Romanian Reports in Physics, Vol. 59, No. 1, P. 165–178, 2007

LOCAL SEISMIC EFFECTS IN SITES LOCATED IN THE SOUTH AND CENTRAL PART OF TRANSYLVANIA BASED ON SPECTRAL RATIOS

V. RĂILEANU, A. BĂLĂ, B. GRECU

National Institute for Earth Physics, Bucharest-Măgurele, P.O.B. MG-2, ROMÂNIA
raivic@infp.infp.ro

(Received July 10, 2006)

Abstract: An assessment of the spectral ratios H/V of seismic records in 18 sites from south Covasna to Aiud in the Transylvania province were achieved based on the data provided by the Vrancea 2001 seismic experiment. A global analysis of the spectral ratio curves shows a transition from 1-3 well outlined peaks with high amplifications (>1.5-2 units) to poorly differentiated peaks and low amplifications on the frequency scale.

Key words: seismic records, spectral ratio, spectral amplification, resonant frequency, local seismic effects.

1. INTRODUCTION

Three previous papers [1, 2, 3] dealt with studies of the seismic effects in several sites based on the spectral ratios derived from seismic records collected during two major experiments: the seismic refraction lines VRANCEA 99 and VRANCEA 2001[4, 5]. Present paper is the fourth in that series and it is continuing the analysis of seismic effects in the south of Transylvania along an alignment from south of the Covasna town through the Rupea and Medias towns to the Aiud town, Fig.1.

The seismic data sets collected during the VRANCEA 2001 seismic experiment comprise information about physical properties along the wave paths from source to receiver and particularly on the shallow part of geological cross-section underneath receiver that leaves its fingerprint on the whole train of waves which emerge from deep levels to surface. This fact allows to see which is the influence of the source and of the local geological and geophysical conditions on seismic effects in the studied sites.

An analysis of the observational and experimental data showed a high influence of the local geological conditions on the size and distribution of the earthquake damages [6,7]. Instrumental records of the seismic events offer the chance to identify the frequencies where the soil amplification occurred. Generally most of seismic instrument networks are limited to a low density of instruments on the surface unit and many large populated areas are not properly covered by instruments. On the other hand even having a densely instrument network it is not of a practical use to expect for a major seismic event in order to record and evaluate the local seismic effects for an unpredictable future earthquake [6].

Alternative solutions were proposed and even successfully applied. One of them is to use microtremor records. A reason for their support is that both microtremor and aftershock analyses use the same method for seeking of spectral peaks which are considered as standing for the resonant frequencies in response to a site. Although not all seismologists consider this method as enough reliable in evaluation of the seismic response of a site [7,8], some of them accept that microtremor could give rough information on site amplifications [9,10]. Though the microtremor method has its shortcomings and new more refined method is not available, it was and is being applied in Japan, Mexic [11], USA [12] and in other countries~~s~~. A combination of microtremor and earthquake data has been used in Romania for the study of the seismic site response in Bucharest [13], followed by a study of site response due to some large Vrancea earthquakes [14].

The microtremor method, known also as Nakamura’s method [10], makes analysis of ambient seismic noise recorded on three component instruments and compares the spectral amplitudes of the horizontal to the vertical records. Applied in different worldwide seismic areas it displayed some agreements with results derived from spectral analyses of S-wave and coda for large earthquakes. A good agreement was observed for spectral peaks at fundamental periods, but spectral amplitudes proved to be different from each other [7].

2. PHYSICAL BACKGROUND

Studies of the earthquake effects performed in different areas of the world proved that the amplification of microtremor and coda amplitudes within a site is a consequence of the trapped energy in the shallow sedimentary layers [15]. Nakamura showed that the effects of the Rayleigh waves are rejected as the ratio of horizontal/vertical components is used. On the other hand other authors [9,16] stated that just the Rayleigh waves assure the success of Nakamura's method. The peak of the fundamental period is produced by the vertical component of the Rayleigh wave going towards zero.

