

NCSRR DIGITAL SEISMIC NETWORK IN ROMANIA

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SUMMARY

Digital seismic instrumentation donated by *Japan International Cooperation Agency (JICA)* to the *National Center for Seismic Risk Reduction (NCSRR, Romania)* allowed the installation in 2003 of a new Romanian seismic network. In 2005-2006 the network was developed by investments from NCSRR within the budget ensured by *Ministry of Transports, Construction and Tourism (MTCT)*. The NCSRR seismic network contains three types of instrumentation: (i) free-field stations - outside the capital city Bucharest (8 accelerometers), (ii) instrumented buildings - in Bucharest (5 buildings), and (iii) stations with free-field and borehole sensors - in Bucharest (8 sites with ground surface sensor and sensors in 15 boreholes with depths up to 153m). Since its installation, the NCSRR network recorded more than 170 seismic motions from 26 earthquakes with moment magnitudes ranging from 3.2 to 6.0. The seismic instrumentation was accompanied by investigations of ground conditions and site response: PS logging tests, single-station and array microtremor measurements. The development of seismic monitoring in Romania is a major contribution of JICA Project, creating the premises for a better understanding and modelling of earthquake ground motion, site effects and building response.

INTRODUCTION

Seismic activity in Romania is due to Vrancea intermediate-depth subcrustal source (focal depth between 60 and 170 km), and to several shallow crustal sources (Banat, Fagaras, etc.). Vrancea source dominates seismic hazard not only in Romania but also in Republic of Moldova and affects large areas in Bulgaria and Ukraine. Strong Vrancea subcrustal earthquakes produced significant damage and victims in Romania and neighbouring countries.

Worldwide, three major ways are used for reducing seismic risk: (i) better design codes accompanied by more performing construction methods and high quality construction materials, (ii) seismic rehabilitation of existing buildings, and (iii) disaster education of population accompanied by intervention preparation of authorities. The first two ways are strongly supported by the acquisition of strong seismic ground motions, the development of seismic networks being of major concern for engineering community and authorities. Seismic instrumentation is essential for the proper establishment of input ground motion for design and for the seismic evaluation and rehabilitation of existing buildings. United States of America and Japan are the major examples of countries understanding the need for improved seismic instrumentation and taking serious actions in this direction.

United States Geological Survey clearly states [USGS, 1995]: "Strong-motion data collected by the USGS have contributed to the improvement of building codes over the decades. These improved codes have saved many lives and reduced damage in recent earthquakes. A growing network of instruments will provide even more extensive data in earthquakes to come. Using this information, scientists and engineers will be able to suggest further improvements to building codes. These improvements will help protect citizens of the United States from loss of life and property in future earthquakes".

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The same understanding exists in Japan where not only there are dense national seismic networks, but local authorities, education and research institutions, and companies also developed their own networks. *K-NET* [*Kyoshin Net*] is one of the most impressive networks in seismic instrumentation. After 1995 Great Hanshin Earthquake, as a proof of understanding the necessity of making available for research seismic ground motions, 1000 free-field digital stations were deployed all over Japan, with an average station to station distance of ~25km. The records are acquired by telemetry and data is available via Internet.

At the *First International Workshop on Vrancea Earthquakes* [Wenzel and Lungu, 1999] held in Bucharest in 1997, the working group "Strong Ground Motion" chaired by Prof. B.Bolt made the following statement: "We recommend the establishment of a National Strong-Motion Program to provide an earthquake recording capability that is vital for earthquake risk reduction and public earthquake safety. The distribution of strong motion equipment should follow the main seismotectonic and geologic features, including local soil condition, and also focus on the instrumentation of representative buildings, industrial structures."

The development of seismic instrumentation in terms of quantity and quality represents a continuous concern and effort of Romanian and foreign institutions and/or projects. Significant efforts were done within *German Research Foundation SFB461* Project [SFB461], *Japan International Cooperation Agency JICA* Project [JICA], and with investments by *State Inspectorate for Constructions*, these activities being implemented by in Romania by *National Institute for Earth Physics (NIEP)*, *National Center for Seismic Risk Reduction (NCSRR)*, and *National Institute for Building Research (INCERC)*. The present paper presents the instrumentation efforts done within the *JICA* project.

NCSRR SEISMIC NETWORK

Within the *JICA* Project in Romania entitled "Seismic risk reduction for buildings and structures" [JICA, 2002], *NCSRR* received seismic instrumentation equipments (*Kinometrics*). *OYO Seismic Instrumentation Corp.* and *NCSRR* installed the equipments in 2003. In 2005-2006 *NCSRR* network was enlarged with Romanian investment (within the budget ensured by *Ministry of Transports, Construction and Tourism MTCT*), other sites being instrumented with *Geosig* equipments and technical support. *NCSRR* network [Aldea *et al.*, 2004, 2006a] contains 3 types of instrumentation: free-field stations (outside Bucharest), instrumented buildings and stations with ground surface and boreholes sensors (in Bucharest).

