

H/V Spectral Ratios Technique Application in the City of Bucharest: Can We Get Rid of Source Effect?

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ABSTRACT: *The main issue of this paper is to show that contrary to many examples of monitored strong earthquakes in different urban areas, the intensity and spectral characteristics of the strong ground motion induced in Bucharest area, by Vrancea intermediate-depth earthquakes, is controlled by the coupled source-site properties rather than by the local site conditions alone. Our results have important implications on the strategy to follow when assessing the seismic microzoning for Bucharest city: we recommend the application of deterministic approaches rather than empirical techniques, like H/V spectral ratios. However, when applied to noise data, the H/V spectral technique succeeds to reproduce the predominant frequency response characteristic for the sedimentary cover beneath the city and the relatively uniform distribution of this structure over the city area. The same technique is clearly inadequate when small earthquakes are considered and our results strongly disagree with any strategy of extrapolation from small and moderate earthquakes to strong earthquakes for microzoning purposes.*

Keywords: Seismic microzonation; Spectral ratio method; Deterministic approach; Bucharest; Vrancea earthquakes

1. Introduction

Although situated relatively far away from the Vrancea seismic source (a peculiar intermediate-depth nest of earthquakes, located in a narrow volume beneath South-Eastern Carpathians, in Romania), the Bucharest metropolitan area is one of the most vulnerable urban areas in the world to the earthquake impact. For example, the earthquake of 4 March 1977 ($M_w = 7.4$), occurred in Vrancea seismic source at 94km of depth and at 170km epicentral distance from Bucharest, caused the collapse of 32 buildings of 8-12 storeys in the town, while about 150 old buildings of 6-9 storeys were strongly damaged, as well as many of them requiring subsequent demolition. The collapse of the tall buildings was, initially, attributed to the coincidence of their fundamental period of free vibration (1-1.5s) with the resonance period of the entire succession of

the Quaternary unconsolidated deposits, underlying the Bucharest urban area, excited by the seismic motion generated by the Vrancea shock.

At present, the debate among seismologists and civil engineers about which of the two key factors, source or surface geology, prevails in controlling the ground motion intensity in Bucharest area is still open. Certainly, an answer based on ground motion computation using physical laws rather than empirical techniques, like H/V spectral ratios or array techniques, based on noise or small earthquake analysis, would be preferable. It is also on account of the possible non-linear behaviour of the unconsolidated (clay) deposits that can explain the variability of the site amplification functions when considering weak- and strong-motion records [24]. However, the computation of the complete wavefield requires a

priori knowledge of a complex system of parameters, which makes this task very difficult in general.

Most of the studies focused on the seismic microzonation of Bucharest (e.g. [5, 23]) are based on the key hypothesis that has not yet reached a general scientific consensus (e.g. [1, 2, 10, 21, 26]): microseismic noise and moderate-to-low seismicity is satisfactorily representative of the site response characteristics expected for the large earthquakes. Though based on rather simple source and structure modelling, the numerical simulation of the strong ground motion in Bucharest for Vrancea earthquakes by deterministic approach [16-18] drew attention on the crucial role played by the particular source-path pattern: the modelling showed that the ground motion characteristics can strongly vary with changing source parameters, even if the geometry and physical properties of the medium between the focus and the site remain practically the same.

The proper answer to the question “are site amplification effects really the only features controlling strong ground motion records in Bucharest?” is crucial for the sound seismic

microzonation of the town, since the cheap approaches, based on the empirical analysis of easily accessible ambient noise recordings (H/V spectral ratios technique, array techniques), are generally preferred to the more complex approaches based on numerical simulation of the expected ground motion.

The purpose of the present paper is to check the validity and relevance of the H/V spectral ratios technique in the particular case of Bucharest area. This endeavour is essential and imperative since considerable efforts have been recently made to solve the problem of microzonation in Bucharest using a large data set of noise and moderate-to-low seismicity records obtained from 32 broadband stations that operated for 9 months within the Urban Seismology experiment [22]. As we shall demonstrate in the case of Bucharest city, the H/V spectral ratios analysis is irrelevant without a careful interpretation of what we know about strong ground motion (observed and modelled) characteristics.

2. Local Structure Setting

Bucharest city, see Figure (1) is situated in the

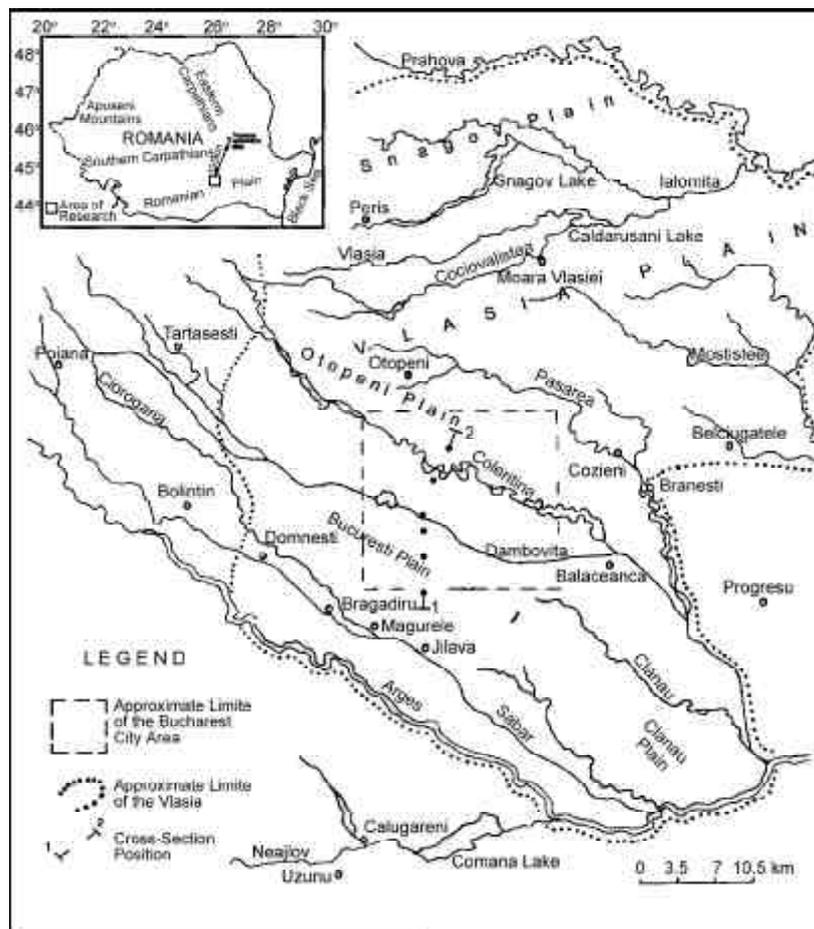


Figure 1. Location of Bucharest city area (marked by the rectangle area) and Vrancea epicentral zone (reverse triangle).