In the following a practical method for computation of spectral ratios of horizontal component (H)/vertical component (V) is presented. It follows more steps [17]:

-computing of the amplitude spectrum for the NS, EW and V components;

-computing of the total horizontal spectrum which is a complex signal:

$CH = NS + i * EW$, complex horizontal component, $i = \sqrt{-1}$,

$CHS = CFT [CH]$ complex Fourier transform,

$HS = (1/\sqrt{2})*|CHS|$ horizontal spectrum,

-HS/V ratio is computed for the whole frequency band used for analysis.

3. SEISMIC DATA AND SPECTRAL ANALYSIS

Basic data set was provided by the field records collected during the VRANCEA 2001 seismic experiments. A seismic refraction line extended over an WNW-ESE alignment of about 450 km length from the Tulcea town in Dobrogea, through Vrancea region, to Aiud town in Transylvania, (Fig.1), was achieved in 2001 by a partnership of universities and research institutes from Germany, Holland, Unites States and Romania. The major target of experiment was the deciphering of the crustal and upper mantle structure based on seismic velocities [18]. 10 big shots (300-1500 kg charge) placed in 10 locations deployed along the seismic line with a mean spacing of 40 km were shot. 150 digital portable instruments with three component receivers (Mark Products, L-4-3D), 1Hz resonant frequency and with a 3 km mean spacing have been deployed from easternmost end of line to Aiud town. Seismic stations have been installed only inside of locality areas. Seismic records have 100 s length and consist of useful seismic signal in the first tens of seconds and of coda and ambient noise in the rest. Such a seismic record represents a complex signal emerged from the deep crustal levels and modulated by shallow local geology. Influence of the local geology can be estimated using some techniques such as Nakamura's method.

Fourier spectra were performed with a dedicated computing program under UNIX known as Seismic Handler [19]. Some small programs were specially written for preparing of the data for processing and their plotting on graphs.

Present study analyses the seismic records generated by seven shot points (from S to Z) in 18 sites from the western margin of Carpathians (south of Covasna town) to the eastern end Apuseni Mountains (Aiud town), see Tab. 1 and Fig. 1.

Table 1

Site investigated and shot points used (x) with their charges

No.	**Site**	**County**	**Shot points and their charges**						
			S 300 kg	**T** 1000 kg	**U** 1000 kg	**W** 300 kg	**X** 600 kg	**Y** 1000 kg	**Z** 1500 kg
1	Păpăuți	Covasna	X	X	X	X			
2	Moacşa	Covasna	X	X	X	X			
3	Valea Crişului	Covasna	X	X	X	X			
4	Aita Mare	Covasna			X	X	X	X	
5	Hoghiz	Braşov			X	X	X	X	
6	Rupea	Braşov			X	X	X	X	
7	Viscri	Braşov				X	X	X	X
8	Grânari	Braşov				X	X	X	X
9	Brădeni	Braşov				X	X	X	X
10	Iacobeni	Braşov				X	X	X	X
11	Copşa Mare	Sibiu				X	X	X	X
12	Biertan	Sibiu				X	X	X	X
13	Mediaş	Sibiu				X	X	X	X
14	Bazna	Sibiu				X	X	X	X
15	Boian	Alba				X	X	X	X
16	Feisa	Alba				X	X	X	X
17	Sânmiclăuş	Alba				X	X	X	X
18	Sâncrai-Aiud	Alba				X	X	X	X

4. DATA PROCESSING

Seismic records for each site were selected from the original digital records (100 samples per second) and saved in new files. Such a file is a record on three components in a site for a shot point derived from original record and comprises the first arrivals with high energy and some later arrivals as well as the coda waves and ambient noise. A spectral analysis for each component of a seismic record is performed using a Fast Fourier Transform procedure. Only the first 40 s of the seismic record are analyzed. No instrument correction is applied as the frequency responses of the three geophone components are practically the same. The output signal of the spectral analyses is computed within range 0.1-20 Hz having 200 samples.

Next step deals with the computation of the spectral ratios using the formula suggested by [17]:

$$SR = (SH/SV) \text{ and } SH = (0.5)^{1/2} * (S^2n + S^2e)^{1/2},$$

where: SR=spectral ratio, SH=amplitude spectrum of the horizontal component, SV= amplitude spectrum of the vertical component, Sn= amplitude spectrum of the north-south component, Se = amplitude spectrum of the east-west component.

