A SUMMARY VIEW ON THE IMPLICATIONS OF AVAILABLE STRONG MOTION DATA ON VRANCEA EARTHQUAKES

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ABSTRACT :

The first strong motion data obtained in Romania were due to the occurrence of the Vrancea earthquakes of 1977.03.04, 1986.08.30, 1990.05.30 and 1990.05.31. The need to consider this information *as a whole* must be strongly emphasized in this view. The paper is devoted to a summary view on the implications of the features of the instrumental data at hand for the features of ground motions originating in the Vrancea seismogenic zone. The features of radiation / attenuation, alternatively in global, directional and spectral terms, are briefly presented. The effect of local conditions on the features of ground motion is then discussed, and locations with a trend to stability of the spectral contents of ground motion, as well as locations with a trend to strong variability of the spectral contents are put to evidence. The importance of the existence of a strong contrast of *S* wave propagation velocity at a relatively small depth of the local geological columns is referred to. The predictability of the features of ground motion is discussed.

KEYWORDS: Accelerograms, spectral contents, attenuation, directionality, local conditions.

1. INTRODUCTION

Numerous accelerographic records were obtained in Romania during the strong Vrancea earthquakes of 1977.03.04 (M_{GR} = 7.2), 1986.08.30 (M_{GR} = 7.0), 1990.05.30 (M_{GR} = 6.7) and 1990.05.31 (M_{GR} = 6.1). The accelerographic networks, at country size for eastern Romania, and at city size for Bucharest, are presented in Figures 1 and 2 respectively. *The authors believe that this wealth of instrumental information obtained during successive strong earthquakes having originated in the same Vrancea seismogenic zone is of paramount importance for understanding the features of the Vrancea seismic activity (and of its effects) and that the outcome of many seismological analyses is bound to be checked against the results of interpretation of strong motion instrumental data in order to check the validity of seismological analyses referred to.*

The strong motion accelerograms obtained during the strong earthquakes referred to were due mostly to the proper functioning of the INCERC (National Building Research Institute) network. Nevertheless, one must mention also some additional accelerograms used, that were obtained by the network of INCDFP (National Institute of Physics of the Earth) and by the network of Bulgaria. A digital network was not operational at the time of occurrence of events referred to.

The limited length provided for this paper made it necessary to renounce to the presentation of numerous data / figures and to refer mostly to previous published works of the authors, where such illustrations are available.

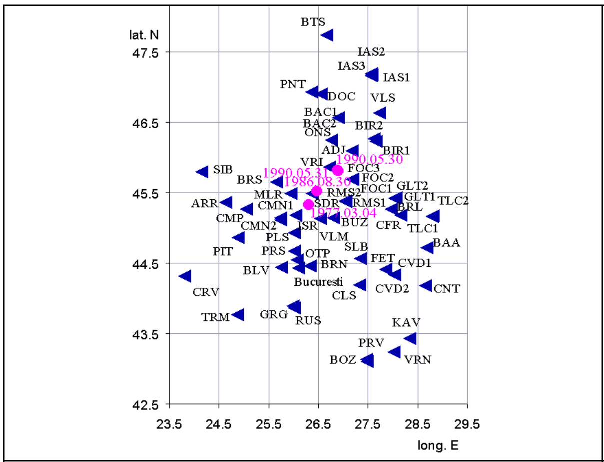


Figure 1. Strong motion network of E. Romania and N-E. Bulgaria

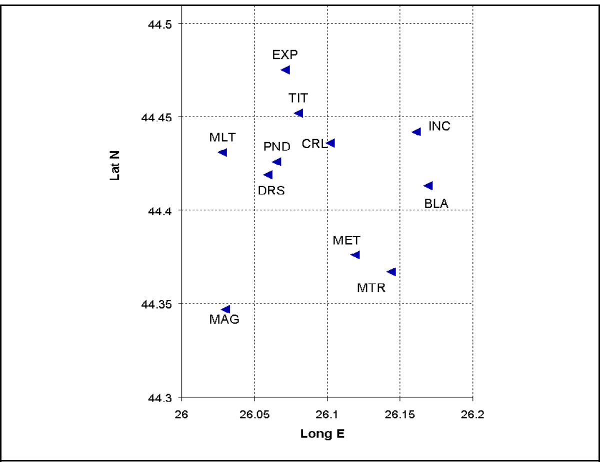


Figure 2. Strong motion network of Bucharest

2. METHODOLOGICAL ASPECTS

The objective of analysis and interpretation of the set of strong motion accelerograms at hand made it necessary to come up with some methodological contributions believed to be appropriate for this purpose. They may be enumerated as follows:

1. The processing of accelerograms was multi-sided. Response spectra for ground level records were determined in each case for 12 azimuthally equi-distant directions, according to the developments of (Stancu & Borcia, 1999). Besides this, global intensities, or intensities related to various spectral bands, were determined according to the definitions and developments of (Sandi & Floricel, 1998), (Sandi & Borcia, 2006). Illustrative sequences of response spectra and of intensity spectra are presented in Figures 3 and 4 respectively.
2. The radiation / attenuation phenomenon was analyzed in relation to various parameters: *PGA* (peak ground acceleration), *PGV*, *PGD*, *PSA* (peak spectral acceleration), *PSV*, I_S (global spectrum based intensity) and $i_s^{\sim}(\varphi,' \varphi'')$ (spectrum based intensities for various frequency bands $(\varphi,' \varphi'')$, where φ denotes frequency, in Hz). This phenomenon was analyzed successively in global terms, in terms of global azimuthal directionality (Fourier expansion with respect to azimuthal angle) and in terms of azimuthal directionality related to various spectral bands (Sandi & al., 2004a). Some comparisons were made with an analytical attenuation law given in (Sandi, 1992), which generalizes Blake's classical law (Blake, 1941).
3. Sequences of response spectra, determined for each of a series of relevant recording stations, were analyzed in qualitative terms, in order to evaluate the stability of spectral contents. The features of local geological columns were considered in this connection. Microtremor records were obtained at several station locations and RFS analysis of records was performed. Transfer functions of upper geological packages were determined in a parametric way. Since it was not clear at which depth to postulate base rocks, a parametric approach was adopted, considering alternatively different overall depths of upper geological packages. Transfer function peaks were compared with peaks of response spectra. The simultaneousness of variation (from one event to the other) of spectral contents of ground motion at recording stations located inside and around Bucharest was investigated (Sandi & al., 2004b). Intensity spectra were also derived for some relevant records (Sandi & Borcia, 2006). Reconciliation of results was undertaken.
4. As a summary of analyses performed, some aspects of the predictability of features of ground motion were investigated and a critical view on the prospects of microzonation of Bucharest was derived.

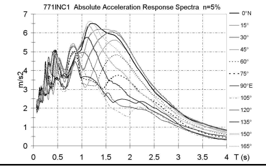
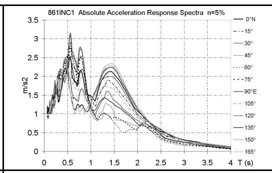
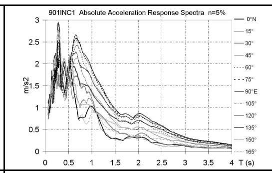
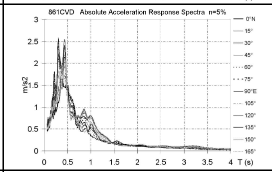
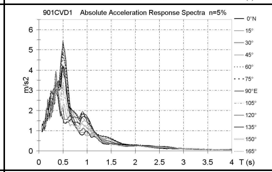
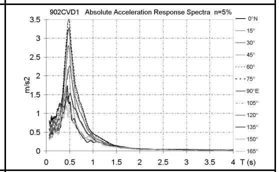
INC (Bucharest / INCERC)				
CVD (Cernavodă / City Hall)				
	1977.03.04	1986.08.30	1990.05.30	1990.05.31

Figure 3. Illustrative sequences of response spectra
along 12 azimuthally equidistant horizontal directions