Romanian Plain, along the roughly parallel valleys of Dambovitza and Colentina rivers. From the geological point of view, the town is located in the central part of the Moesian Platform, at an average epicentral distance of 160km from the Vrancea region. Topographically, the city is built on a plain slightly dipping towards southeast, following the direction of the Dambovitza and Colentina rivers, which divides the city into several morphological units, see Figure (2): Dambovitza-Colentina interstream, Baneasa-Pantelimon Plain, Cotroceni-Vacaresti Plain, and the meadows along the above-mentioned rivers. The hydrostatic level ranges between 1 and 5m in Dambovitza and Colentina meadows, between 5 and 10m in the Dambovitza-Colentina interstream, and below 10m in the Cotroceni-Vacaresti and Baneasa-Pantelimon plains.

Lithological information has been compiled from geological, geotechnical and hydrogeological boreholes. The synthesis of the geological data available for Bucharest area was firstly presented by Liteanu [11] and then by others, e.g., Măndrescu and Radulian [14], and Lungu et al [12]. The lithological

succession from the bottom upwards for the Lower and Upper Quaternary deposits [15] is characterized by the so-called, 'Fratesi layers', overlaid by marl complex and finally the Mostistea sands'.

The Fratesi complex consists of three layers of sand and gravel, designed as A (upper layer), B (middle layer) and C (lower layer), separated by two intercalated layers of clay, see Figure (3). The layers have a similar structure, with coarse sands and gravel at the bottom, and medium-fine sands transforming gradually to clays in the upper part. The entire complex is gently dipping from south to north and becomes thicker along the same direction, see Figure (3).

The next structural unit of the sedimentary deposit, overlying the Fratesi layers, is the marl complex, represented through a succession of marl and clay, sometimes sandy marl with intercalation of fine sands (Middle Pleistocene). The rocks composing the marl complex correspond from the granulometric point of view to some lacustrine formations, placed beneath shallow faces in which the determinant material was represented by pelitic fraction. The marl complex has

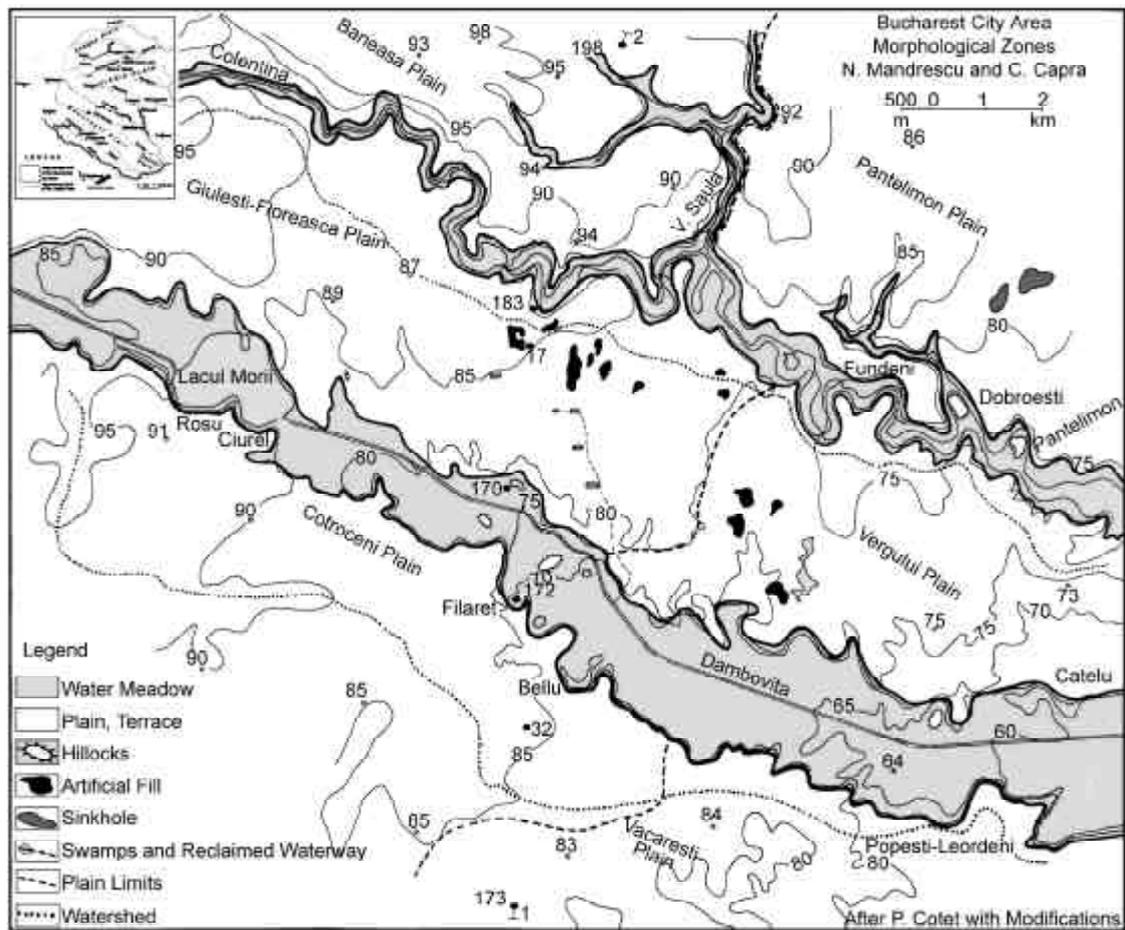


Figure 2. Morphological zones in the Bucharest city area, as delimited in Figure (1).

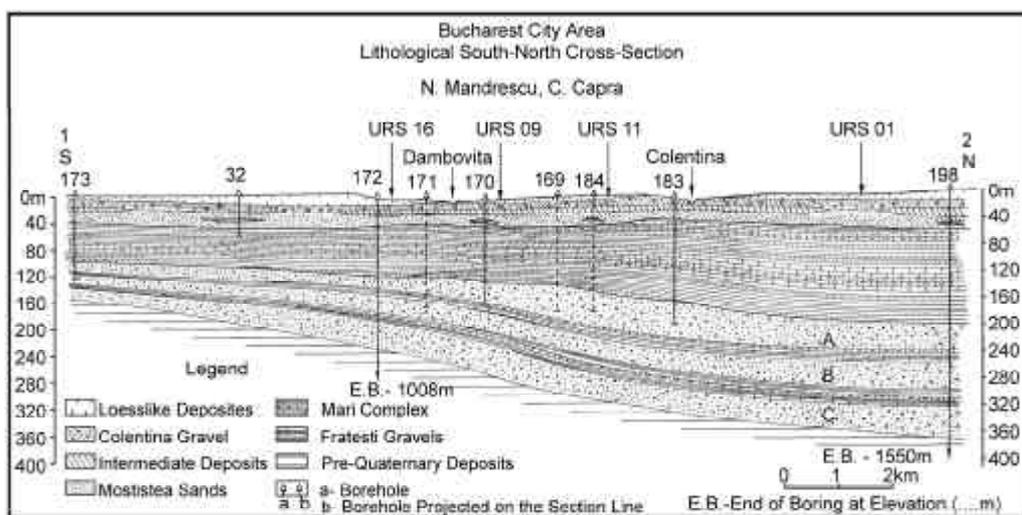


Figure 3. Lithological South-North vertical cross section across (section 1-2 in Figure (1)) Bucharest area. The spectral ratios for the four URS stations represented in the figure are given as examples in Figure (4).

a thickness of 47-130m with an average velocity of S-wave of 0.420km/s. The complex undergoes a slight descend from south to north, accompanied by an increase of the deposits thickness in the same direction, see Figure (3).