Seismic signal is a convolution between the source signal (explosion and ambient noise) and spectral peculiarities of the propagation paths (here including finally the shallow geology stack of site). If the spectral ratio curves obtained for the same site but for different shots are compared they show both common and particular features. The last ones are very probably related to the seismic sources and propagation paths which are quite different from one site to the other, while the common features are preponderantly caused by local geology. If the spectral ratio curves for the same site but for different shot points are stacked then the common features will be enhanced and the others will be diminished. This last procedure of the enhancement of common peculiarities which in the most extent are due to the local geology was applied for all the studied sites.

5. RESULTS

For each site four spectral ratio curves assigned to four shot points (Table 1) were derived and finally a mean curve as an average of them was computed.

In order to see how different from each other are the spectral ratio curves in the same site but for different shot points let analyse the site Păpăuți and its records from shot points S, T, U and W (Figs. 1-2). Spectral ratio curve (thick line) for the shot point S (104 km ESE of the site) displays low amplifications < 1.5 units and a few peaks which are enveloped by the mean curve (dashed line). For the shot point T (48 km ESE) a bit higher amplification > 1.5 units is observed and at least from 0-10 Hz its peaks are pretty well overlapped by the average curve. The closest shot point U (7 km ESE) gives the highest amplification with values >2.0 units and with local peaks which are very well overlapped by the average curve. Shot point W (40 km WNW) shows an maximum amplification around 1.5 units around 2 Hz and a attenuation (<1) between 5-12 Hz.

Spectral ratio curves resulted from the four shot points indicate different amplification levels mainly as a function of distance to source but about the same frequency peaks with different amplitudes from one shot to the other. The common peaks for all curves suggest a common cause and it can be only the local geology crossed by the seismic waves to reach the surface receiver. The mean curve of the four individual spectral ratio curves comprises the enhanced common peculiarities and the diminished particular features of waves from each shot point.

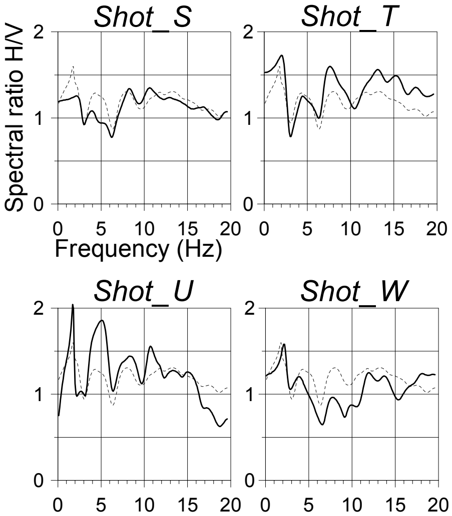

Fig. 2 – Spectral ratio curves (thick full line) derived from seismic records generated by the shot points: S, T, U, and W and recorded at the Păpăuţi site. The four curves display different amplification levels in respect with the mean curve (thin dashed line) mainly as a function of distance to source. Note that about the same frequency peaks but with different amplitudes are kept from one shot to the other.

In the following let see which are peculiarities of each site as they can be seen on the averaged curves of spectral ratios (Figs.1, 3a-c).

1. *Păpăuţi Site* (Fig.3a) is located within the Sfântu Gheorghe-Covasna Depression. Three significant peaks with amplification of 1.3-1.6 units can be seen on the spectral ratio curve at 1.8 Hz, 4.2 Hz and 8 Hz. Beyond 10 Hz a relatively constant amplification of 1.3 units is noticed between 11 and 15 Hz and then it is diminished down to 1 unit for ~19 Hz. The resonant frequencies within the interval from 1-10 Hz could be generated by shallow Neogene sedimentary layers with thicknesses of tens of meters.

2. *Moacşa site* (Fig.3a) belongs as well to the Sfântu Gheorghe-Covasna Depression. Spectral ratio curve shows an amplification of 1.3 units for frequencies <2 Hz. Between 2.5-3.8 Hz an amplification of ~1.5 units is remarked. From 5-9 Hz amplification is almost unitary and from 10-18 Hz it increases up to 1.3 units with some light peaks at 12.6 Hz, 15.2 Hz, 18.8 Hz. Resonant frequencies within the range 2-4 Hz are supposed to be generated by the shallow Neogene and Quaternary layers having thickness of a few tens of meters.