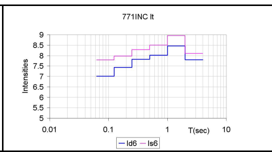
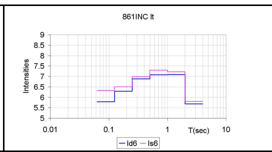
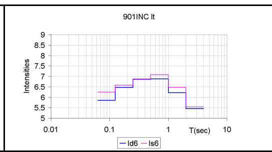
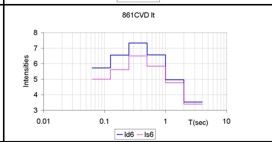
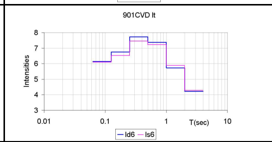
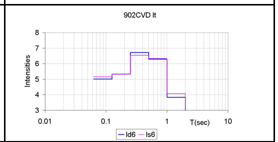
INC (Bucharest / INCERC)				
CVD (Cernavodă / City Hall)				
	1977.03.04	1986.08.30	1990.05.30	1990.05.31

Figure 4. Illustrative sequences of averaged intensity spectra
$i_s\tilde{}(\varphi', \varphi'')$ (red) and $i_d\tilde{}(\varphi', \varphi'')$ (blue), for 6 dB intervals

3. SUMMARY ON RADIATION / ATTENUATION FEATURES

The main features provided by the analysis of radiation / attenuation were presented in more detail in (Sandi & Floricel, 1995) and (Sandi & al., 2004a). The main results obtained can be summarized as follows:

1. Straight regression lines corresponding to the analytical attenuation law proposed in (Sandi, 1992) appeared to be in fair agreement with the cloud of observation data. The outcome of this kind is presented in Figure 5, for the three events for which rich instrumental information was at hand. The columns correspond to global intensities I_S and to intensities $i_s\tilde{}_{6i}$ (φ', φ''), related to various 6 dB frequency intervals respectively.
2. Attenuation rates were as expected for the event of 1986.08.30, but unexpectedly low for the following two events. Macroseismic data of NE Bulgaria confirmed this fact on 1990.05.30. Attenuation rates were different for different spectral bands. The differences of regression line slopes, corresponding to the differences of attenuation rates are easily visible in Figure 5.
3. Attenuation scatter tended to be highest for *PGA*, *PGV* and *PGD*, but lowest for spectrum based intensities. This is shown in Table 1, where a summary on this subject, derived in (Sandi & Floricel 1995), is presented.
4. Directionality of radiation / attenuation was strong in all cases, and it was also different for different events and, to some extent, even for different spectral bands. A summary view on this subject is presented in Figure 6, where attenuation roses (statistical isoseismals for intensities 7., 6., and 5. respectively) are given for the three events for which rich instrumental information was available, again for global intensities or for intensities related to various frequency bands, the same as in Figure 5.

	I_S	$i_s\tilde{}_{62}$ (0.5 Hz, 1.0 Hz)	$i_s\tilde{}_{63}$ (1.0 Hz, 2.0 Hz)	$i_s\tilde{}_{64}$ (2.0 Hz, 4.0 Hz)	$i_s\tilde{}_{65}$ (4.0 Hz, 8.0 Hz)
1986.08.30, $M_{GR} = 7.0$					
1990.05.30, $M_{GR} = 6.7$					
1990.05.31, $M_{GR} = 6.1$					

