Romanian Reports in Physics, Vol. 61, No. 2, P. 347–358, 2009

SITE EFFECTS INVESTIGATION IN THE CITY OF TIMISOARA USING SPECTRAL RATIO METHODS

E. OROS

National Institute of Research and Development for Earth Physics, Bucharest, Seismological Department, Research Group Timisoara, eoros@mail.com

(Received June 6, 2008)

Abstract. The investigation of the site-effects using spectral ratio methods in the city of Timisoara is presented. A non-reference-site technique, often called Nakamura's method is used to determine the resonance frequencies, f_r, of the uppermost sedimentary layers. The method was applied on *i*) seismic noise time-series (HVSRN); *ii*) earthquakes waveforms recorded by Timisoara Seismic Station (TIM). The resonance frequencies and H/V ratios amplitudes were mapped for a first-order evaluation of site response and to emphasize lateral variations of the seismic ground motion as a microzonation main step. These frequencies were also correlated with the local geology, the observed macroseismic intensities in the city and with the theoretical fundamental frequencies of the buildings.

Key words: spectral ratios, resonant frequency, earthquakes, seismic noise.

1. INTRODUCTION

It is well known that the effects of local geology on ground motion during an earthquake can be very strong and very different in near sites, as Milne noted one hundred years ago: "It is an easy matter to select two stations within 1000 feet of each other where the average range of horizontal motion at the one station shall be five times, and even ten times, greater than it is at the other.", [18] from [6].

The ground motion recorded at surface generally depends of source, path and local peculiarities. The site-effects refer to the modification of the seismic waves due to the 3D variations of geological structures and their composition near the surface of the Earth. These modifications (site response) determine frequently stronger ground motion at specific frequencies on sediments sites (resonance frequencies of site-sediment columns, *fr*), what is of critical interest for engineers. The investigation of the local ground conditions for assessing the site effects can use active or passive methods. The passive methods base on spectral investigations of the ambient seismic noise or small earthquakes. These methods use mainly in urban areas because their easier applicability, low cost and low time consumption. Two passive methods are usually applied: *i*) Site-to-Reference Spectral Ratios (SRSR) and *ii*) Horizontal-to-Vertical Spectral Ratios (HVSR).

HVSR method applied on the recordings of only one station, often called Nakamura's method is an attractive and efficient non-reference-site technique [31]. It is useful i) to empirically estimate and map the resonance frequency of the uppermost sedimentary layers and ii) to constrain the geological and geotechnical models used for numerical computations. It can be applied with success both, to seismic noise (HVSRN) and to waveforms of the earthquakes [3–4, 8–10, 12–13, 15, 20, 27–28]. The HVSR applied on S-waves of the earthquakes is similar to the receiver-function technique of [14] and it has the same results as HVSR applied on noise and coda [5, 7, 29, 30, 32].

Even if the amplification factor is not still understood the values of HVSRN peak amplitude could be generally considered as the lower bound of the site amplification [31].

HVSRN also became for several years an exploration tool because in a 1-D case f_r is linked to the shear-wave velocity and the sediment thickness, e.g. [11]. In addition, HVSRN is also useful in calibrating site response studies at specific locations. The correlation of the data about f_r and vulnerability can help to identify the potential damage to buildings and lifelines.

Timisoara is the greatest town from the western part of Romania having a high level of seismic hazard due to local and regional crustal earthquakes. The city experienced several strong local earthquakes [24, 25]. Macroseismic available data [22] in the city reflect the presence of the site-effects. Superficial geology in the town and surroundings consist in thick Quaternary unconsolidated sediments with lateral heterogeneities [26, 34] that can generate important site-effects. HVSR techniques have been applied in the present study in order to gain new data useful to characterize the seismic response of the sedimentary layers in terms of fr and relative amplification levels. We correlated f_r derived by the HVSR analysis with the fundamental frequencies of the buildings from Timisoara and with the macroseismic data.

The first attempts to use seismic noise spectra for the microzonation of Timisoara city was accomplished in [17], where different types of spectra using the predominant frequencies on horizontal and vertical components were described. Detailed analysis of the same spectra, by mapping and zoning the differences between the horizontal and vertical components was performed by [21]. The resonance frequencies of the soil columns using the HVSRN method have been firstly estimated in [22].

2. DATA AND ANALYSIS

2.1. EARTHQUAKE WAVEFORMS AND SEISMIC NOISE TIME-SERIES

The HVSR method has been applied on data that were acquired, selected and processed according to the recommendations of Sesame European Project, D23.122005 [31]. The spectral ratios were computed using J-Sesame and geopsy free software (http://sesame-fp5.obs.ujfgrenoble.fr and http://geopsy. org).

The seismological data used in the investigation were obtained from different sources, as it follows:

1. Ambiental Seismic Noise (ASN) recorded by TIM station (5 digital seismograms). The time windows of noise time-series were selected preferable before the earthquakes and/or as late as it was possible after the end of the earthquakes. HVSRN method has been applied on ASN windows selected from the waveforms according with the recommendations from [31] to assure reliable results (e.g. min 10 windows with the length of min 10 s to obtain f_r reliable over 1 Hz).