Free-field seismic stations for ground motion attenuation analysis

Six *Kinometrics ETNA* stations were installed in 2003 on the SW direction starting from Vrancea epicentral area toward Bucharest, for ground motion attenuation analysis. All of them are in buildings with 1 or 2 storeys, which can be considered as a free field condition. Ground conditions are not yet known. Two *Geosig IA-1* accelerometers were installed in 2006 and 2007, on a perpendicular axis to the SW. Details about the free-field stations are given in Table 1, and their distribution is in Figure 1.

Table 1: *NCSRR seismic network - free-field stations in Romania*

No.	Site	Station ID	Sensor location	Equipment
1	Giurgiu	GRG	Ground Floor of 2 storey bldg.	<i>ETNA (Kinometrics)</i>
2	Ploiesti	PLO		
3	Focsani	FOC	GF of 1 storey bldg.	
4	Buzau	BUZ		
5	Ramnicu Sarat	RMS		
6	Urziceni	URZ		
7	Constanta	CST	Free-field	<i>IA-1 (Geosig)</i>
8	Brasov	BRV		

Seismic stations for structural monitoring

Two residential buildings and two public buildings were instrumented in 2003. In 2006 the *Technical University of Civil Engineering Bucharest UTCB* main building was also instrumented. Details about *NCSRR* building instrumentation are given in the present proceedings [Aldea *et. al.*, 2007a].

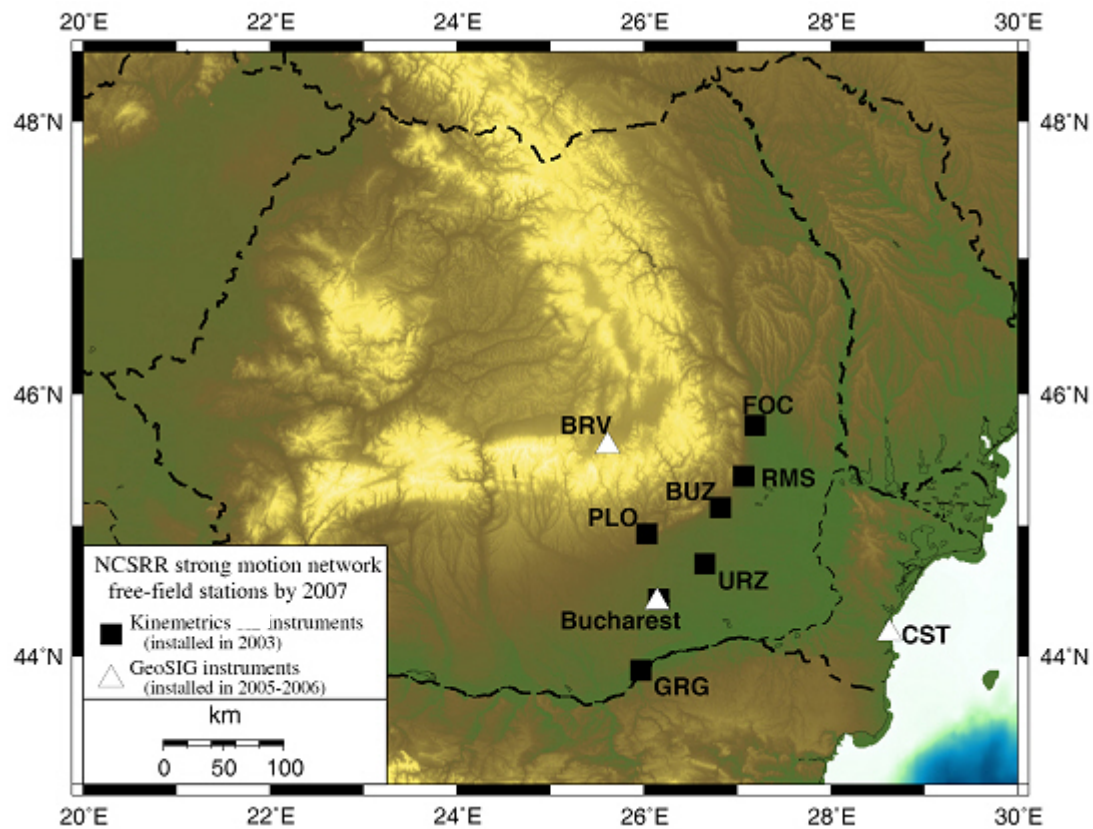


Figure 1: NCSRR free-field seismic network in Romania

Seismic stations for site effects assessment in Bucharest

NCSRR installed in 2003 in Bucharest seven (7) *Kinematics K2* stations with sensors at ground surface (close to free-field conditions) and in boreholes at two levels of depth: the first level at about 30m depth and the second level between 50m and 153m depth. In 2005 another site was instrumented with *Geosig* equipments (free-field and a 30m depth borehole). At all the stations the soil profile of the boreholes is known, and NCSRR and *Tokyo Soil Corp.* (Japan) performed down-hole tests. A brief description of the borehole instrumentation is given in Table 2 and their location within Bucharest in Figure 2.