The upper part of the marl complex is continuously covered by a bank of sands (Mostistea sands) with a general thickness of 10-15m (Upper Pleistocene). The average velocity of S-wave propagation is between 0.274 and 0.371km/s.

The complete succession of Pliocene and Quaternary deposits to the top of the Upper Pleistocene shows that the whole region was affected permanently by negative vertical movements. The predominant periods of oscillation, T , of the subsurface layers over Bucharest territory, computed introducing in the simple relation $T = 4h/\beta$, where β is the S-wave velocity and h the layer thickness. The available borehole data range between 1.0 and 1.9s, and increase from south to north, as a consequence of the constant increase of the thickness of the Quaternary cohesionless deposits [13, 15].

3. Application of H/V Spectral Ratios Technique

An experiment of recording seismic noise deployed 16 recording sites in the Bucharest area, starting September until November in 1997 [5]. At each site, the signal has been recorded with three-component 2-Hz Mark Products velocity sensors for at least 30 minutes. The sites were selected to be adjacent to boreholes with drilling reaching the bedrock, i.e. to sites with precisely known thickness of the sedimentary cover. Recently, within the URS (Urban

Seismology) project, carried out by the Collaborative Research Center 461 "Strong Earthquakes" of Karlsruhe University and the National Institute for Earth Physics of Bucharest, 32 broadband stations operated between October 2003 and August 2004 [22]. The full processing of the impressive data set collected during the experiment is presently in progress.

The application of Nakamura technique ([19] to estimate H/V spectral ratios from the data of 1997 experiment shows that with the exception of one site, the predominant peak is relatively stable within the period in the range from 1 to 2 seconds, with an average of 1.4s, interpreted as a broad and stable soil resonance. In the simple horizontal layer resonance interpretation ($T = 4h/\beta$), a resonance peak around 1.4s could correspond to a $\sim 120m$ thick layer of unconsolidated sediments, with a shear wave velocity $V_s \sim 0.35km/s$. The spatial variation of the resonance period at the measurement sites varies in the range from 1.15s to 1.60s, with no correlation with the variation of the thickness of the sedimentary cover indicated by geological data (shift towards lower frequencies from S to N).

The same technique was applied to the data recorded in the URS experiment and our analysis confirms the previous results. Examples of H/V spectral ratios for several sites in Bucharest are given in Figure (4). A prominent peak response in the period range from 1s to 2s is visible in all cases, independently from the particular location of the site. These results do not contradict the general uniform subsoil structure beneath the city area described in the local structure setting section. In addition, since the sites selected in Figure (4) are aligned roughly on

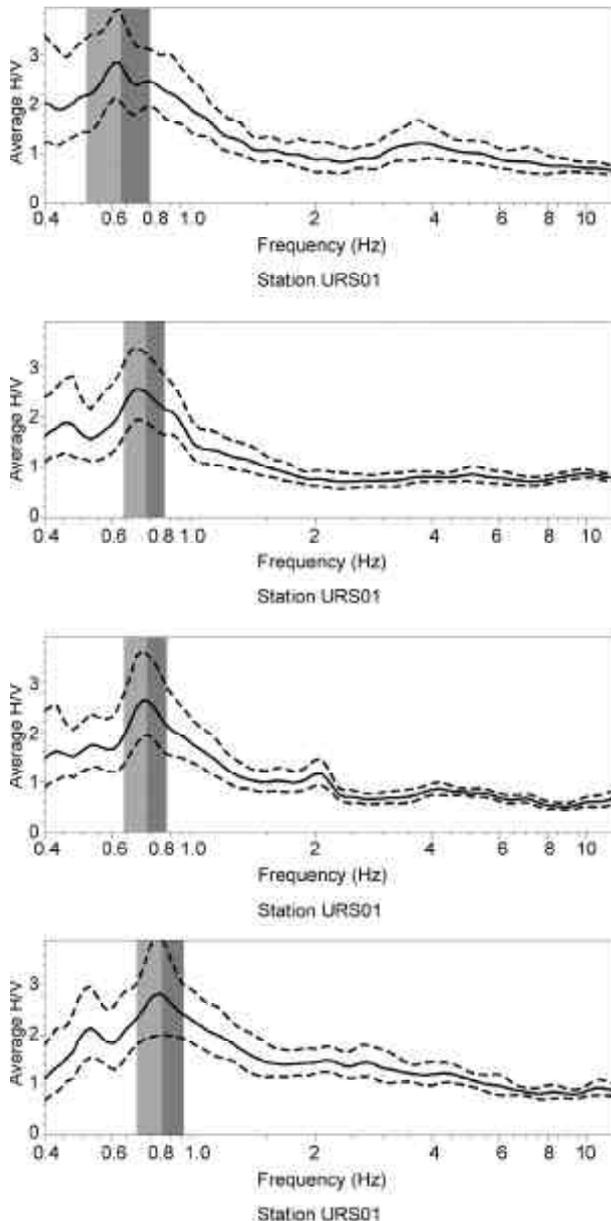


Figure 4. H/V spectral ratios for the ambient noise recorded in different sites in Bucharest area during URS experiment.

a N-S direction, a gradual decrease of predominant frequency (increase of the prominent period) from south to north in correlation with the slight increase of the sedimentary deposit thickness in the same direction can be noticed.

In a next step, the *H/V* spectral ratio method was applied to earthquakes in order to test if the results obtained in such a way come close to the results obtained using ambient noise. Certainly, in this case, the source information and the geometry of the problem are significantly different as compared with the noise case. The earthquakes are located at intermediate depths (91-154km) in a confined volume located at about 160km epicentral distance from Bucharest city, see Figure (1) and Table (1). The fault plane solutions are given in Table (2) and represented in Figure (5). They show reverse faulting processes that are characteristic for Vrancea intermediate-depth seismicity. The solutions for the largest shocks (1977, 1986 and 1990) are close to each other, while some variations are noticed for the smaller events. In all cases, the radiation patterns indicate rather similar behaviour of the radial and transversal components.