2. S- and Coda-waves from 7 small earthquakes recorded by TIM station (Table 1). The waveforms were band-pass filtered (0.1–20 Hz). HVSR applied on time windows with lengths of 10–30 s to obtain reliable results over 0.3 Hz and 1.0 Hz. The coda-waves started at twice the S-travel time from the origin [28]. Sometimes S-waves and coda were processed together to obtain acceptable time lengths of the samples [31]. This choice did not affect the reliability of the results [1]. The Radial or North component to vertical component spectral ratio method [14] was applied on P and/or S waves (a compromise between the decrease in amplitude and the time length of the windows was accepted for a reliable estimation of fr [31]).

3. Noise Fourier Spectra obtained by [17] in 23 sites and reprocessed by [21]. The samples of ASN have been obtained by a 3 component, $T = 1.0$ s velocimeter and they are only of 5 minutes length [17]. Thus, the HVSRN obtained in this paper on these data are reliable only for $f > 2$ Hz [31].

The seismograms analyzed in this study were recorded by TIM station using two types of seismic instruments:

a) Teledyne 3C-S13, $T = 1$ s, 50 sps/s, A/D 16 bit, HVSRN applied on minimum 10 windows with lengths at lest of 10 s. The resonance frequencies are so reliable for $f \geq 1.0$ Hz because technical reasons [31].

b) Kinemetrics K2 CMG40T-EpiSensor, extended bandwidth DC to 200 Hz, 100 sps/s. HVSRN applied on minimum 10 windows with a length at lest of 30 s, f_r is reliable for $f \geq 0.3$ Hz [31].

Table1

The list of the earthquakes used in the spectral analyzes

No.	Date dd.mm.yyyy	Origin time hh:mm:ss	LatN (degree)	LongE (degree)	Deph (km)	Mw	Epicentral distance (km)
1	22.07.2000	07:51:03	45.737	21.441	11.8	3.4	17
2	16.08.2000	22:13:59	45.463	21.290	16.3	3.5	31
3	17.02.2002	16:27:38	44.880	22.410	3.7	3.1	133
4	23.05.2002	03:26:00	44.728	21.660	7.6	3.8	160
5	23.02.2003	03:20:16	44.337	21.643	7.8	3.2	159
6	01.03.2003	20:09:46	45.493	20.060	16.6	3.0	95
7	07.02.2008	16:45:32	45.870	20.793	19.7	3.9	37

All samples of ASN and earthquakes waveforms were cosine tapered (5%) and Fourier transformed. The windows of the time samples were often overlapped with different percents (5–50%). The spectral amplitudes were then smoothed according to the [12] logarithmic window ($b = 40$) and used to compute horizontal to vertical component H/V ratios. For noise and coda-waves the horizontal component is the squared average of the NS and EW components.

TIM station has a very low level of detectability and many of the recorded seismic events have a very low signal-to-noise ratio [23]. Thus, only seven waveforms of earthquake that fulfilled some conditions, e.g. signal-to-noise high ratios could be selected for the analysis (Table 1). However, only four events (the events 1, 2, 4, and 7 in Table 1) were processed for a complex spectral analysis.

The 7 February 2008 event has a special importance for our study because the waveform that was obtained with a broad band instrument is of high quality, with unclipped waveform within maximum energetic waves range and with a long time window of ASN. It also allows us a reliable analysis in a broader band of frequencies (0.3–20 Hz) than all other available waveforms.

2.1. GEOLOGICAL SETTING

Timisoara is situated in the Western Plain of Romania, on the south-eastern border of the Pannonian Depression where the crust has a thickness of 26–28 km and the transition limit between the upper to lower crust is at 15–20 km [34].

The sedimentary formations of Neogene (Miocene and Pannonian) and Quaternary ages cover unconformable a Proterozoic-Paleozoic crystalline basement and have thicknesses of about 1750 m in Timisoara area [19, 33, 34]. They have a quite monotone composition [34]: i) Miocene formation consists from a thin succession of conglomerates and marls; ii) Pannonian series has marls in the basis, followed by sandy layers on the upper half.

The uppermost sedimentary layers (Quaternary formations) consist by Pleistocene and Holocene sediments deposited conformable over Pannonian and are generally formed by gravels and sands in the basis, coated by a complex succession of formations of the terraces of Paleo-Timis and Bega Rivers: sand, clay, silt, gravel, loess, etc. with large 3D variations [33]. The layers of Quaternary sediments have thicknesses generally increasing from East-North-East toward West-South-West, with an average value of about 100-140 m in the city area [19], [33]. There are at the surface many anthropic debris fillings with thickness up to 3–4 m, especially in the downtown of Timisoara [2].