Table 2: NCSRR Bucharest seismic stations with sensors at ground-surface and in boreholes

No.	Site	Station ID	Surface sensor location	Depth of sensor in shallow borehole, m	Depth of sensor in deep borehole, m	Equipment
1	UTCB Tei	UTC1	free field	-28	-78	<i>K2 + FBA-23DH (Kinematics)</i>
2	UTCB Pache	UTC2	1 storey building	-28	-66	
3	NCSRR/INCERC	INC	1 storey building	-24	-153	
4	Civil Protection Hdq.	PRC	1 storey building	-28	-68	
5	Piata Victoriei	VIC	free field	-28	-151	
6	City Hall	PRI	free field	-28	-52	
7	Municipal Hospital	SMU	free field	-30	-70	
8	UTCB Plevnei	UTC3	free field	-30		<i>GSR24+AC23 DH (Geosig)</i>

Sampling rate is set at 100Hz, pre-trigger time is 30s, post-trigger time is 60s, and full scale is $\pm 2g$ for all stations. For *Kinematics* stations time is set by GPS, for *Geosig* stations it is set by internet-time-servers. *Kinematics* stations are stand-alone stations, but recently GSM data retrieval is implemented with support from *JICA* and *Orange*. *Geosig IA-1* stations are internet based, while *GSR* station is stand-alone.

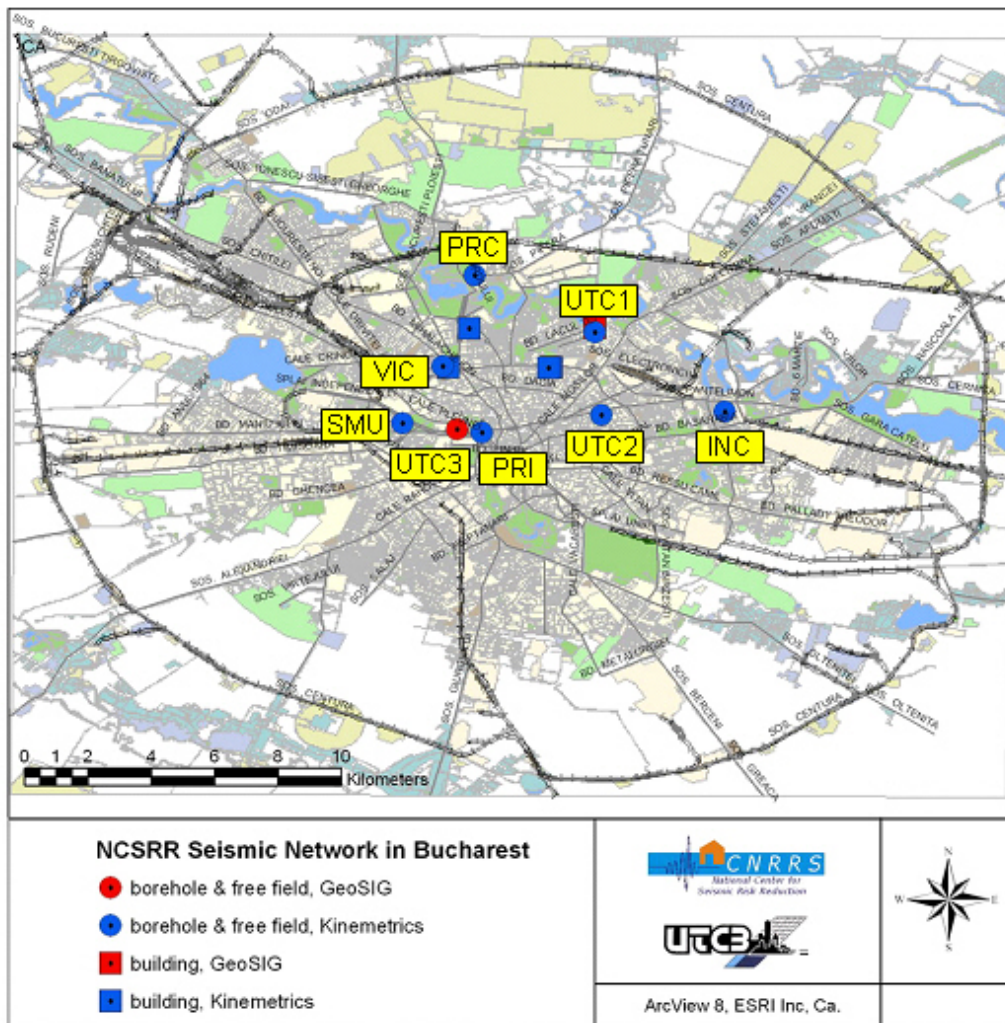


Figure 2: NCSRR seismic network in Bucharest

EARTHQUAKE RECORDS

Since its installation in 2003, the NCSRR network recorded more than 170 seismic motions from 26 earthquakes with moment magnitudes ranging from $M_w=3.2$ to 6.0 .