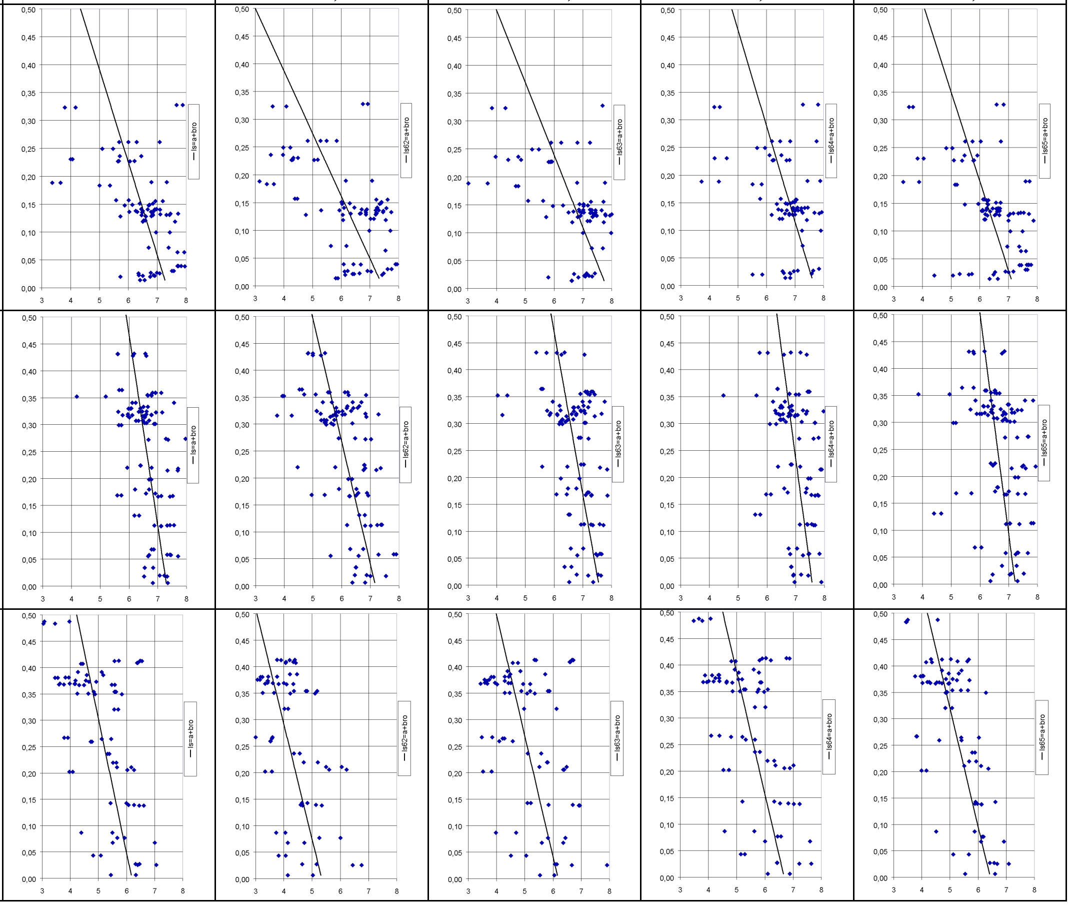


Figure 5. Regression lines for various events and frequency bands

Table 1. Outcome of statistical analysis of attenuation based on instrumental data (Sandi & Floricel, 1995)

Event	Parameters									
	Average atten-uation of I_S	R. M. S. values of ground motion parameters						Fourier coefficients for azimuthal I_S distribution		Dominant radiation azimuth for I_S
	$I_0\tilde{} - b\,\rho$	$\log_2 PGA$	$\log_2 PGV$	$\log_2 PGD$	$\log_2 EPAS$	$\log_2 EPVS$	I_S	a_1 / b_1	a_2 / b_2	
1986. 08.30	7.7 – 7.6 ρ	0.925	0.999	1.025	0.836	1.012	0.873	-0.09 -0.01	0.14 0.23	*N 59 °E*
1990. 05.30	7.2 – 2.1 ρ	0.662	0.790	0.901	0.653	0.735	0.588	-0.03 0.09	0.24 -0.08	*N 161 °E*
1990. 05.31	5.9 – 2.6 ρ	0.910	0.916	0.756	0.883	0.911	0.584	0.01 0.63	-0.16 -0.47	*N 71 °E*