Bega River crosses the city from East to West. From geotechnical point of view, the superficial levels of the lithological columns (30–40 m) show three different units disposed along Bega River: predominant clays in the northern part of the city and sands in the South with structures of transition between them e.g. sandy-clays [2]. On a NS geological profile described by [26] it can be noticed a succession of sands and clays and marls into layers thicker to the South of area.

4. RESULTS AND DISCUSSIONS

The main results obtained in this work refer mainly to the resonance frequencies (fr) of the site-sedimentary geology (site-soil columns) and the corresponding relative site-amplification factor (A) derived from the amplitude of spectral ratios values (A_{HV}) [12].

The average spectral ratios in the TIM station site derived from noise and coda-waves and their standard deviations are presented in Fig. 1. The following values can be noted: $f_{r\mathrm{coda}}=2.4\pm0.3$ and $A_{\mathrm{HVcoda}}=3.2\mathrm{Hz}$ and $f_{r\mathrm{noise}}=2.3\pm0.3$ Hz and $A_{\mathrm{HVnoise}}=2.0$, respectively.

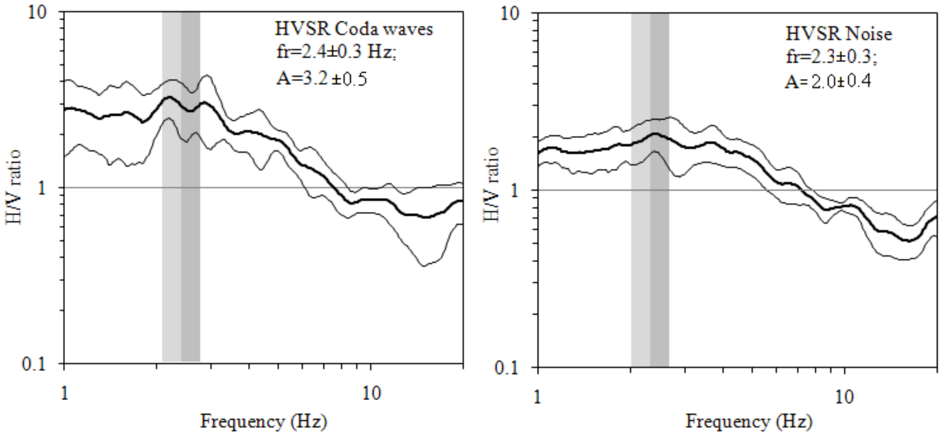

Fig. 1 – The single-station H/V spectral ratios obtained using earthquakes and ambient noise at TIM station. Thick black line is the average ratio and the thin gray lines show the average ±1 S.D. interval. The values of the resonance frequencies, f_r, correspond to a range defined by the two gray fields (average values derived from individual spectral ratios: N=7 for coda waves and N=5 for noise).

The HVSR (radial to vertical component ratios) derived from the seismograms of the M_w=3.9, 07 February, 2008 earthquake are presented in Fig. 2. The lower bound of the analyzed frequency band is only 0.3 Hz due to the limited length of the waveform: each of the 10 windows of noise that could be selected was only 30 seconds length. Between 1.0 Hz and 20.0 Hz all *H*/*V* ratios computed on P and S waves, coda-waves and noise have resonance frequencies f_r between 2.0 Hz to 2.5 Hz, similar with the average values derived from more data (Fig. 1). The values of spectral ratios corresponding to these frequencies range from A_{HV}=1.6 (noise) to A_{HV}=5.2 (S and coda waves).

It is obvious from the two diagrams on the bottom of Fig. 2 that we can notice two main resonance frequencies for noise and coda-waves HVSR, $f_{r1} = 0.6$ Hz and $f_{r2} = 2.3$ Hz, with $A_1 = 4.6$–7.0 and $A_2 = 1.6$–4.2, respectively. Similar values obtained in [22] at high frequency level ($f_r = 2.2$ and $A_{\mathrm{HV}} = 1.7$). We interpret the low frequency *H*/*V* peaks ($f_{r1} = 0.6$ Hz) as the fundamental resonance frequency that correspond to deeper interface of high impedance contrast. The higher resonance frequency ($f_{r2} = 2.3$ Hz) may be linked to the presence of other impedance contrast at upper level of sediments detectable by the HVSR method (impedance contrast greater than 2 as is mentioned in [12]). However, we do not exclude the interpretation of these values in terms of a velocity anomaly.

Certainly, these f_r observed at TIM station site describe overall seismic site response at two scales, that means in other words the deep soil-column response and the upper soil-column responses, at 0.6 Hz and 2.3 Hz, respectively.

Geotechnical and geophysical data at this location are necessary for a realistic analysis of these results obtained by HVSR method.