Between the earthquakes recorded by NCSRR network, 21 are from Vrancea subcrustal source, 2 from Vrancea crustal source, 2 from shallow sources in Bulgaria and 1 from North-Dobrogea shallow source. A synthesis of the distribution of the records with regards to the seismic source and type of instrumentation is given in Table 3, the main characteristics (as indicated on NIEP and EMSC websites) of the recorded seismic events are presented in Table 4 and the location of these events is shown in Figure 5. It can be observed that 95% of the seismic records are due to Vrancea subcrustal source.

Table 3: Distribution of NCSRR seismic records with source type and instrumentation type

Earthquake source	No. of recorded earthquakes	No. of records	Distribution of no. of records with instrumentation type		
			Free-field	Buildings	Boreholes
Vrancea subcrustal	21	165	51	41	73
Vrancea crustal	2	2	2	-	-
Bulgaria shallow	2	5	-	-	5
North Dobrogea shallow	1	2	1	-	1
Total	26	174	54	41	79

Table 4: Characteristics of the seismic events recorded by NCSRR seismic network

No.	Date	Seismic source	Origin time (UTC)	Coordinates		Focal Depth (km)	Moment magnitude M_w	
				lat.	long.			
				(°N)	(°E)			
1	05/10/2003	Vrancea subcrustal	21:38:18	45.57	26.46	145.6	4.6	
2	17/12/2003	Bulgaria crustal	23:15:15	43.19	27.44	60.0	4.6	
3	24/12/2003	Vrancea subcrustal	13:44:59	45.06	26.08	86.0	3.8	
4	21/01/2004		05:49:10	45.6	26.4	117.7	4.1	
5	07/02/2004		11:58:22	45.72	26.64	146.0	4.4	
6	30/04/2004	Vrancea crustal	09:19:36	45.6	27.13	16.9	3.2	
7	14/05/2004	Bulgaria crustal	11:09:37	43.5	26.5	10.0	*	
8	10/07/2004	Vrancea subcrustal	00:34:58	45.52	26.49	150.4	4.3	
9	27/09/2004		09:16:23	45.69	26.32	166.1	4.6	
10	03/10/2004	North-Dobrogea	09:02:01	45.16	29.09	5.0	5.1	
11	27/10/2004	Vrancea subcrustal	20:34:32	45.83	26.77	98.6	6.0	
12	17/11/2004		11:31:02	45.74	26.72	127.4	4.4	
13	14/05/2005		01:53:22	45.67	26.47	144.0	5.2	
14	18/06/2005		15:16:40	45.79	26.91	135.0	5.0	
15	05/09/2005		14:23:35	45.76	26.62	90.0	4.4	
16	08/09/2005		16:35:50	45.52	26.37	140.0	4.3	
17	10/09/2005		Vrancea crustal	04:56:55	45.25	27.21	22.0	3.8
18	26/10/2005		Vrancea subcrustal	22:51:21	45.66	26.57	141.8	4.3
19	13/12/2005			12:14:45	45.78	26.79	144.0	4.8
20	18/12/2005			15:09:43	45.41	26.04	60.0	3.7
21	16/02/2006	02:49:40		45.71	26.66	130.0	4.1	
22	06/03/2006	10:40:46		45.69	26.53	145.0	4.8	
23	19/03/2006	11:05:53		45.65	26.48	157.8	4.4	
24	23/09/2006	Vrancea subcrustal	05:44:07	45.54	26.40	130.8	4.3	
25	17/01/2007		13:17:22	45.56	26.41	120.0	4.3	
26	14/02/2007		06:56:34	45.49	26.52	159.4	4.2	

* not reported by agencies

In Figure 4 are represented the magnitudes versus the focal depths of the recorded Vrancea subcrustal earthquakes. The average magnitude of recorded events is ≈ 4.5 , and the average focal depth is 130 km.