Let us first look at the results of the *H/V* analysis applied to ambient noise and to different size Vrancea earthquakes, recorded with a Lennartz *LE-3D/5s* digital instrument at the *INC* station, the only site which has recorded all the strong Vrancea earthquakes since 1977 event. The horizontal component *H* of the ratio is the spectrum of the resultant of the two horizontal components or the spectrum of the maximum horizontal component. The representation of *H/V* for the ambient noise, computed as average for 10 windows of 30min. each, selected at different day times, is given in Figure (6). Two distinct peaks

Table 1. List of the selected earthquakes with recordings available at INCERC station. S/N ratio is computed for 1 Hz when noise window before P arrival is available (nor possible for SMAC-B instruments).

No.	Date	Time	Lat. (°N)	Lon. (°E)	Depth (km)	Epicentral Distance (km)	M _w	S/N Ratio	PGA EW Comp.	PGA NS Comp.
1	1977/03/04	19:21	45.77	26.76	94	155	7.4	-	163.1	194.9
2	1986/08/30	21:28	45.52	26.49	131	123	7.1	-	88.7	95.3
3	1990/05/30	10:40	45.83	26.89	91	165	6.9	-	76.6	98.7
4	30/12/1997	04:39	45.54	26.32	139	123	4.6	43	2.6	2.6
5	19/01/1998	00:53	45.64	26.67	105	139	4.0	7	0.3	0.5
6	28/04/1999	08:47	45.49	26.27	151	117	5.3	510	8.3	16.6
7	04/03/2001	15:38	45.51	26.24	154	119	4.8	110	3.2	3.0
8	27/10/2004	20:34	45.84	26.63	105	160	6.0	1535	23.7	22.0

Table 2. Fault plane solutions for the earthquakes of Table (1).

No.	Plane A			Plane B			P-axis		B-axis		T-axis		No Polarities
	az.	dip	slip	az.	dip	slip	az.	pl.	az.	pl.	az.	pl.	
1	220	70	98	17	22	68	303	23	37	8	144	65	60
2	235	65	83	73	24	106	330	20	238	7	131	69	232
3	236	63	101	33	29	70	318	17	51	9	168	70	133
4	254	45	117	30	51	66	146	3	55	18	245	71	26
5	46	79	123	153	35	20	111	26	219	33	350	46	26
6	201	68	67	70	31	134	308	20	210	21	77	60	33
7	327	75	93	136	15	79	55	30	147	3	241	60	26
8	239	88	96	347	6	18	324	43	59	6	155	47	38

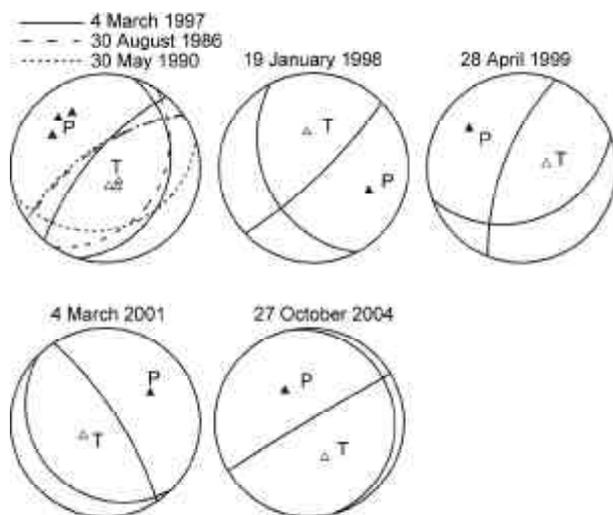


Figure 5. Fault plane solutions of the study earthquakes of Table (1).

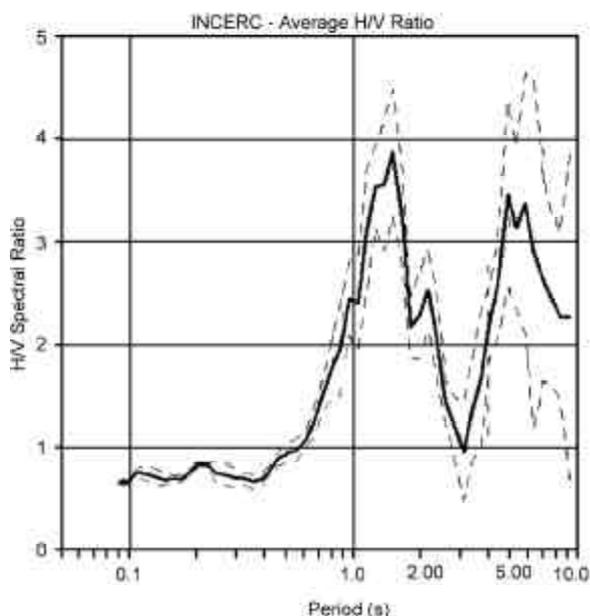


Figure 6. H/V spectral ratios for the ambient noise recorded at INCERC station. Solid line: average of 10 windows; dashed lines: \pm standard deviation.

are visible, one centred between 1s and 2s, the other centred between 5s and 7s. Stationarity tests (using different time intervals during one day) show that the period band and amplitude of the peaks are stable. The distribution of the H/V ratios is quite close to the result obtained by Bonjer et al [5]- see diagram for site 16 in their Figure (2). The peak in the 1-2s period band roughly agrees with the one dimensional resonance period of the sedimentary cover.

To identify possible source effects, as examples, the different size Vrancea earthquakes listed in Table (1) were selected. The associated H/V spectral ratios estimated using the recordings at INCERC station are plotted in Figure (7). The shape of the H/V ratios changes significantly from one event to another. For the largest earthquake (March 1977), a prominent and remarkably confined peak around 1.5s is observed and it coincides with the first peak shown in Figure (6). For the two events with magnitude around 7 (August 1986 and 30 May 1990), the dominating peaks occur at 2.3s and 1s, respectively, thus not matching the prediction based on noise analysis. As shown above, the focal mechanism characteristics seem not to influence the spectral ratios significantly. A better agreement with noise-based predictions is obtained with the smallest earthquakes (January 1998 and March 2001), even though some differences in the amplitude level are observed. The peak around 5s is well seen in the ambient noise case, see Figure (6) and for the smallest, $M=4.0$, earthquake, see Figure (7), but it is not seen in the case of the stronger signals. The noise measurements were performed with a Lennartz ($LE-3D/ 5s$) sensor, which performs satisfactorily well down to 0.2Hz, while the accelerometers are unstable and very poor at low frequencies (SESAME project report, 2001-www.obs.ujfgrenoble.fr). Therefore, any analysis above 5s is