The *H*/*V* ratios obtained in the 23 locations of Timisoara were reprocessed in this paper and were grouped in four main ratios types or site-effects patterns (Fig. 3a). These patterns have: *i*) specific resonance frequencies ranges (corresponding to 80% from H/V amplitude), with the following median values: $f_{r\mathrm{A}} = 2.6$ Hz, $f_{r\mathrm{B}} = 3.8$ Hz, $f_{r\mathrm{C}} = 6.6$ Hz) and ii) wide range of *H/V* ratios amplitude (A_{HV} = 1.5–4.5). To define this typology of HVSRN we used even A_{HV} values smaller than 2, recommended as the lower limit of a reliable *H/V* ratio [31]. We made this choice only in cases of very similar and clear shapes of HVSRN ellipticity (peaks and troughs) [12].

The 2D distribution of f_r and A_{HV} are presented in Fig. 3b.

The observed ellipticity may be related to the complexity of the stratification, impedance contrast and the velocity gradient. Thus, in the case of type A, the ellipticity is narrow, with a prominent trough controlled by a relative simple stratification of the sediments and a higher contrast of seismic impedance. For type B and C the ellipticity is wider and shifted to higher frequencies and have troughs with small amplitudes which could be explained by velocity gradient and the complexity of the lithological stratification.

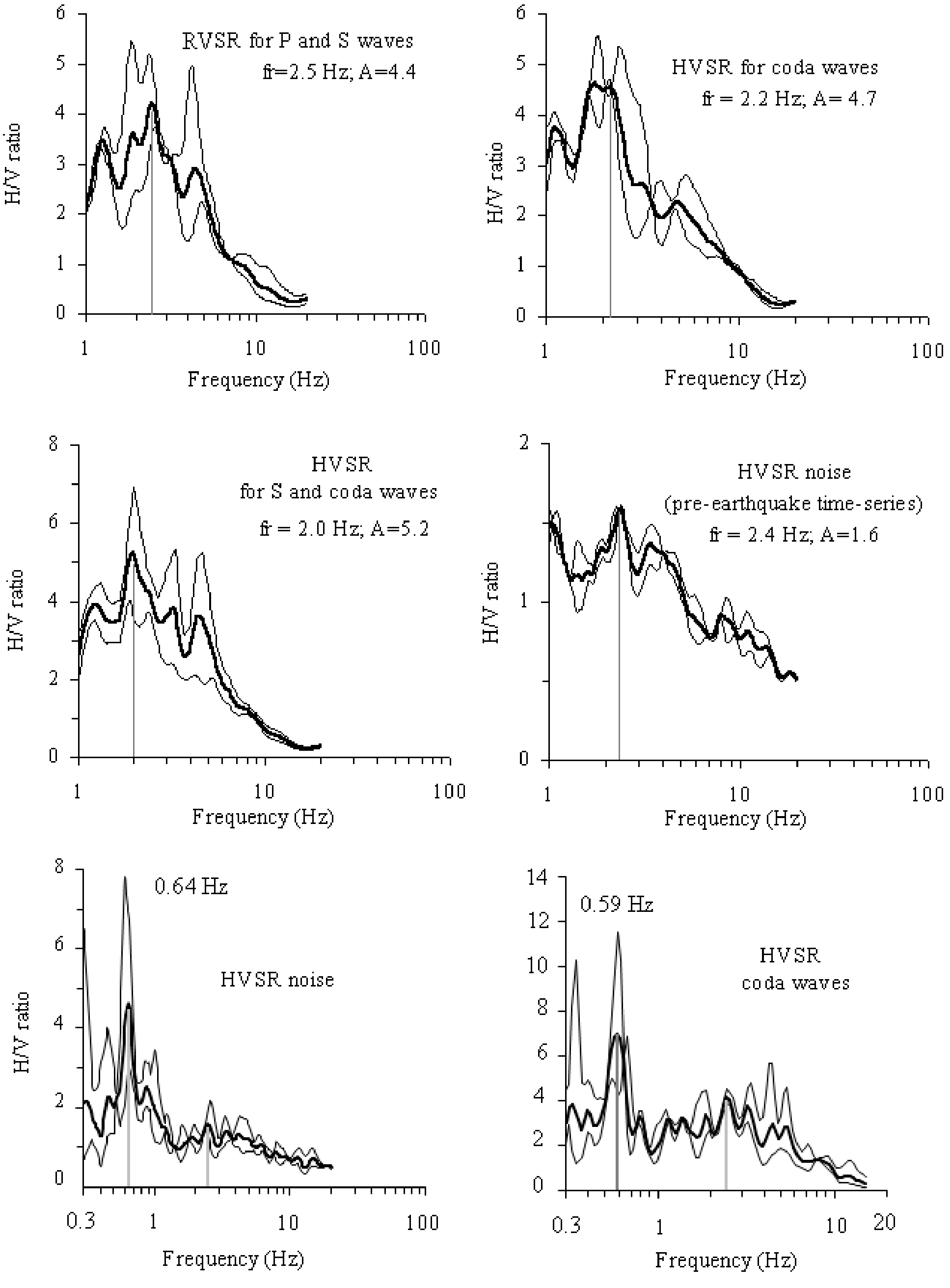

Fig. 2 – *H*/*V* spectral ratios computed for the 07 February, 2008 earthquake, recorded by TIM station and for the pre-event seismic noise time-series. Thick black line is the average ratio and the thin gray lines show the average ±1 S.D. interval. The thin vertical gray bars mark the resonance frequencies.