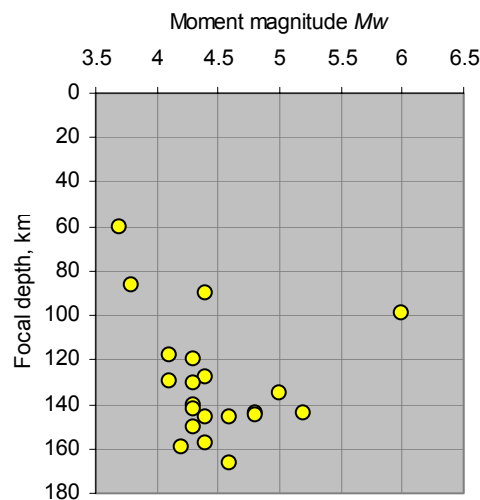


Figure 4: Distribution of magnitudes versus focal depth of recorded earthquakes

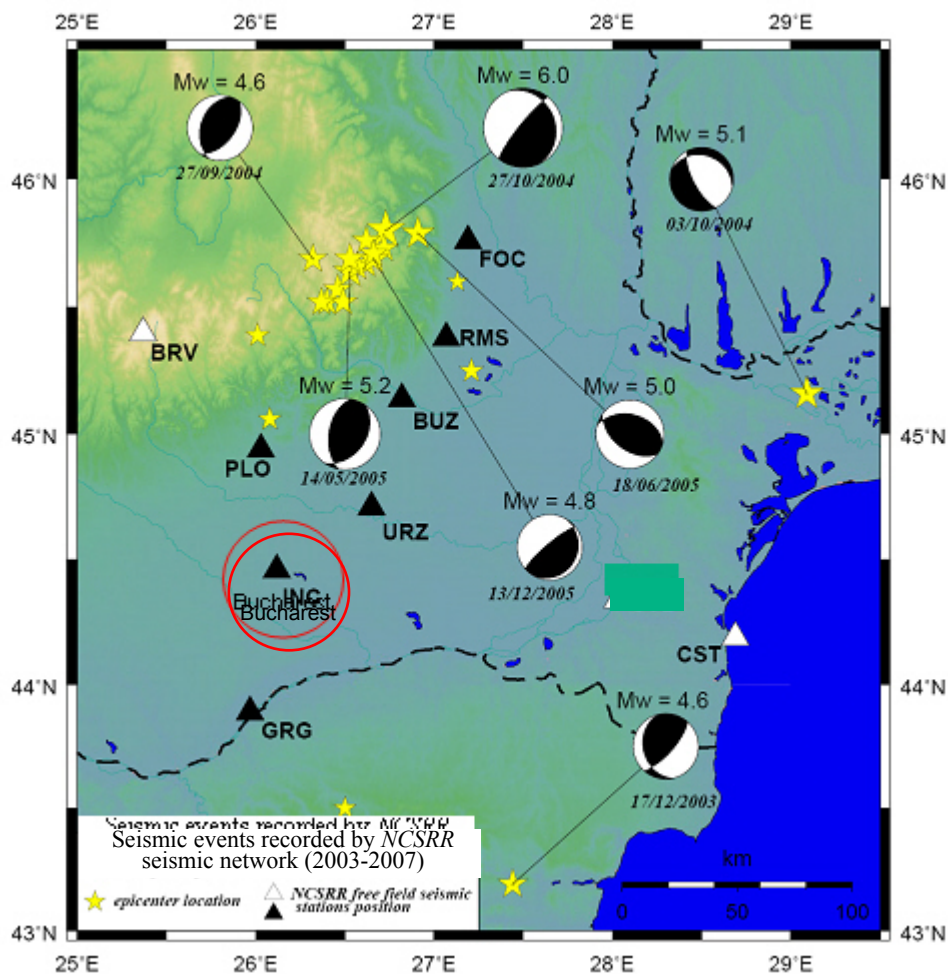


Figure 5: Epicentre location map of seismic events recorded by NCSRR seismic network (fault plain solutions from Harvard CMT and ETHZ)

Earthquake records outside Bucharest

The free-field seismic stations recorded 54 seismic motions (number of records per station: BUZ - 9, FOC - 11, GRG - 5, PLO - 8, RMS - 9, URZ - 12) from which 51 motions due to Vrancea subcrustal earthquakes. In Figure 6 is presented the distribution of magnitudes with epicentral distances corresponding to the existing records (only for the events from Vrancea subcrustal source).

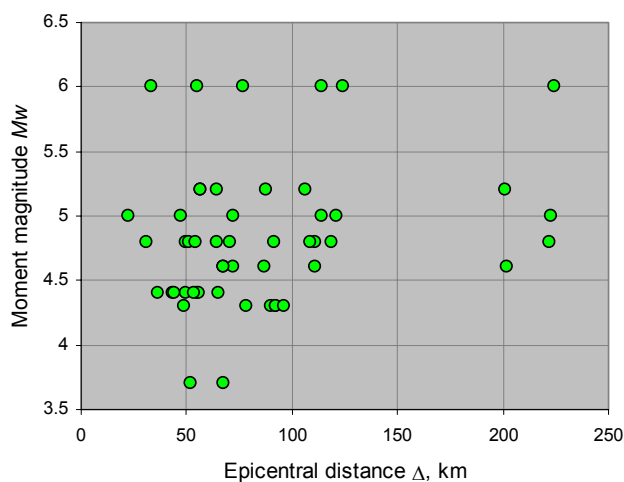


Figure 6: Distribution of magnitudes with epicentral distances of records

In Figure 7 are shown the distribution of maximum horizontal peak accelerations (left) and the distribution of Japan Meteorological Agency seismic intensity (right) with epicentral distance, for the records outside Bucharest (to be used in ground motion attenuation studies), due to Vrancea subcrustal events.