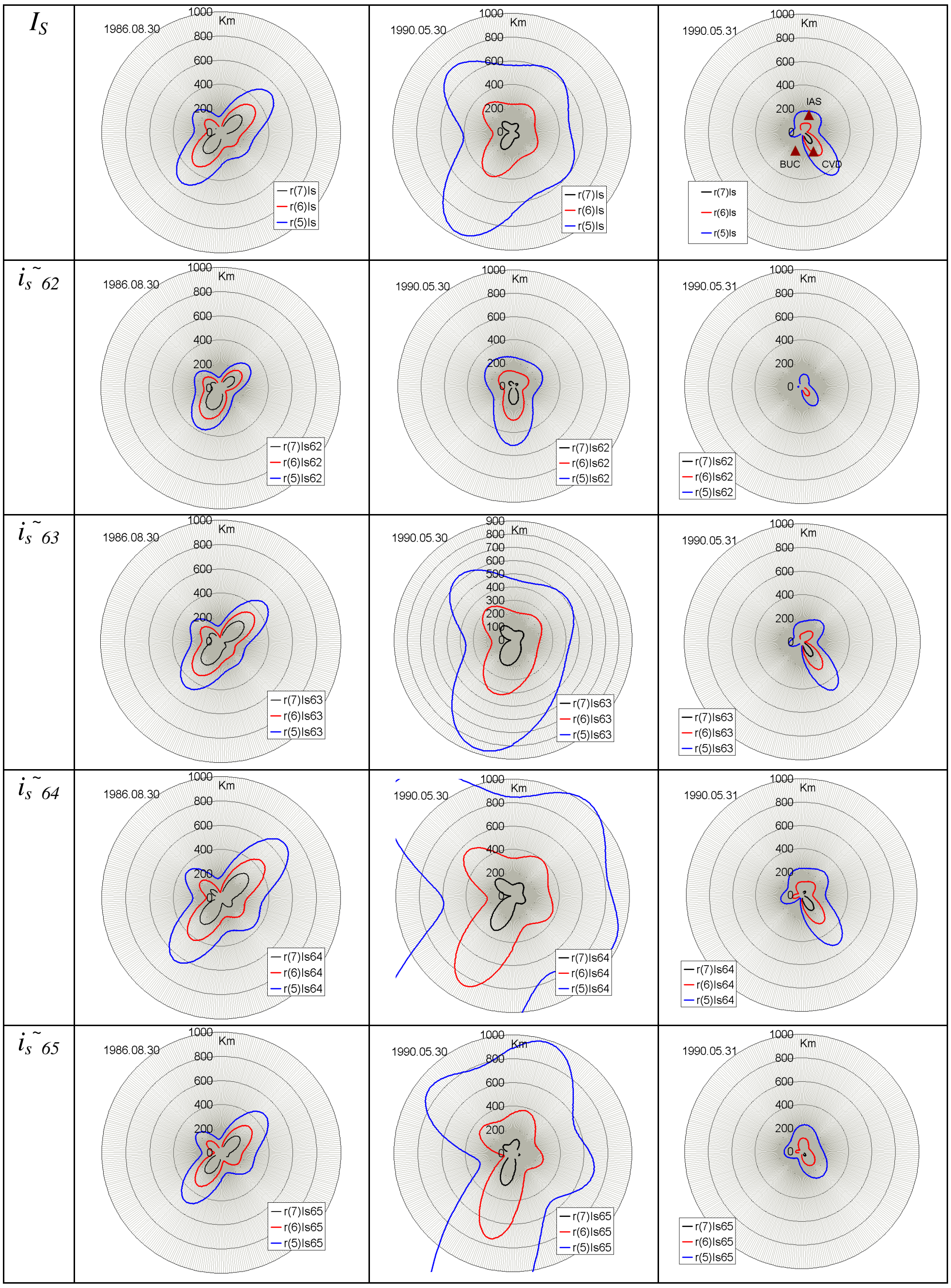


Figure 6. Directionality of attenuation, for various events and frequency bands
(common scale, up to epicentral distance of 1000 km)

4. SUMMARY ON FACTORS INFLUENCING THE GROUND MOTION FEATURES

The main features provided by the analysis of the dependence of spectral contents of ground motion on source mechanisms and on local geological conditions were presented in more detail in (Sandi & al., 2004b) and (Sandi & Borcia, 2006). The main results obtained can be summarized as follows:

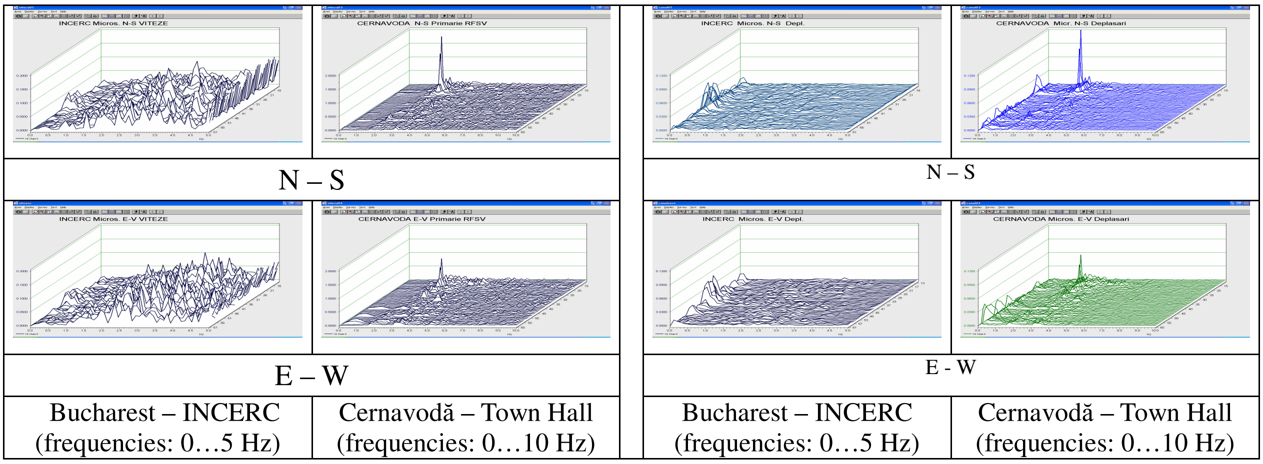
1. There are recording stations for which a strong trend to stability of spectral contents of ground motion