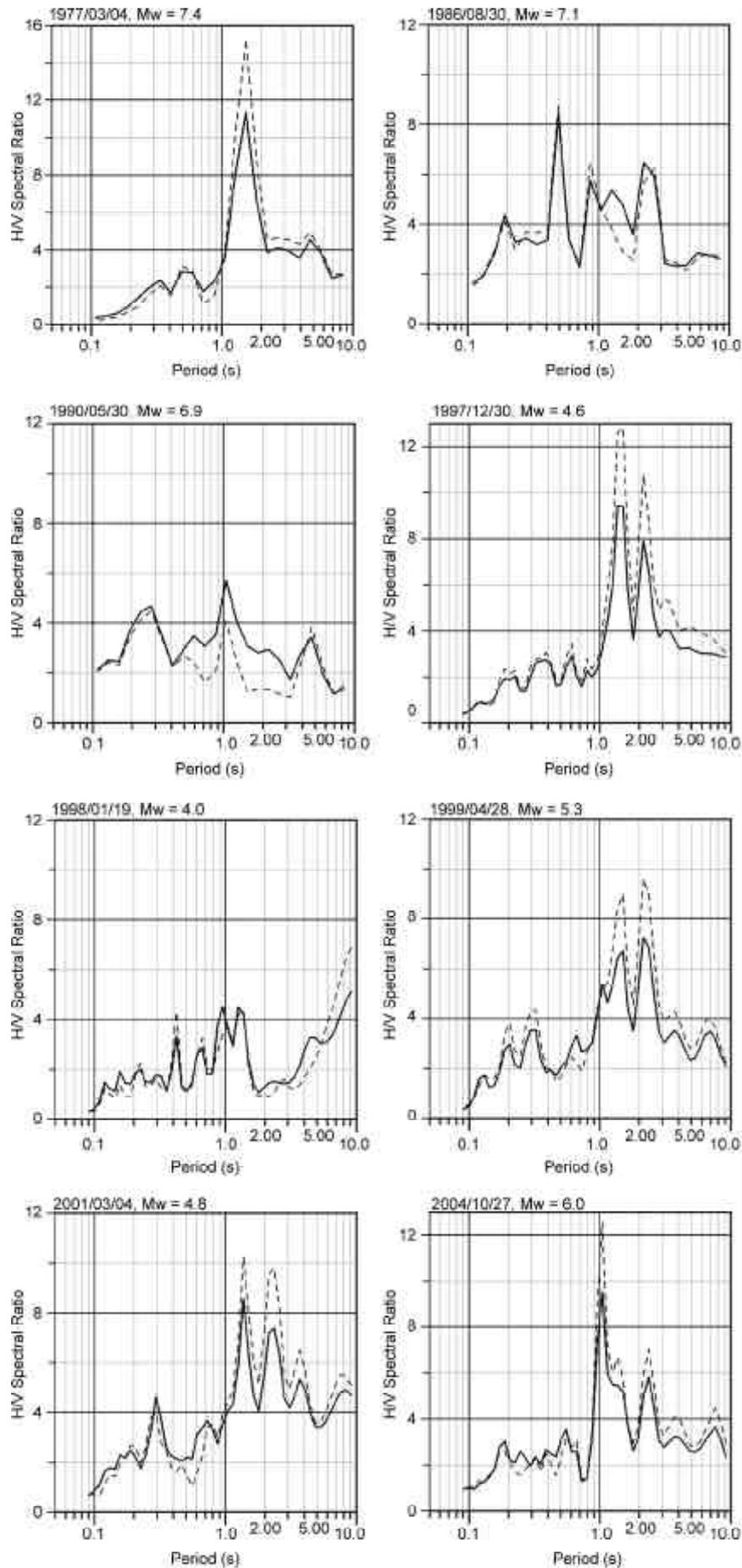


Figure 7. H/V spectral ratios for the study earthquakes (see Table 1) recorded at INCERC station. Solid line taking H as the resultant of the horizontal components; dashed line taking H as the maximum among the horizontal components.

doubtful for earthquakes, due to instrumental noise (decrease of the amplitude of the seismic signal recorded by accelerometer sensors towards the electronic noise level of the acquisition system with increasing period). In these circumstances, we prefer in the subsequent discussions to limit our attention to periods below 3s.

There is no real consensus until now about the physical meaning of the H/V technique and the proportion between body waves and surface waves in the H/V spectral ratios. However, for the relatively large-scale shallow structure characteristic for the Bucharest area, a plausible physical meaning of the H/V technique is directly related to the ellipticity curve of Rayleigh waves and its efficiency relies on its ability to identify the fundamental frequency of the soft soils, since the vertical component of Rayleigh wave motion systematically vanishes around the fundamental S-wave resonance frequency. While for ambient noise, the H/V ratios concern essentially the surface waves, in the case of the deep Vrancea events, they refer mainly to body waves. Moreover, the incidence angle of the waves strongly differs in the case of noise as compared with the case of earthquakes. Therefore, the comparison between the H/V ratios for ambient noise, see Figure (6) versus earthquakes, and Figure (7), is not straightforward and should be done with much care. One of the main results that come out from our analysis shows that the application of H/V technique using Vrancea earthquakes appears to be less useful than using ambient noise measurement.

If we look at the absolute Fourier spectra, the results are completely different for earthquakes below and above magnitude 7: the amplitude in the period range from 1s to 2s is practically negligible in the case of small and moderate earthquakes, and it becomes progressively more important as the magnitude increases, as can be seen in Figure (8). The resonant amplification (period) by the sedimentary cover is visible only for the largest earthquakes ($M > 7$), i.e. when the source radiates also at periods coinciding with the fundamental resonance range of the sedimentary cover, and it clearly depends on magnitude ($\sim 1.6s$ for $M_w 7.4$ event, $\sim 1.3s$ for $M_w 7.1$ event, $\sim 1.2s$ for $M_w 6.9$ event and $\sim 1.0s$ for $M_w 6.0$ event). This result supports the idea that the source size (MW) controls the ground motion characteristics in Bucharest area, the sedimentary layer response being a secondary effect, which becomes relevant only if properly excited by the seismic source. The dependence of the frequency content of the seismic

ground motion on earthquake magnitude is also revealed by the deterministic microzoning analysis [7].

The dependence on magnitude of the ground motion spectral shape and H/V ratios can in principle be due not only to source effects, but also to variations in the incidence angles and non-linear behaviour of soils during strong shaking. The fluctuations of the incidence angle should not be important, having in mind the focus-site geometry. The non-linear effects could be important and they can have some contribution in the change of spectral shapes, but we feel more reasonable, due to the very small strain induced by Vrancea events in Bucharest, to invoke the coincidence of the source predominant frequency with the resonant frequency response of the sedimentary layer beneath the city, as the main factor.