3. *Valea Crişului site* (Fig.3a) is settled on the eastern margin of Baraolt Mountains and along of a small brook. About 1.3 units amplifications are observed for the frequencies <1 Hz. Some attenuations <1 unit follow between 1.5-8.5 Hz while from 9-15 Hz a mean amplification of 1.1 units is apparent with some light peaks 9.2 Hz, 11.8 Hz and 13.5 Hz. Within the range 15-18 Hz a gradual amplification is noticed with 1.5 units for 18.5 Hz. Peak resonance frequencies <1 Hz could be due to some thicker layers of one or more hundred meters of the sedimentary cover.

4. *Aita Mare site* (Fig. 3a) is located on the Olt Valley between Baraolt and Perşani Mountains. Within the range of frequencies <1 Hz amplifications are slight grater than 1. The peak observed between 4-5 Hz reaches an amplification of ~1.3 units and on the flanks of peak the amplifications decrease towards 1.0 unit. That resonance peak could be due to the shallow sediments of a few tens of meters thick which compound the Olt river terrace. A secondary peak at 16.2 Hz/1.25 units amplification could be due as well the very shallow sedimentary layers of the Olt river terrace.

5. *Hoghiz site* (Fig. 3a) is settled on the western margin of Perşani Mountains on the Olt river wich flows close to the village. The highest and well individualised amplifications can be seen on this site in comparison with the previous sites. Two main peaks dominate the spectral ratio curve: first for 2.1 Hz and 2.5 units amplifications and the second with a larger resonance range: 6.2-8.2 Hz and ~2 units amplifications. In between the two peaks the amplification lowers to 1 unit. For frequencies < 1 Hz the amplification is 1.6 units. A slight amplification of 1.2 units is also observed between 16-18 Hz. The first two significant peaks are likely due to the first shallow sedimentary layers with thicknesses of several tens meters (2 Hz) or thinner layers in the thickness range of 10 m (6-8 Hz).

6. *Rupea site* (Fig. 3a) It is placed at the eastern margin of Transylvania Depression, close of a small river. A highlighted amplification peak of 2.5 units is apparent in the 3.2-4.5 Hz frequency range. On the sides of peak the amplifications decrease down to 1.3-1.5 units for lower frequencies and less than 1 unit for frequencies >7 Hz. The first resonance peak could be due to the shallow layers of 10-20 m thickness, possible a thinner layer of the river's terrace.

7. *Viscri site* (Fig. 3b) All the following sites are situated within the Transylvanian Depression. This site is placed on a hilly area. Spectral ratio curve shows amplifications of seismic energy up to 1.4 units for 1.3 Hz and 13.5-15.5 Hz range, respectively. A smaller peak of 1.2 units for 8.5 Hz can be also seen. A desamplification (<1 unit) is observed for the 3-7 Hz range. The first peak (1.3 Hz) could be due to some well outlined sedimentary layers with hundred meters thickness which compound the upper Neogene stack.

8. *Grânari site* (Fig. 3b) is settled along a valley with a small brook. Spectral ratio curve displays a main peak with high amplification of 3.2 units for 1.8-2.8 Hz range. A few secondary peaks with smaller amplifications (~2 units) modulate the spectral ratio curve at the frequency of 4.5 Hz and 2 units of amplification, 7 Hz/1.75 units and 9.4 Hz/1.5 units. Beyond of 13 Hz the amplification is approaching of 1 unit. First peak reaches the highest amplification in respect with the previous sites. It could be generated by shallow Quaternary and Neogene layers of about 50-80 m thicknesses if it is assumed a mean shear wave velocity of 400-600 m/s for that stack. Secondary peaks are a result of vibrations of the very shallow thinner layer of 10 m thickness or less.