can be observed (prototype: Cernavodă / City Hall) and recording stations for which a strong variability of spectral contents of ground motion can be observed (prototype: Bucharest / INCERC), as put to evidence in Figure 3. The trend to stability could be observed where there exists, at small depth, an interface of strong contrast of *S*-wave propagation speed along the local geological column, while the strong variability could be observed at locations where such a contrast is absent.

2. The comparison of response spectra corresponding to different directions of motion for a same event and for a same recording station emphasized considerable differences of ordinates for some frequencies or periods (ratios going up to 1:3 or even 1:4). This happened in spite of the fact that the geological column is unique and could be due mainly to the features of source mechanism and of wave propagation. *A look at the ensemble of instrumental data obtained simultaneously inside and around Bucharest does not support at present a microzonation of the City of Bucharest.*
3. A considerable variety / variability of dominant periods, from one station to the other and (for some recording stations) from one event to the other was obvious.
4. The main spectral peak of $T \approx 1.5$ s, observed on 1977.03.04 at Bucharest INCERC, became on 1986.08.30 a secondary peak at the same place, as well as at other recording stations located inside or around Bucharest and totally disappeared on 1990.05.30 at all stations referred to (Sandi & Borcia, 2006). It can be ergo inferred that the main factor having influenced the spectral content inside and around Bucharest was represented by the source mechanism. Long dominant periods, in the range of 1.5 s, should thus be expected in case of strong earthquakes for extensive areas of Southern Romania, where thick relatively soft geological layers exist. On the other hand, the features of transfer functions derived for such a site emphasize a potential of occurrence of even longer dominant periods in case of highest magnitude earthquakes.
5. The RFS analysis of microtremors showed that in case of a station like that of Bucharest / INCERC microtremors present steadily a chaotic character, while in case of a station like that of Cernavodă / Town Hall there are also time intervals for which microtremors have strongly increased amplitudes and quite sinusoidal character, the corresponding frequency being close to the dominant frequency put to evidence by strong motion accelerograms, put to evidence in Figure 3. This may be seen in Figures 7 and 8.
6. The results of parametric analysis of (ground surface acceleration / base rock acceleration) transfer functions emphasize the need to consider thick geological packages in order to explain and anticipate the spectral features of ground motions. A parametric approach was used, in order to investigate the implications of adopting alternative models for a geological column, going stepwise from the consideration of a single, upper, layer, up to the consideration of a thick package of 8 layers, according to data of Table 2. The outcome of Figure 10 (in abscissa: periods, log; in ordinate: transfer function, log; both with equi-intervals 0.5) shows a trend to stabilization of the transfer function and the fact that, for a geological column like in Bucharest, there are several important long period peaks of comparable importance. This provides an explanation for the features of spectral contents of ground motion, as observed and discussed previously.