It can be assumed that the source radiation control upon the shape of the H/V ratios become less important for the small size earthquakes. To test this hypothesis, the spectral ratios computed for noise windows were recorded just before the P-wave arrivals were compared with the spectral ratios computed from the records of the smallest earthquakes (19/01/1998 $M_w = 4.0$ and 30/12/1997 $M_w = 4.6$) of our selection in Figure (9). Most of the peaks in the H/V ratios can be associated to noise contribution (since for these earthquakes the seismic radiation is negligible above 1s), although some source influence is still noticeable, as secondary peaks around 0.4s for the 1998 event and around 0.3s for the 1997 event, in agreement with the source scaling laws for Vrancea subcrustal sources (e.g., [9]). Despite the fluctuations and difference in amplification, in all cases the spectral ratios using noise and earthquake windows suggest the presence of a peak within the 1-2s range, close to the average 1.4s resonance period determined from microseisms, see Figure (6).

The major implication of our analysis-the progressive source radiation control upon the shape of the H/V ratios as the earthquake magnitude increases-is in agreement with the numerical simulation of the strong ground motion in Bucharest for Vrancea earthquakes made by the deterministic approach [16-18]. This is in agreement with the observed damage distribution, that the characteristics of the observed motion change significantly when source parameters change, while the geometry and structure of the medium between the focus and the site is practically the same. From this point of view, those site amplification effects separate from source effects can not be considered.

4. Site Versus Source Effects

As shown above, the site effects due to the local geology in the Bucharest area are effects of second order in comparison with the source effects: the period of the peaks in the H/V ratios changes for

different earthquakes: therefore the H/V ratio technique is not efficient in removing the source effects for our study case. For sufficiently small earthquakes, when the signal/noise ratio is low, the source effect is much less visible than for the larger events. As a consequence the use of moderate

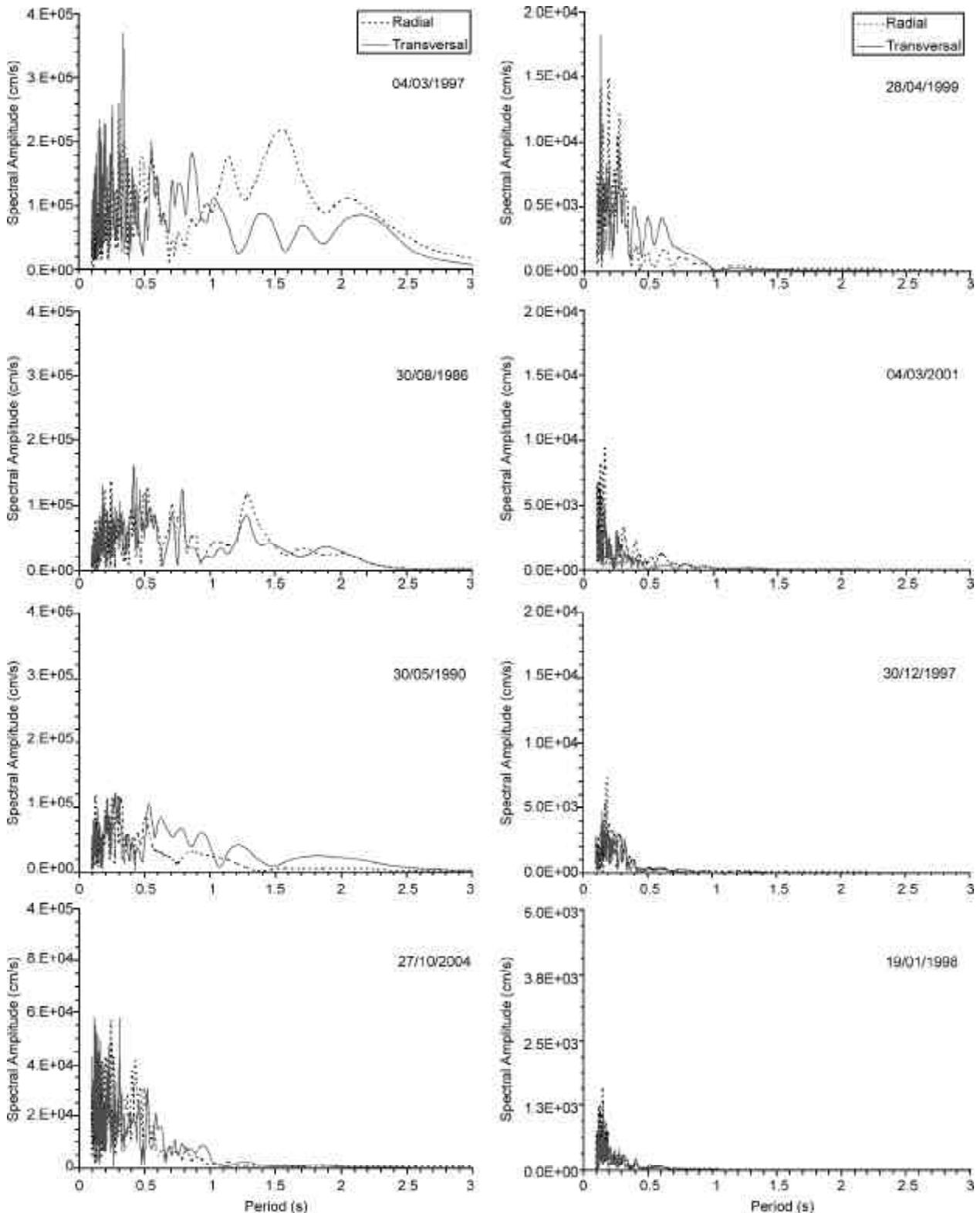


Figure 8. Fourier amplitude spectra of S-wave radial and transversal components, for the study earthquakes, see Table (1) recorded at INCERC station. Note that for the events of 27 October 2004 and 19 January 1998, the vertical scale is amplified by a factor of 4.

