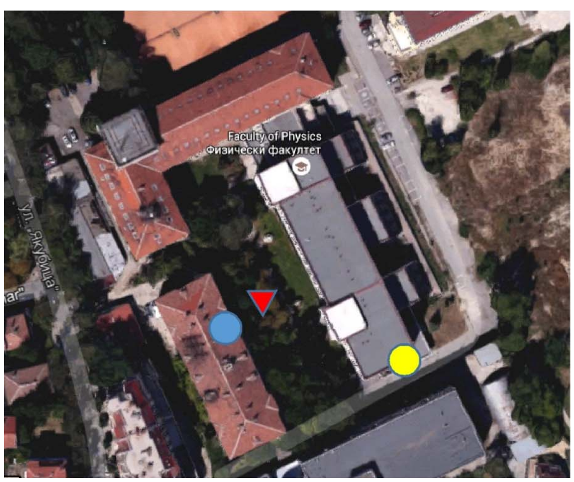

Figure 2: Locations of vibration mode measurements of (i) subsoil in the space between the buildings of the Faculty of Physics of Sofia University (red triangle); (ii) building A of Faculty of Physics (yellow circle); and (iii) building V of Faculty of Physics (blue circle).

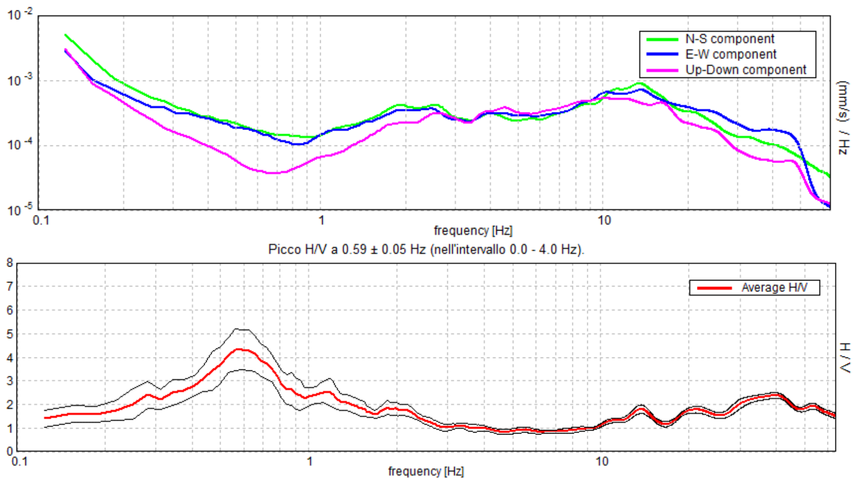

Figure 3: Top: single components (N-S, E-W, U-D) spectra at the space between the buildings of Faculty of Physics. Bottom: H/V (average $\pm$ standard deviation) curves for the same location.

curve exhibits a clear resonance peak at frequency 0.6 Hz (Figure 3). Using the relation $f_0 = (2n-1)V_S/4H$ we obtain an estimate of the local sediment thickness between about 210 m and 330 m, assuming V_S in the sedimentary cover is in the range 500–800 m/s. This result is in agreement with current knowledge about the Sofia graben geology [5]. During the Pliocene and the Quaternary Sofia Valley was a lake, until it dried out after the Iskar River cut its way through the Stara Planina Mountain. As a consequence Sofia Valley is covered by sediments with thickness ranging between 200 and 800 m [6].

All buildings have a natural frequency of vibration. When the fundamental frequency of a building is close to that of the underlying soil, the probability of damage or collapse of the building during strong earthquakes increases.

We measured the vibration modes of the Building V of FPh (first flexion mode at 3.3 Hz in transversal direction and 3.7 Hz in longitudinal direction) and of the Building A of FPh (first flexion modes at 2.7 Hz and 2.9 Hz respectively) (Figure 4). This result is in agreement with the general rule that for similar type of construction the higher is the building, the smaller is its eigen-frequencies. Vibration eigen-frequencies of the structures in the FPh area differ significantly from the resonance frequency of the subsoil at the site (Figure 3), indicating lack of double-resonance effects in case of strong earthquakes.

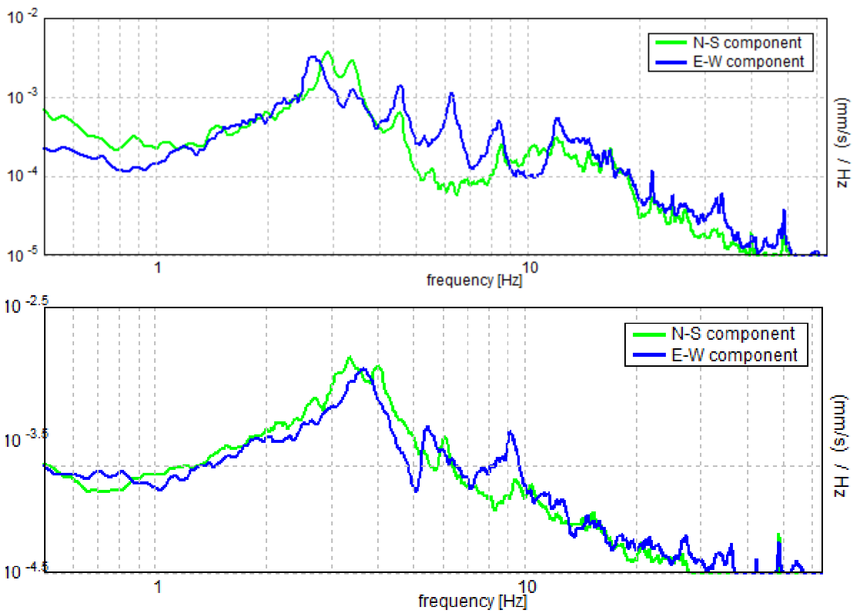

Figure 4: Single components (N-S, E-W, U-D) spectra of Building A (top) and Building V (bottom) vibrations. Largest peaks correspond to the first flexion modes of the corresponding components.

4 Summary and Conclusions

This study presents a first attempt to investigate site effects in Sofia and its vicinity using microtremor H/V ratio survey method. For Vitosha seismic station we observed a completely flat H/V curve indicating that it is set on a stiff bedrock with no stratigraphic amplification of seismic motion above 0.1 Hz. In fact, the station was specifically designed and built in a way to prevent distortion of seismic waveforms due to local geological conditions [7]. In the Lozenets district of Sofia we obtained a resonance peak indicating a thick sediment layer, in agreement with other regional geological data. We found that nearby buildings of the Faculty of Physics of Sofia University have resonance frequencies that differ significantly from the resonance frequency of the subsoil at the site, thus preventing resonance amplification of vibration during an earthquake.

The H/V method provides an easy, cost-effective and non-invasive approach to study site effects [8] and may be part of any future seismic hazard investigation in the Sofia region.

Microtremor H/V spectral ratio measurements were used to map the thickness of soft sediments [9–12]. Sofia graben is characterized by complex geology and varying sediment cover layer thickness. The method may give insight on the regional geology, provided a number of measurements in different locations are carried out.

In summary, the microtremor H/V ratio method may give important results on seismic hazard assessment and local geology study especially in urban areas.

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