Table 2. Input data for Bucharest – INCERC type site

No. of layer, k (counted downwards)	Layer depth intervals (m)		Layer thickness, h_k (m)	Densities ρ_k (t/m^3)	S wave propagation speed c_s (m/s)
	Min.	Max.			
1	0	70	70	1.6	320
2	70	130	60	1.8	420
3	130	200	70	2.2	640
4	200	600	400	2.2	700
5	600	1000	400	2.2	1340
6	1000	2000	1000	2.6	2040
7	2000	2400	400	2.4	1710
8	2400	2800	400	2.8	2650



a.. for microtremor velocities b. for microtremor displacements

Figure 9. Running Fourier spectra

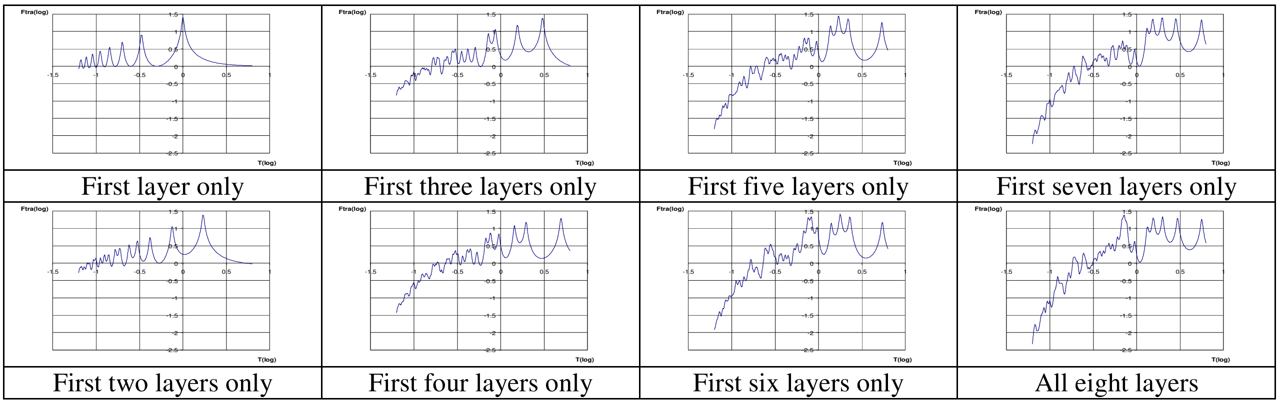


Figure 10. Results of stepwise analysis of transfer function for Bucharest site type

5. SOME CONSEQUENCES FOR FORECASTING GROUND MOTION FEATURES

1. Given the isoseismals determined for most strong earthquakes of the past, like those of 1802.10.26, 1940.11.10, 1977.03.04 and 1986.08.30, it may be stated that the most important radiation direction is the by now classical NE – SW direction. On the other hand, the possibility of other radiation patterns, like that of 1471.08.29, which led to severe destruction at least at the Suceava citadel (Ştefănescu, 1901), the Moldoviţa Monastery (Nistor, 1923) and the Neamţ Monastery (on site collected information), or those of 1990.05.30 and 1990.05.31, should in no case be neglected.
2. Following the earthquake of 1977.03.04, there was a large agreement that a velocity / acceleration corner period of 1.5 or 1.6 s is appropriate for some extensive zones of Southern Romania. On the other hand, some facts representing a warning on the potential of occurrence of motions with longer corner periods (Sandi & al., 2004b) should be taken into account: on one hand the response spectra for the Rm. Sărat record of 1990.05.30 (and to some extent of Buzău record of the same event), which were almost flat up to a period of 2.5 s.; on the other hand, the transfer function features for geological columns like that of Bucharest, which put to evidence some relevant spectral peaks for periods longer than 1.6 s.

6. FINAL CONSIDERATIONS

1. The consideration of the system of instrumental data obtained during strong earthquakes should be dealt with as a cornerstone in the analysis of the features of Vrancea seismicity.
2. It is most important to consider the whole of instrumental information, thus avoiding possibly erroneous conclusions provided by the consideration and analysis of a single record.
3. The picture of radiation / attenuation directionality may significantly differ from one event to the other and even for different spectral bands, for a same event. This fact should be taken into consideration in the development of seismic zonation of Romania and of neighbouring countries affected significantly by Vrancea earthquakes.
4. There is a strong trend to stability (and predictability) of spectral content of ground motions for locations where there exists, at small depth, an interface of strong contrast of *S*-wave propagation speed, but strong variability may be expected at locations where the strong contrast is absent.
5. The consideration in design of the properties of soil up to a depth of just some tens of meters, as specified by several codes, appears to be totally inadequate in case of Vrancea earthquakes.
6. Instrumental data at hand make attempts of microzonation of Bucharest most questionable.

ACKNOWLEDGMENTS

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