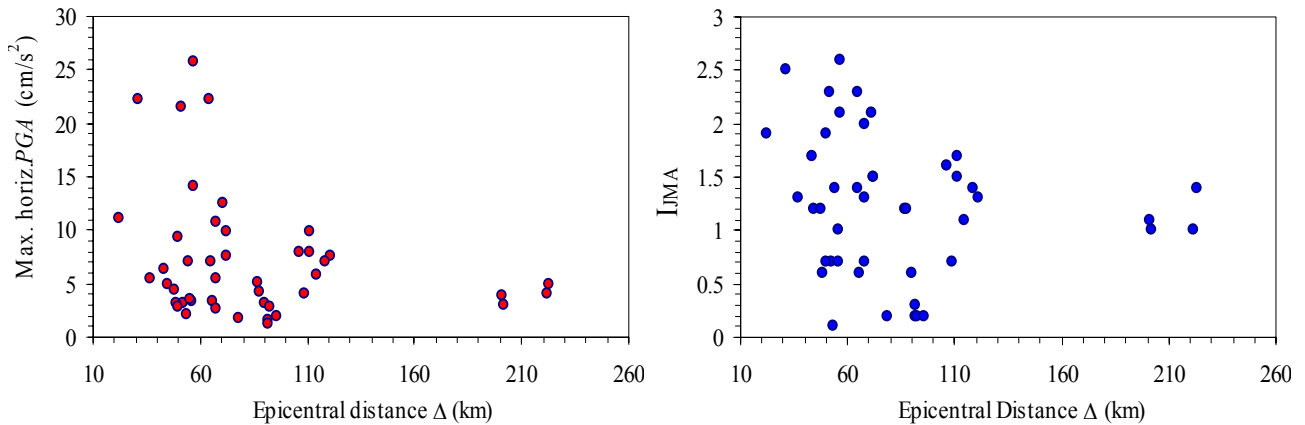


Figure 7: Distribution of max. PGA and I_{JMA} with epicentral distance for the records outside Bucharest

The data from the strongest earthquake (Oct.27, 2004) are not represented in Figure 3 for scaling reasons; those values are indicated in next chapter. One can notice that for the seismic events with moment magnitudes up to 5.2, the maximum peak accelerations are below 30cm/s^2 (the majority of data below 15cm/s^2). The JMA seismic intensities are below 3 for all these small earthquakes.

The attenuation law for strong ground motions due to Vrancea subcrustal earthquakes developed by Lungu *et al.* [1999], is used for predicting PGA attenuation for two scenarios: (i) $M_W=4.5$ and $h=130\text{km}$ (average values for the recorded database), and (ii) $M_W=6$ and $h=98.6\text{km}$ (the largest recorded event). The attenuation relation format is:

$$\ln PGA = c_0 + c_1 M_W + c_2 \ln R + c_3 R + c_4 h + \varepsilon \quad (1)$$

where: PGA is peak ground acceleration at the site, M_W - moment magnitude, R - hypocentral distance to the site, h - focal depth, c_0, c_1, c_2, c_3, c_4 - data dependent coefficients and ε - random variable with zero mean and standard deviation $\sigma_\varepsilon = \sigma_{\ln PGA}$.

The regression was performed using data from three strong Vrancea events (04/03/1977, 30/08/1986 and 30/05/1990), i.e., the max. peak ground acceleration from 80 records from Romania, Moldova and Bulgaria [Lungu *et al.*, 1999]. In Figure 8 are compared the max PGA recorded within $NCSR$ network and the attenuation curves corresponding to the scenarios described above. A satisfactory match can be observed.