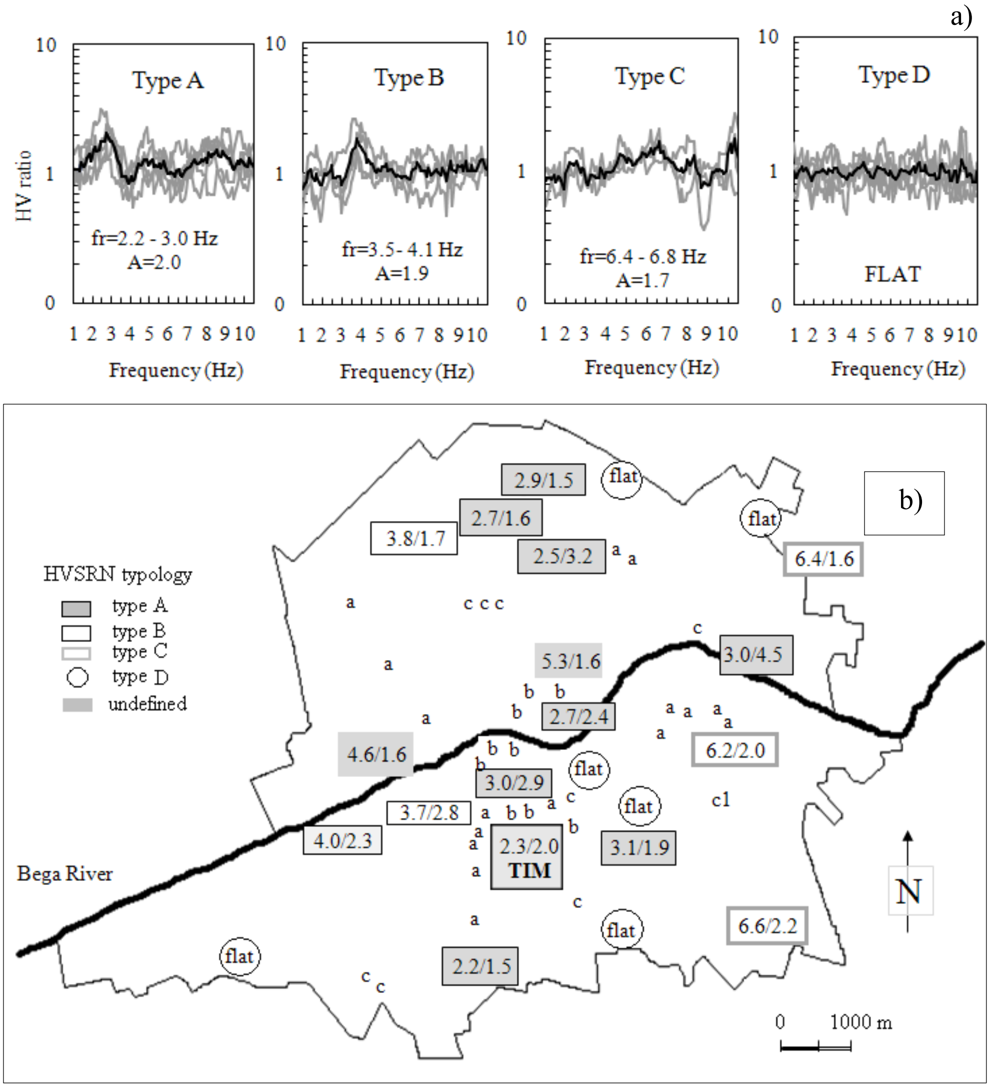

Fig. 3 – HVSRN typology in the city of Timisoara: a) main types of HVSRN with their specific range of *fr* and A_{HV}. Black line = average curve, grey lines = the individual spectral ratios; b) 2D distribution of the *fr* and A_{HV}, TIM = TIM seismic station, a, b, c = types of buildings with damages corresponding to $I = 5.5–6.0$ EMS degrees: a, b-masonries (b = 1 to 3 stories), c-buildings of reinforce concrete with 4–9 stories, c1- industrial halls of reinforce concrete.

Three approximately NS elongated zones can be roughly described in the map from Fig. 3b using the f_r parameter. This distribution seems to be controlled by local deeper geology because the geotechnical zoning shows an opposite pattern, with zones distributed almost parallel with the Bega River course, on a

NNE-SSW direction [2]. The A_{HV} spatial distribution displays an clear separation of a zone with $A_{\mathrm{HV}} > 2.0$ in the South of the city, near of Bega River. This general distribution can be comparable with some geological and geotechnical characteristics, like the depth of the table water, impedance contrast, thickness of the sedimentary layers, velocity anomalies, and so on. More investigations need this kind of microzonation.