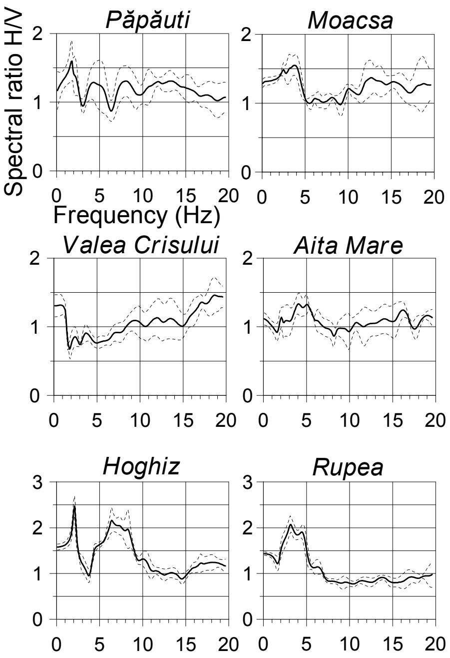

Fig. 3a – Mean spectral ratio curves (thick line) for six sites: Păpăuţi, Moacşa, Valea Crişului, Aita Mare, Hoghiz and Rupea as an average of four shot records, see Table 1. Dashed lines stand for a plus/minus standard deviation.

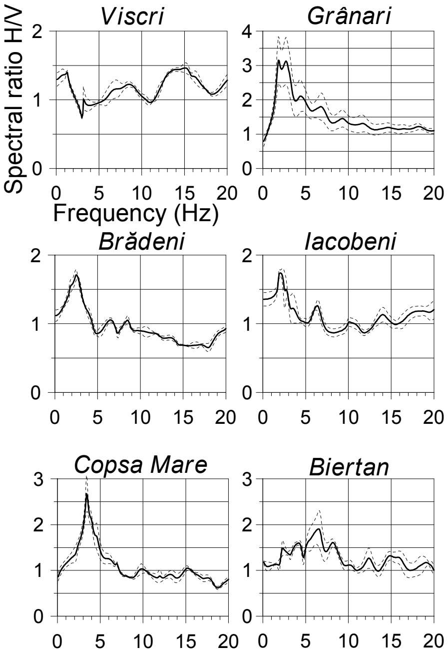

Fig. 3b – Mean spectral ratio curves (thick line) for six sites: Viscri, Grânari, Brădeni, Iacobeni, Copşa Mare and Biertan as an average of the four shot records, see Table 1. Dashed lines stand for a plus/minus standard deviation.

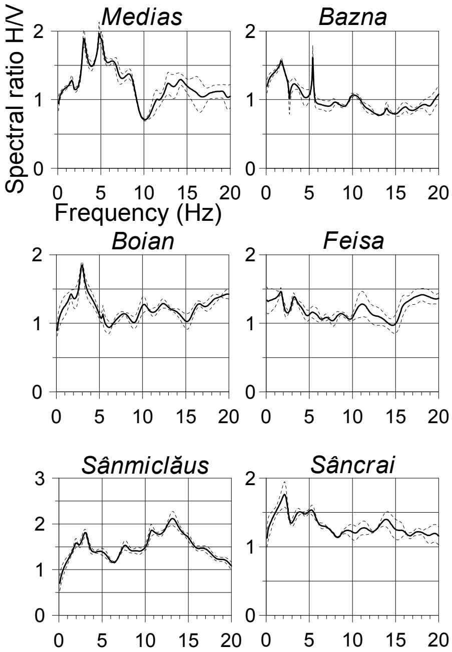

Fig. 3c – Mean spectral ratio curves (thick line) for six sites: Mediaş, Bazna, Boian, Feisa, Sânmiclăuş and Sâncrai as an average of the four shot records, see Table 1. Dashed lines stand for a plus/minus standard deviation.

9. *Brădeni site* (Fig. 3b) is very close to a lake. High level of water table could influence the ground seismic behaviour during of an earthquake. Spectral ratio shows a major peak of ~1.75 units for 2.3 Hz. For frequencies >4.5 Hz amplification gets ≤ 1 unit, what means that the seismic energy is diminished in respect with the incident energy under site. Main resonance frequency could be due to the shallow sedimentary pack of 50-80 m thick like for the Grânari site.