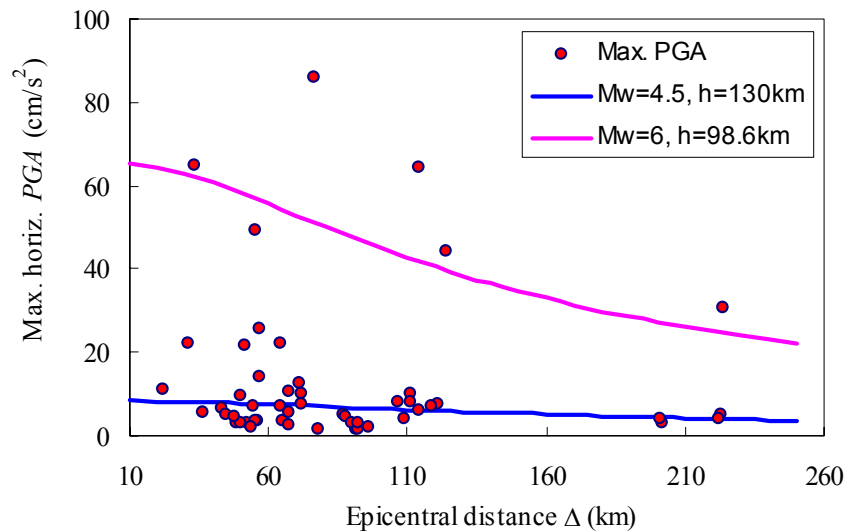


Figure 8: Comparison of recorded data with attenuation curves

Earthquake records inside Bucharest

The seismic stations inside Bucharest recorded a total of 120 motions, from which 41 at building stations and 79 at stations with boreholes (number of records per station: UTC1 - 11, UTC2 - 16, UTC3 - 2, INC - 14, PRC - 11, VIC - 4, PRI - 6, SMU - 15). Information about records in buildings is given in the present proceedings [Aldea *et al.*, 2007a].

In Figure 9 is presented the distribution with earthquake magnitude of the maximum horizontal peak accelerations recorded at the stations with boreholes. The data from the strongest earthquake (Oct.27, 2004) is not represented for scaling reasons; those values are indicated in next chapter.

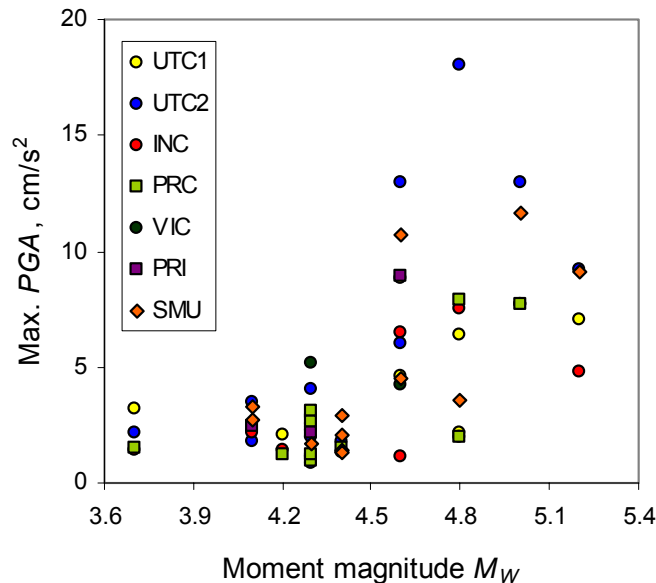


Figure 9: Distribution of max. PGA with magnitude for the records inside Bucharest

For the earthquakes with magnitude $M_w < 4.5$, all accelerations are smaller than $15 cm/s^2$. For the earthquakes with magnitudes between 4.5 and 5.2 the peak accelerations are generally in between 5 and $15 cm/s^2$. It can be also noticed that in general the largest peak accelerations were recorded at UTC2 and SMU stations. However, the data from these small earthquakes and limited number of stations does not indicate a clear difference between different zones within the city, as it was observed clearly during the Aug.30, 1986 strong event ($M_w = 7.2-7.3$), as shown in the microzonation map (Lungu *et al.*, 1997, Aldea, 2002).

27th OCTOBER 2004 VRANCEA SUBCRUSTAL EARTHQUAKE ($M_w = 6.0$)

The October 27, 2004 Vrancea earthquake ($M_w = 6.0$, focal depth 98.6km) is the strongest recorded until now by the NCSR seismic network and is the strongest event since 1990. The earthquake was felt on large areas and produced almost no damage as reported by news agencies. A summary of news is presented here.

"Authorities said there were no immediate reports of injuries or damage. It struck at 11:34 p.m. and was felt in several Romanian cities, including Iasi, Bacau and the capital, Bucharest, where it knocked out telephone service. The quake also rattled portions of Turkey, Moldova and Ukraine, Turkey's private NTV television reported. In some Istanbul neighbourhoods, people rushed out of their homes in panic, NTV said. The observatory's telephone lines were jammed with people calling seeking information." *Associated Press*

"An earthquake hit Romania on Wednesday night, shaking buildings in the Bucharest but apparently causing little damage, Reuters witnesses said. Hundreds of people called emergency services soon after the quake struck at 11:24 p.m., but ambulance officials told Reuters nearly all of them were suffering panic attacks and it seemed there were no serious casualties. Bucharest's streets were mainly calm, but some people gathered on main avenues in their nightclothes, waiting for news and trying to find out what had happened.