Using the A_{HVSRN} values and the results of obtained by [12] we could estimate the relative site-amplification factor (A). For example, at TIM station site where more high quality data about f_r and A_{HV} derived from noise analysis exists for $f > 1.0$ Hz ($f_r = 2.3$ Hz, $A_{\mathrm{HV}} = 2.0$), by multiplying with the coefficient 2.5 from [12], we obtain $A = 5.0$. This value is similar to the mean A_{HV} value derived from P, S and coda waveforms of the 7 February, 2008 earthquake.

In addition, the Radial (R) and transversal (T) Fourier Spectra of four local earthquakes have been computed (Fig. 4). All these spectra generally expose several maxima at frequencies comparable with those determined by HVSR methods for TIM station site. Except the 23 May 2002, the other ones occurred toward WNW or ESE from TIM location and display peaks at higher frequencies, too ($f = 4.6$-5.1 Hz and even $f = 10.3$ Hz). This amplification at higher frequencies could be determined by the source (azimuth, depth, focal mechanisms) and path characteristics. For the 07 February, 2008 event ($M_w = 3.9$) a low frequency secondary peak can be observed at $f = 0.6$, which is the fundamental resonance frequency obtained by HVSR method.

According with [12, 20, 31] and using our results the site-effects in the location of TIM station could be first-order characterized by i) $A_{\min} = 4.0$ for $f = 0.6$; ii) $A_{\min} = 5$ for $f = 2.0$–3.0 ± 0.3 Hz/T=0.3–0.5 s.

The accelerations recorded in the western part of Timisoara during the 12.07.1991, $M = 5.7$ earthquake shows the following periods at the maximum accelerations: $T = 0.2$–0.3 s ($f = 3.3$–5.0 Hz). For the 02.12.1991, $M = 5.6$ earthquake the accelerogram started with $T = 0.8$ and continued with $T = 0.2$-0.3 s (Gioncu, personal communication).

The macroseismic observations gathered inside the city [22] generally correspond to I =V-VI EMS and I = VI EMS degree. These data are symbolized on the map from Fig. 3b with letters that also correspond to different types of the damaged buildings. The macroseismic effects corresponding to the intensity $I = 6$ EMS degrees were observed frequently at the masonries (up to 1-3 stories). It can be noticed from Fig. 3b and Fig. 5 that these buildings had their fundamental frequency [16] similar to that of the site-sediments column. The most damaged masonries concentrate in zones with spectral ratios of type A and B and within the areas where the greatest A_{HV} values have been observed (Fig. 3b).

Finally, taking into account an average velocity of about 300 km/sec and $f_r = 0.6$ Hz, the depth $h = 128$ m of the strong impedance contrast result. This value correlates very well with the average thickness of the Quaternary strata [19, 33].

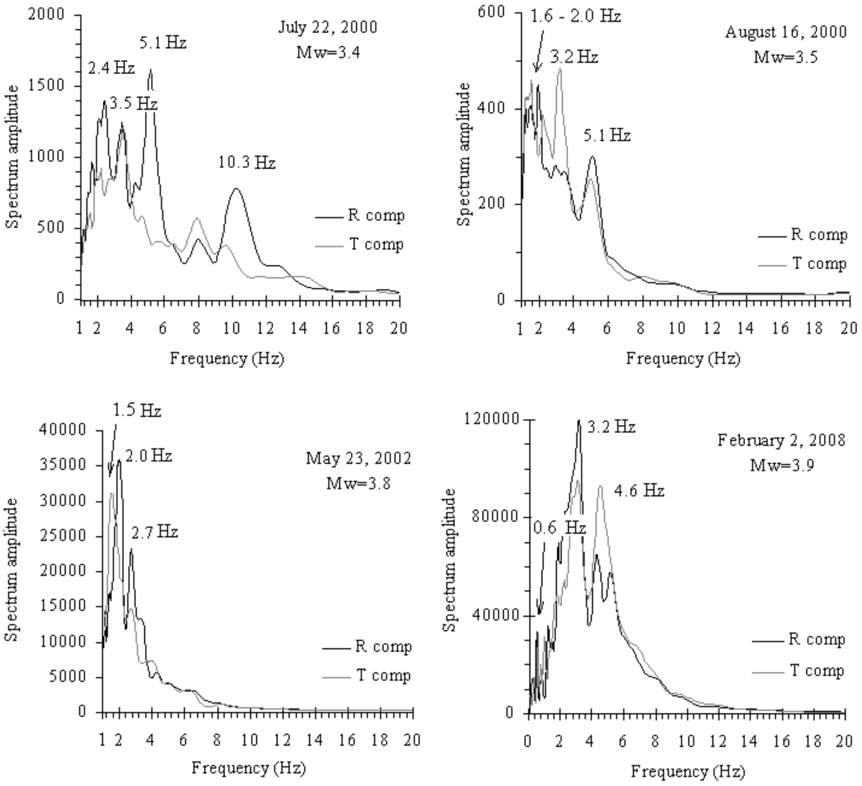

Fig. 4 – Radial (R) and Transversal (T) Fourier Spectra of four earthquakes recorded by Timisoara Seismic Station (TIM). The values of the predominant frequencies are noted explicitly.