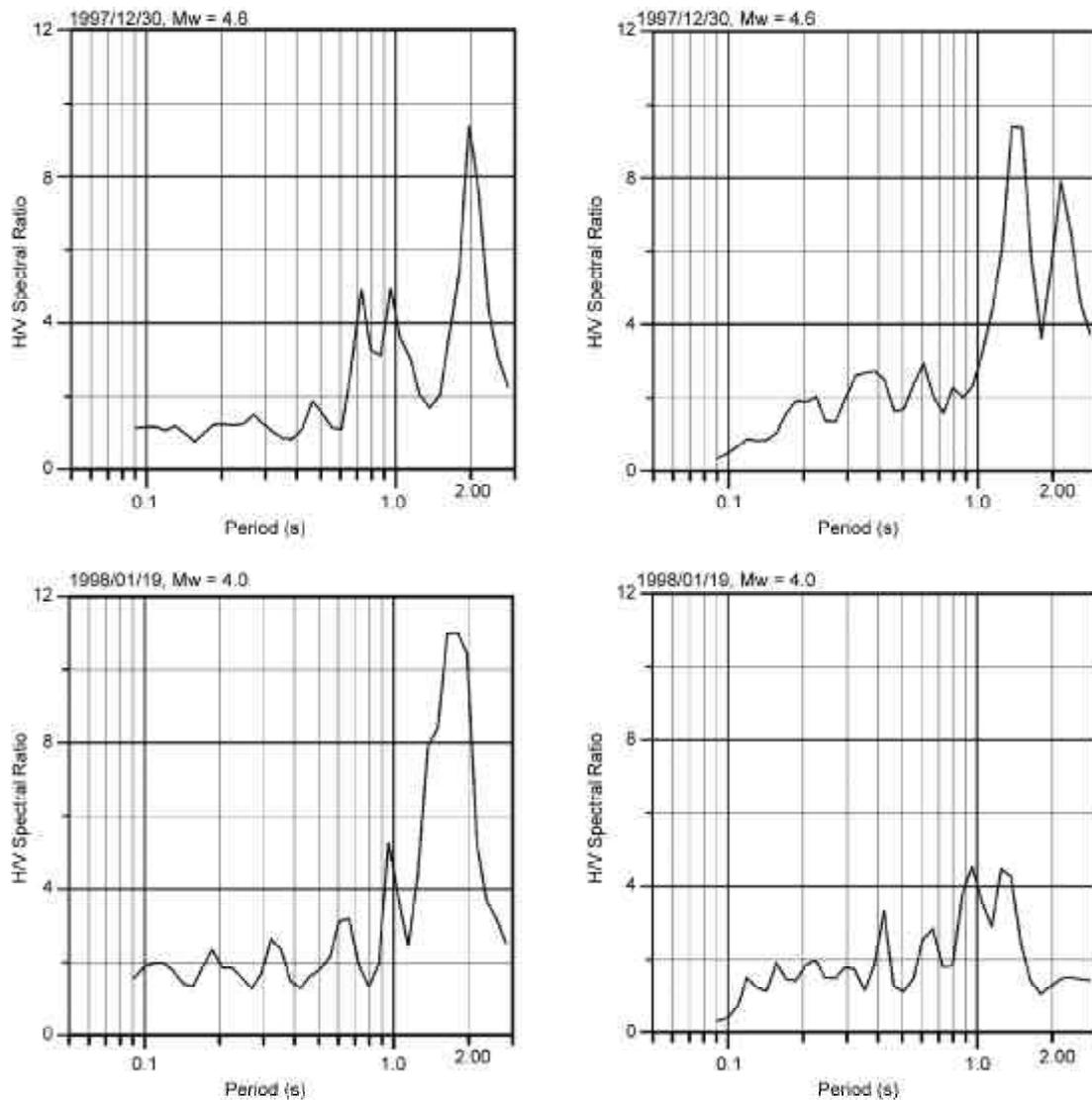


Figure 9. H/V spectral ratios computed at INCERC station for the earthquakes of 30/12/1997 and 19/01/1998 for noise (left), P-wave signal (middle) and S-wave signal (right). The windows for S-wave and P-wave trains and noise prior to P-wave arrival time are of 10s each.

seismicity to predict the response to large events is invalid, even assuming negligible possible non-linear effects. If we re-evaluate the H/V ratios for the smallest events from our dataset, taking portions of signal, like short windows around S-wave arrivals (excluding as much as possible the reverberations around S-wave arrivals), the H/V ratios contain clear source effects as shown by predominant peaks below 1s, differentiated from the peaks obtained from noise measurement (compare Figure (10) with Figure (9)). If we enlarge the windows in the signal to include the S-wave trains, the shape of the H/V ratios changes and gets closer to that of the ratios obtained for the associated noise windows. If the source is not sufficiently strong, the site response contribution is well visible in the enlarged time window (right side of Figure (10)) and it controls the spectral ratios

shape. This is not the case when the source is strong enough, as was demonstrated in the previous section. Similar observations apply to P-wave trains.

The strong ground motion induced in Bucharest area in the case of major Vrancea intermediate-depth earthquakes is characterized by unusually high long-period amplitudes. Similar unusual high long-period amplitudes at large distance from the focus were observed in the case of the 1985 Michoacan, Mexico earthquake, for example. The striking difference between Bucharest and Mexico City cases is the soil profile structure, which shows much stronger lateral variations in the last case. Therefore, for Mexico City area the local geology is clearly controlling the strong ground motion experienced by earthquakes (e.g., [3, 4, 8]). On the contrary, following our analysis, the response of the