10. *Iacobeni site* (Fig. 3b) is placed along a narrow valley with a small brook. General form of spectral ratio curve is close to those of the last two sites: Grânari (8 km distance) and Brădeni (20 km). The main peak of the spectral ratio reaches 2.75 units for 2.1 Hz. The following peaks have a smaller amplification: 2.8 Hz/2 units and 6.3 Hz/1.25 units. In the 7-13 Hz range the amplifications are <1 unit. For frequencies < 1 Hz are observed amplifications of 1.4 units suggesting a shallow stack of sediments having > 100 m thickness. The main peak resonance could be generate by a layer stack of 50-80 m thick like for Grânari and Brădeni sites.

11. *Copşa Mare site* (Fig. 3b) is situated along a narrow valley with a small brook. A very well outlined peak is shown by the spectral ratio curve: a high amplification of 2.7 units is reached for 3.3 Hz. On the flanks of peak the amplification quickly decreases down to 1 unit or even less. Beyond 7 Hz amplification becomes <1 unit. It seems that the shallow sediments of 20-30 m thick could give that 3.3 Hz resonance peak.

12. *Biertan site* (Fig. 3b) is settled along a narrow valley with a small brook like the previous four sites. Although the topography of this site seems to be comparable with the previous four sites the spectral ratio curve has another configuration. A succesion of smaller peaks on a increased background from 2 Hz to 6.8 Hz is seen. For 6.8 Hz the highest amplification of 1.8 units is reached. From 6.8 Hz to 10 Hz amplification gradualy decreases down to about 1 unit. The succesive peaks on the spectral ratio curve suggest a stack of relatively thin layers which being excited by seismic energy vibrate in a succesion of proper modes associated both individual layers and the whole stack of layers.

13. *Mediaş site* (Fig. 3c) is located on the main terrase of the Târnava Mare river. Spectral ratio curve has a larger peak area between 2-8 Hz with 2 lobes for 3 Hz and 5 Hz respectively, where amplification is increased up to ~2 units. Another two secondary peaks for 6.3 Hz and 8.3 Hz having amplitudes of 1.3 and 1.5 units respectively can be observed. This site are settled on a alluvium stack of gravel, sand and clay, etc and underneath it some Quaternary and Neogene harder rocks exist. Frequencies of 3 and 5 Hz could be due to some layers of 15-20 m thickness and with shear wave velocities ≥ 300 m/s which compound the Târnava terrace.

14. *Bazna site* (Fig. 3c) is settled along a small brook and on hilly topography. Two peaks with amplifications around 1.5 units are observed for 1.8 Hz and 5.3 Hz, respectively. Beyond 6 Hz amplifications are <1 unit, except around 10 Hz where it is ~1 unit. The first amplification peak for 1.8 Hz could be generated by the shallowest sedimentary layer having a thickness of a few of tens meters.

15. *Boian site* (Fig. 3c) is located on a valley area with a small brook. The main and significant amplification peak reaches ~1.8 units for 3 Hz. Other secondary peaks having low amplifications < 1.25 units are noticed for 8 Hz, 10.3 Hz and 13.5 Hz. Main peak could be generated by the first sedimentary layer with a thickness of a few tens of meters which likely includes thinner layers with proper frequencies ≥ 8 Hz. The thicker layer seems to be better individualized in respect with underlaining layer which could have some higher thickness and velocity in comparison with the former.

16. *Feisa site* (Fig. 3c) is placed on a hilly area. Spectral ratio curve shows a weak amplification <1.5 units for a few poorly differentiated peaks. Two peaks for 1.8 Hz and 3.2 Hz are prominent and then the amplification decreases almost gradually up to about 10 Hz. Other two peaks for 11 Hz and 18 Hz reach amplification levels of 1.3-1.4 units. This site has the less amplifications among the analysed sites until now.

17. *Sânmiclăuş site* (Fig. 3c) It is situated on a slight hilly area and not far of Târnava Mică river. Spectral ratio curve displays a high background amplification on average between 1.5-2.0 units for 2-3 frequency groups with peaks around 3 Hz/1.8 units, 7.5 Hz/1.5 units, 10.7 Hz/1.8 Hz and 13.2 Hz/2.1 units. Higher

frequencies >10 Hz could be generated by the first sedimentary layers of the Târnava river terrace with a few meters thickness and shear wave velocities of 100-300 m/s. Amplification occurred for 3 Hz resonance frequency could be due to a thicker stack of sediments with thicknesses of several tens of meters and shear wave velocities > 300 m/s.