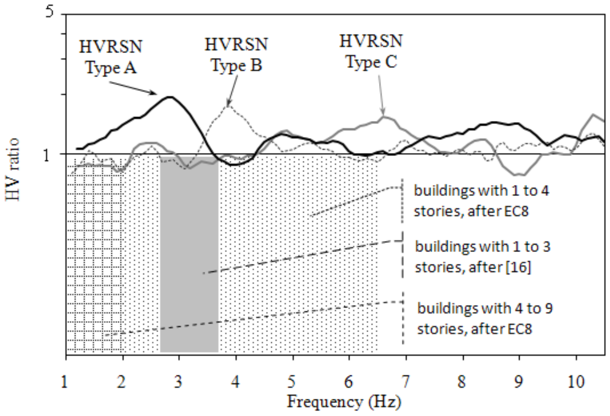

Fig. 5 – HVSRN mean types and their resonance frequencies f_r of the site-sediment columns *versus* the fundamental frequencies of the different types of buildings (after EC8 and [16]).

3. CONCLUSIONS

Two main resonance frequencies were obtained by HVSR investigation on ASN and local small earthquakes recorded at TIM seismic station: $f_{r1} = 0.6$ Hz and $f_{r2} = 2.3$ Hz. The first one correlates well with the depth of the Quaternary/ Pannonian limit, as it is estimated in [19, 33], being the fundamental resonance frequency in this site. The second f_r could be interpreted as another impedance limit at a few meters under the surface with potential for amplification of the ground motion at frequencies of engineering interest (Fig. 5).

Three approximately NS elongated zones can be roughly described in the map of the city (Fig. 3b) using HVSRN typology, defined at high frequencies ($f > 1.0$ Hz). The greatest amplitudes of HVSRN ($A_{HV} = 2.0$–4.5) roughly concentrate within zones defined by A and rarely B types of HVSRN, but especially at South of Bega River, in downtown. These A_{HV} values correlate well with damages (I=V-VIEMS) distribution in the city during the $M_w = 5.6$, 12 February, 1991 earthquake. The accelerograms recorded for this event show predominant frequency similar with f_r that was derived from HVSRN investigation.

Acknowledgment. The paper is a part of Ph thesis of the author. For all colleagues who support me in this work, especially prof.dr.ing. Gh. Mărmureanu, dr. Mihaela Popa and N. Mandrescu I have special thanks.

REFERENCES

1. Aki K., *A note on the use of microseisms in determining the shallow structures of the earth's crust*, Geophysics, **30**, 665 (1965).
2. Anastasescu D., Gadea A., *Antiseismic protection and the reabilitating of the existing building in Timisoara*, Bull. Agir, **4**, 46–50, (2000).
3. Bonnefoy-Claudet S., Cornou C., Bard P. Y., Cotton F., Moczo P., Kristek J., Faeh D., *H/V ratio: a tool for site effects evaluation. Results from 1-D noise simulations*, Geophys. J. Int., **167**, 827–837, doi: 10.1111/j.1365-246X.2006.03154.x (2006).
4. Bonnefoy-Claudet S., Köhler A., Cornou C., Wathelet M., Bard P. Y., *Effects of Love Waves on Microtremor H/V Ratio*, Bull. Seism. Soc. Am., **98**, *1*, 288–300 (2008), doi:10.1785/0120070063.
5. Bonilla L. F., Steidl J. H., Lindley G. T., Tumarkin A. G., Archuleta R. J., *Site amplification in the San Fernando Valley, California: variability of site effect estimation using S-wave, coda, and H/V methods*, Bull. Seism. Soc. Am., **87**, 710–730 (1997).
6. Boore D., *Can site response be predicted?* Journal of Earthquake Engineering, **8**, Special Issue 1 1–41 (2004).
7. Castro R. R. and RESNOM Working Group, *P- and S-wave site response of the seismic network RESNOM determined from earthquakes of northern Baja California, Mexico*, Pure Appl. Geophys., **1052**, 125–138 (1998).
8. Field E. H., Jacob K. T. Y., *A comparison and test of various site response estimation techniques, including three that are non-reference-site dependent*, Bull. Seism.Soc.Am., **85**, 1127–1143 (1995).
9. Gueguen P., Cornou C., Garambois S., Banton J., *On the Limitation of the H/V Spectral Ratio Using Seismic Noise*, Pure appl. geophys., **164**, 115–1340033–4553/07/010115–20 (2007), doi: 10.1007/s00024-006-0151-x.