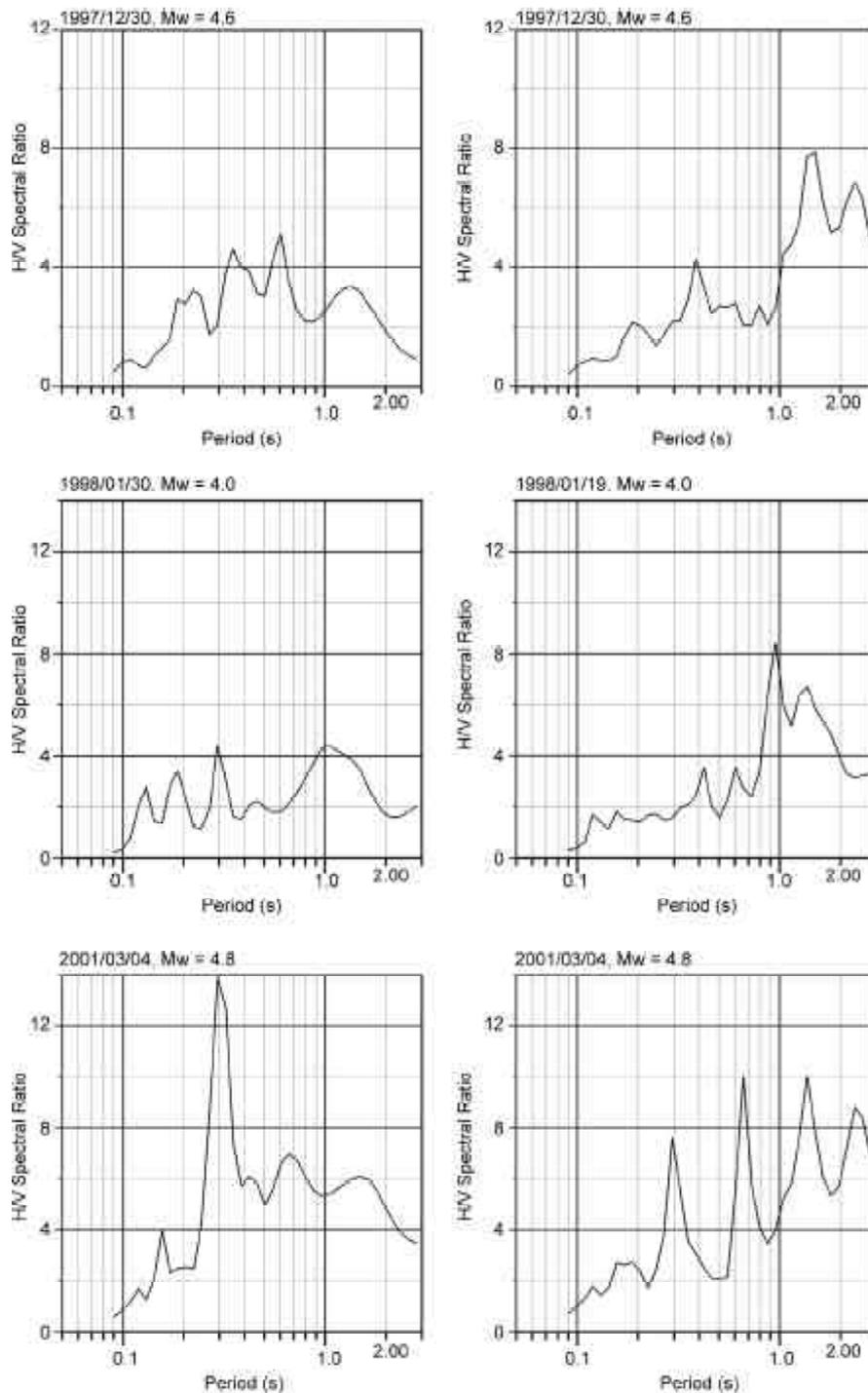


Figure 10. H/V spectral ratios computed at INCERC station for the earthquakes of 30/12/1997, 19/01/1998 and 4/03/2001 for 2-sec and 5-sec windows selected around the S-wave arrival time.

near-surface low-velocity layer is not capable to dominate the features of the earthquake ground shaking in Bucharest due to the Vrancea events. Only for ambient noise and small earthquakes, the *H/V* ratios are relatively stable and can be used to infer only the resonance frequency of the sediment-to-bedrock soil. However, even if the periods of the amplification are relatively constant, a common feature of our analysis is the great variability of the amplification level. Since *H/V* spectral ratio technique

is a frequency domain technique, the dominant frequency, and especially, the amplification factor are very sensitive to the signal-to-noise ratio and smoothing procedure, and in this way, the greater variability can be explained when using earthquake data.

Another consequence of our main outcome refers to the ground motion variability over the city area. Since the lithological composition and physico-mechanical characteristics of the subsoil deposits,

their geological layering, geometry and spatial distribution are varying but slowly over the Bucharest area, see Figures (2) and (3), and a relatively small variation of the amplification factors for noise and small earthquakes across Bucharest and neighbouring areas is expected. The inspection of the available observations shows that the *PGA* amplitude per earthquake differs from one site to another by a factor of less than 2 (one example is given in Table (3) for the earthquake of 27 October 2004), and does not show a reliable and systematic spatial pattern (to be eventually correlated with variations in the local structure). For large events, the changes can be as large as a factor of 3, which implies local increments of macrosismic intensity of at least one degree (e.g. [25] and references therein, [20]). This is in agreement with the deterministic seismic ground motion modelling and the observed damage distribution [7].

5. Conclusions

The main objective of the present work is to identify the role of the shallow sedimentary cover versus that of the seismic source upon the seismic ground motion characteristics in Bucharest area. Due to their control of the seismic hazard of the town, Vrancea earthquakes is considered, for which we have available relatively extended instrumentally measured site effects. In particular, the stability and reproducibility of the *H/V* technique is investigated and, by a thorough comparison, the meaning of the technique and its actual relevance in the site effect estimates for seismic microzoning purposes is tested.

The test of the local geological control on the seismic ground motion level and spectral content, for different size Vrancea events recorded at the same site illustrates the increasing effect of the source with increasing magnitude, prevailing upon the local site effect, as magnitude exceeds 7. This effect can not be explained by the focal mechanism or focus-site geometry variations, as the analysis of our dataset showed.

The fundamental phenomenon responsible for the amplification of seismic ground motion over soft sediments is the trapping of seismic waves, in a given frequency band, due to the impedance contrast between sediments and the underlying bedrock, with the possible formation of local surface waves (for 2D or 3D structures, like sedimentary basins). Many studies show that the amplification patterns (the fundamental resonance period) revealed by *H/V* technique can be well correlated with surface geology, if the geology is simple and with a strong impedance contrast to the bedrock, but the absolute level of amplification cannot be determined in a straightforward way (e.g., [10]). One explanation for the non-suitability of the *H/V* ratio technique in the case of Bucharest area is that the impedance contrast between the sedimentary layers and the bedrock is rather small and therefore the couple between source and site factors should be always considered. The earthquake magnitude, that determines the frequency content of the source spectrum is controlling the excitation of the sedimentary layers. This explains why the *H/V* ratio technique is not suitable for earthquake data.

As our results suggest, the long-period seismic wave amplification in Bucharest area is the joint effect of the deep soil deposits and seismic source radiation. Only the largest Vrancea shocks ($M > 7$) are able to effectively excite the resonance period of the sedimentary shallow layer (in the range 1-2s) which are responsible for the collapse of the tall buildings in the city. Due to this reason, the extrapolation from small-to-moderate earthquakes analysis is practically of no use to model the strong motion characteristics for microzoning purposes. The same reason can be used to explain why the damage in Bucharest dramatically increases when the earthquake size is above a critical value ($M \sim 7$), and relatively minor effects are reported for magnitudes below 7.

The *H/V* spectral ratio technique was originally used for microtremors and not for earthquake data

Table 3. PGA values recorded in Bucharest for the 27 October 2004 event.

Station	Latitude	Longitude	Component	PGA (cm/s ²)	PGV (cm/s)
BAP	44.4058	26.1189	EW	58.1	2.55
			NS	27.6	1.32
BST	44.4457	26.0983	EW	30.0	2.13
			NS	20.8	1.19
BTM	44.4370	26.1066	EW	38.0	2.32
			NS	18.6	1.08
BVC	44.4300	26.1016	EW	41.6	2.25
			NS	17.2	1.25
INC	44.4409	26.1623	EW	23.7	1.840
			NS	22.0	1.534

and its physical concept is not yet clear for earthquake data. In its initial form [19], it was based on the assumption that the vertical component of motion generated by microtremors is free from near surface influence. Although the technique has been recently applied by some researchers to earthquake data for site effect estimation (if earthquake recordings are used, the *H/V* technique is usually called the receiver function technique, e.g. [27]), since our results show that it is questionable to use *H/V* technique for site effect estimation in the case of Vrancea earthquakes. If *H/V* ratios for Bucharest case mainly reflect the ellipticity of Rayleigh waves, and the surface waves generation is clearly dependent on the incident waves at site, we may conclude that the application of the *H/V* technique is not adequate for intermediate-depth events.

Therefore, the major outcome of our study is the recommendation to question any strategy of extrapolation from micro, small and moderate earthquakes to large shocks to obtain the seismic microzonation map in the Bucharest area for strong Vrancea earthquakes.

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The *GEOPSY* package (www.geopsy.org) was used for *H/V* ratios computation.

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