18. *Sâncrai-Aiud site* (Fig. 3c) is settled on the terrace of the Mureş river. It is noticed a main peak for 2 Hz with amplifications of 1.75 units. It could be effect of a thicker layer having several tens meters thickness which in our opinion is the river terrace which comprises send, gravel and clay. Other secondary peaks having amplifications ≤ 1.5 units for 3 Hz and 5.5 Hz could be due to some thinner layers of the river terrace. Another peak for 13.8 Hz having an amplification relatively higher than the adjacent peaks could be the effect of shallow layer with a few meters thickness. The relatively low amplification levels noticed within this site could be due to the relatively long distances from the shot points (SP) to site: 22 km for SP Z, 65 km for SP Y, 110 km for SP X and 153 km for SP W.

6. CONCLUSIONS

Seismic records provided by the Vrancea 2001 crustal experiment allowed getting of new information on the local geological and geophysical conditions of the receiver sites located within the western half of seismic line from Păpăuți village (south of Covasna) to Aiud town. Eighteen sites were studied: Păpăuți, Moacşa, Valea Crişului, Aita Mare, Hoghiz, Rupea, Viscri, Grânari, Brădeni, Iacobeni, Copşa Mare, Biertan, Mediaş, Bazna, Boian, Feisa, Sânmiclăuş şi Sâncrai-Aiud.

For each site four records from the nearest four shots were analysed in order to compute the spectral ratio of the horizontal/vertical components. The spectral ratios for each site and shot were obtained by a multi-step processing of the field data. An average of the four spectral ratio curves for each site is done and one standard deviation is computed.

General features of previous findings [1, 2, 3] are once again confirmed: the amplitude and frequency of spectral ratios depend not only on source - receiver distances and of energy released by the seismic source, but also on the local geological and geophysical conditions. We should remark as a common peculiarity that the spectral amplification peaks are located within the same frequency windows, regardless of the position and magnitude of the source, which suggests a strong influence of the local conditions.

A global analysis of the spectral ratio curves for the eighteen sites shows a transition from 1-3 well outlined peaks with high amplifications (>1.5-2 units) to poorly differentiated peaks and low amplifications on the frequency scale.

The best outlined peaks are occurred in the following sites: Copşa Mare (3.3 Hz/2.7 units), Grânari (1.8-2.8 Hz/3.2 units), Hoghiz (2.1 Hz/2.5 units and 6.2-8.2 Hz/ 2 units), Brădeni (2.3 Hz/1.75 units), Iacobeni (2.1 Hz/2.75), Rupea (3.2-4.5 Hz/2.5 Hz), Mediaş (3-5 Hz/1.8-1.9 units) and Boian (3 Hz/1.8 units). At the other end of the scale there are poorly differentiated spectral ratio peaks within the following sites: Aita Mare, Valea Crişului and Feisa. Other sites such as Păpăuți, Moacşa, Viscri, Biertan, Bazna, Sânmiclăuş and Sâncrai present intermediate cases with more or less individualised peaks.

As a last remark the highest peaks are noticed between 1-5 Hz and they could be generated by shallow layers with thickness in the tens of meters range.

Acknowledgement. This study were funded by the Ministry of Education and Research, under Grant no.33357/2004, cod CNCSIS 215. VRANCEA 2001 seismic experiment was funded by German Science Foundation, via CRC 461 of University of Karlsruhe. Three component geophones were provided by GeoForschungZentrum Potsdam, Germany.