10. Horike M., Boming Zhao B., Kawase H., *Comparison of Site Response Characteristics Inferred from Microtremors and Earthquake Shear Waves*, Bull. Seism. Soc.Am., **91**, *6*, 1526–1536 (2001).
11. Ibs-von Seht M., Wohlenberg J., *Microtremor Measurements Used to Map Thickness of Soft Sediments. Bull*, Seism. Soc. Am., **89**, *1*, 250-259 (1999).
12. Konno K., Ohmachi T., *Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor*, Bull. Seism. Soc. Am., **88**, 228–241 (1998).
13. Lachet C., Hatzfeld D., Bard P. Y., Teodulidis N., Papaioannou C., Savvidis A., *Site effects and microzonation in the city of Thessaloniki (Grece). Comparison of different approaches*, Bull. Seism. Soc. Am., **86**, *6*, 1692–1703 (1996).
14. Langston C., Corvallis A., *Oregon, crustal and upper mantle receiver structure from teleseismic P and S waves*, Bull. Seism. Soc. Am. **67**, 713–724 (1977).
15. Lermo J. F., Chavez Garcia F. J., *Site effects evaluation using spectral ratios with only one station*, Bull. Seis. Soc. Am. **73**, 1574–1594 (1993).
16. Lungu D., Cornea T., Aldea A., Arion C., *Risck, vulnerability and seismic hazard generate by Vrancea source in Romania*, (in Romanian), 2nd Conference of Seismic Enigeneering, Bucharest, 8–9 Nov., 2001, Vol. **1**, pp. 33–72.
17. Mândrescu N., Hlevca A., Raileanu V., Pompilian A., Oros E., *Data concerning the microzonation of the city of Timisoara* (in Romanian), Internal Raport NIEP, 1989.
18. Milne, J. Seismology. Kegan Paul, Trench, Trubner, & Co., London, st ed., 1898.
19. Mutihac V., Ionesi L., *Goelogy of Romania* (in Romanian), Technical Press, Bucharest, 1982.
20. Nakamura Y., *A method for dynamic characteristics estimation of subsurface using ambient noise on the ground surface*, QR Railway Tech. Res. Inst., **30**, 25–33 (1989).
21. Oros E., Nitoiu L., *Considerations on seismic microzonation of the city of Timisoara* (in Romanian), Internal Raport NIEP, 1993.
22. Oros E., *Ambient seismic noise measurements in Timisoara city (Romania) – Preliminary results about soil's predominant frequencies*, Vol. of Abstr. European Geophysical Society, the 27th General Assembly, Nice, France, 21–26 April 2002. Paper ES02-A-06635, 2002.
23. Oros E., *Banat Seismic Network (Romania). Evolution and performances*, St. Cerc., Geofizica, **41**, pp.112–125 (2003).
24. Oros E., Popa M., Moldovan I. A., *Seismological Data-Base for Banat Seismic Region (Romania) - Part 1: The Parametric Earthquake Catalogue*, Romanian Journal of Physics, **53**, *7–8*, (2008).
25. Oros E., *Review of Historical Seismicity in the western and south-western territory of Romania (Banat Seismic Region)*, Acta Geodaetica et Geofisica Hungarica, **43**, *2–3*, 153–161 (2008).
26. Pascu M. R., *Underground waters in Romania* (in Romanian), Technical Press, Bucharest, 1984.
27. Picozzi M., Parolai S., Albarello D., *Statistical Analysis of Noise Horizontal-to-Vertical Spectral Ratios (HVSR)*, Bull. Seism. Soc. Am., **95**, *5*, 1779–1786 (2005), doi: 10.1785/ 0120040152.
28. Rautian T. G., Khalturin V. I., *The use of coda for determination of the earthquake source spectrum*, Bull Seism. Soc. Am., **68**, 923–948 (1978).
29. Seekins L. C., Wennerberg L., Margheriti L., Hsi-Ping Liu, *Site Amplification at Five Locations in San Francisco, California: A Comparison of S Waves, Codas, and Micro tremors*. Bull. Seism. Soc. Am., **86**, 3, pp. 627–635 (1996).
30. Satoh T., Kawase H., Matsushima S., *Differences Between Site Characteristics Obtained From Microtremors, S-waves, P-waves, and Codas*, Bull. Seism. Soc. Am., **91**, *2*, pp. 313–334 (2001).
31. *** *Site Effects assessment using ambient excitations*, SESAME Project (2001–2004), http://sesame-fp5.obs.ujfgrenoble.fr.
32. Triantafyllidis S P., Hatzidimitriou P. M., Theodulidis M., Suhadolc P., Papazachos C., Raptakis D., Lontzetidis K., *Site effects in the city of Thessaloniki estimated from acceleration data and 1D local soil profiles*, Bull. Seism. Soc. Am. **89**, 521–537 (1999).
33. Uruioc S., *Mineralogy and Petrology of soils from Central and Northen zone of Banat* (in Romanian), University Press Timisoara, 2002.
34. Visarion M., Polonic P., Ali-Mehmed E., *Contribuţii geofizice la cunoaşterea structurii sectorului Nord-Estic al D. Panonice şi a unităţilor limitrofe*, Stud. tehn. ec., D, **12**, 45–57, Bucureşti, 1979.