REFERENCES

1. V. Raileanu, *Local seismic effects in five sites south of Bacau, Romania, using spectral ratio derived from crustal seismic refraction data*, Romanian Journal in Physics, **46**, *9–10*, 617–627 (2001).
2. V. Raileanu, *Study of the spectral ratios derived from seismic refraction data for evaluation of the local seismic effects in six sites between south of Mizil-west of Giurgiu,* Romanian Journal in Physics, **47**, *9–10*, 919–931 (2002).
3. V. Raileanu, A. Bala, B. Grecu, *An assessment of local seismic effects in sites located from the North of Dobrogeato the Eastern Carpathians Bend,* Romanian Reports in Physics, **57**, *2*, 267–279 (2005).
4. F. Hauser, V. Raileanu, W. Fielitz, A. Bala, C. Prodehl, *VRANCEA99 - The Crustal structure between the southeastern Carpathians and the Moesian Platform from a refraction seismic profile in Romania,* Tectonophysics, **340**, *3–4*, 233–256 (2001).
5. V. Raileanu, A. Bala, F. Hauser, C. Prodehl and W. Fielitz, *Crustal properties from S-wave and gravity data along a seismic refraction profile in Romania,* Tectonophysics, **410**, 251–272 (2005).
6. L.C. Seekins, L. Wennerberg, L. Margheriti and H.-P. Liu, *Site amplification at Five locations in San Francisco, California: A comparison of S-waves, Codas, and Microtremors*, Bull.Seism.Soc.Am, **86,** 627–635 **(**1996).
7. E.H. Field, S.E. Hough and K.H. Jacob, *Using microtremors to assess potential earthquake site response: a case study in Flushing Meadows, New York City,* Bull.Seism.Soc.Am, **80**, 1456–1480 (1990).
8. E. Field, and K. Jacob, *The theoretical response of sedimentary layers to ambient seismic noise* Geoph.Res.Lett., **20**, 2952–2928 (1993).
9. J. Lermo, F.J. Chavez-Garcia, *Site effect evaluation using spectral ratios with only a station*, Bull. Seism.Soc.Am, **83,** 1574–1594 (1993).
10. Y. Nakamura, *A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface*, QR of RTRI, **30**, *1*, 25–33 (1989).

11. H. Kobyashi, K. Seo, S. Midorikawa, T. Samano and Y. Yamazaki, *Seismic microzoning study of Mexico City by means of microtremor measurements*, in: Proc. 4th International Conference on Seismic Zonation, vol.**3**, Earth.Eng.Res.Inst. Stanford, Ca, 557–564, 1991.
12. M. Dravinski, H. Yamamaka, Y. Nakajima, H. Kagami, R. Keshavamurthy and K. Masaki, *Observation of long period microtremors in San Francisco metropolitan area*, in: Proc. 4th International Conference on Seismic Zonation, vol.**3**, Earth.Eng.Res.Inst.Stanford, Ca, 401–407, 1991.
13. K.P. Bonjer, M.C. Oncescu, L. Driad and M. Rizescu, *Weak and strong ground motion of intermediate depth earthquakes from Vrancea region* (F. Wenzel, D. Lungu, O. Novak, eds.), in: *Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation*, Kluwer Acad.Publ., Netherlands, 149–162 (1999).
14. B. Grecu, M. Popa and M. Radulian, *Seismic ground motion characteristics in the Bucharest area: sedimentary cover versus seismic source control*, Rom. Report in Physics, **55**, *3*, 322–331 (2003).
15. S.W. Phillips and K. Aki *Site amplification of coda waves from local earthquakes in Central California*, Bull.Seism.Soc.Am, **76**, 627–648 (1986).
16. C. Lache and P. Bard *Numerical and theoretical investigations on the possibilities and limitations of the "Nakamura's" techniques*, J.Phys.Earth, **42**, 377–397 (1994).
17. C. Lachet, D. Hatzfeld, P. Bard, N. Theodulidis, C. Papaioannou and A. Savvaidis, *Site effects and microzonation in the city of Thessaloniki (Greece): comparison of different approaches*, Bull.Seism.Soc.Am, **86**, 1692–1703 (1996).
18. F. Hauser, C. Prodehl, M. Landes, A. Bala, V. Raileanu, J. Bribach, J. Knapp, C. Diaconescu, C. Dinu, V. Mocanu, W. Fielitz, S. Harder, G.R. Keller, E. Hegedus, R.A. Stephenson, *Seismic target Earthquake-prone Region in Romania*, EOS, Transactions, American Geophysical Union, **83**, *41*, pp 457, 462–463 (2002).
19. K. Stammler *SeismicHandler–Programmable Multichannel Data Handler for Interactive and Automatic Processing of Seismological Data* Computers & Geosciences, **19**, *2*, 135–140 (1993).