"No victims or collapsed buildings have been reported in Bucharest so far but we have been flooded with phone calls from people asking if they should abandon their homes," a police emergency center spokesman

said. An ambulance controller in the capital added: <We got about 300 phone calls, mostly from people having panic attacks in the first hour after the quake.> A spokesman for the Interior Ministry, D. Marcel, said so far not there had been no reports of significant damage. Witnesses said cracks had appeared in Bucharest's historic City Hall and plaster was falling off. Residents feared they would see more evidence of damage at first light. In Braila, eastern Romania, the wall of an abandoned building collapsed and the windows of office building had been shattered, the Interior Ministry's Marcel added. Bulgarian civil defense officials said the tremors had been felt on their side of the border, but it was too early to tell if there was any significant damage in the country." *Reuters*

All *NCSRR* seismic stations outside Bucharest recorded the event, the peak ground accelerations are given in Table 5. One may notice the highest horizontal *PGAs* at Focsani, Buzau and Ploiesti stations, with the maxima of 86cm/s^2 (EW comp.) at Buzau. A peculiar powerful vertical motion was recorded at Ramnicu Sarat with a P waves peak of 219.6cm/s^2 .

Table 5: Oct. 27, 2004 Vrancea earthquake - *PGA* at *NCSRR* free field stations

Station name	Station ID	Peak ground acceleration <i>PGA</i> , cm/s^2		
		NS	EW	Vertical
Focsani	FOC	62.9	64.6	82.2
Ramnicu Sarat	RMS	41.4	49.0	219.6
Buzau	BUZ	67.9	86.0	80.8
Urziceni	URZ	33.7	44.3	38.9
Ploiesti	PLO	64.5	49.2	34.8
Giurgiu	GRG	22.9	30.6	15.3

The *Japan Meteorological Agency* seismic intensity had values below 4: 3.9 (FOC), 3.6 (RMS and BUZ), 3.5 (PLO), 3.4 (URZ), and 2.8 (GRG). *JMA* seismic intensity 3 is described as follows: "Felt by most people in the building. Some people are frightened. Dishes in a cupboard rattle occasionally. Electric wires swing slightly.", and *JMA* intensity 4 "Many people are frightened. Some people try to escape from danger. Most sleeping people are awakened. Hanging objects swing considerably and dishes in a cupboard rattle. Unstable ornaments fall occasionally. Electric wires swing considerably. People walking on a street and some people driving automobiles feel the tremor." Even the *JMA* intensity is computed with a formula calibrated using Japanese records and corresponding damage, these descriptions generally match the newspaper data.

In Bucharest, all stations with boreholes recorded the Oct.27, 2006 earthquake ($M_w=6$) except VIC one (due to the absence of electric supply). The recorded peak ground accelerations *PGA* are presented in Table 6. All *NCSRR* instrumented buildings in Bucharest recorded the earthquake. Details are given in the present proceedings [Aldea *et. al.*, 2007a].

Table 6: Oct. 27, 2004 Vrancea event - peak accelerations at *NCSRR* stations in Bucharest

Station		UTC1			UTC2			INC			PRC			PRI			SMU		
		NS	EW	V	NS	EW	V	NS	EW	V	NS	EW	V	NS	EW	V	NS	EW	V
Surface	<i>PGA</i>	34.9	58.4	34.4	41.6	40.9	24.8	29.7	29.6	24.9	29.0	49.2	34.0	29.8	79.0	33.1	54.6	44.5	50.8
Shallow sensor	Depth	-28 m			-28 m			-24 m			-28 m			-28 m			-30 m		
	<i>PGA</i>	28.5	14.6	11.1	21.6	16.8	11.5	13.9	12.5	8.3	20.3	13.1	11.2	16.6	37.7	11.8	11.6	18.5	8.2
Deep sensor	Depth	-78 m			-66 m			-153 m			-68 m			-52 m			-70 m		
	<i>PGA</i>	16.5	23.1	9.8	15.6	23.5	7.0	11.3	11.4	6.7	12.7	19.4	8.8	13.2	22.2	9.6	12.6	18.1	8.9

A certain variability within the city can be observed, with highest values in the vicinity of Dambovitza river (PRI and SMU), and with the lowest value in eastern Bucharest (INC). It can be noticed that the top ~30m of soil had the most important contribution for the level of the *PGA* by at least doubling the recorded values, while from the deep borehole to the shallow one there are no major changes. The *JMA* intensity computed from the ground surface records was: 3.4 (SMU), 3.3 (UTC2), 3.2 (UTC1 and PRI), 3.0 (INC and PRC).

The surface/borehole spectral ratio (SBSR) method has pro and contra arguments (Atakan, 1998 and Safak, 1997). Since the *NCSR*R sensors in deep boreholes are not located on/in the bedrock, the SBSR does not give a complete image on the site response, but gives information on the response during earthquakes of the soil column between two sensors. The surface (S) over deep borehole (B2) spectral ratios for the 27/10/2004 event are presented in Figure 10 (where the two lines indicate the B2/S ratios for EW and NS components). The frequencies corresponding to the first identified peaks in Figure 10 are given in Table 7.

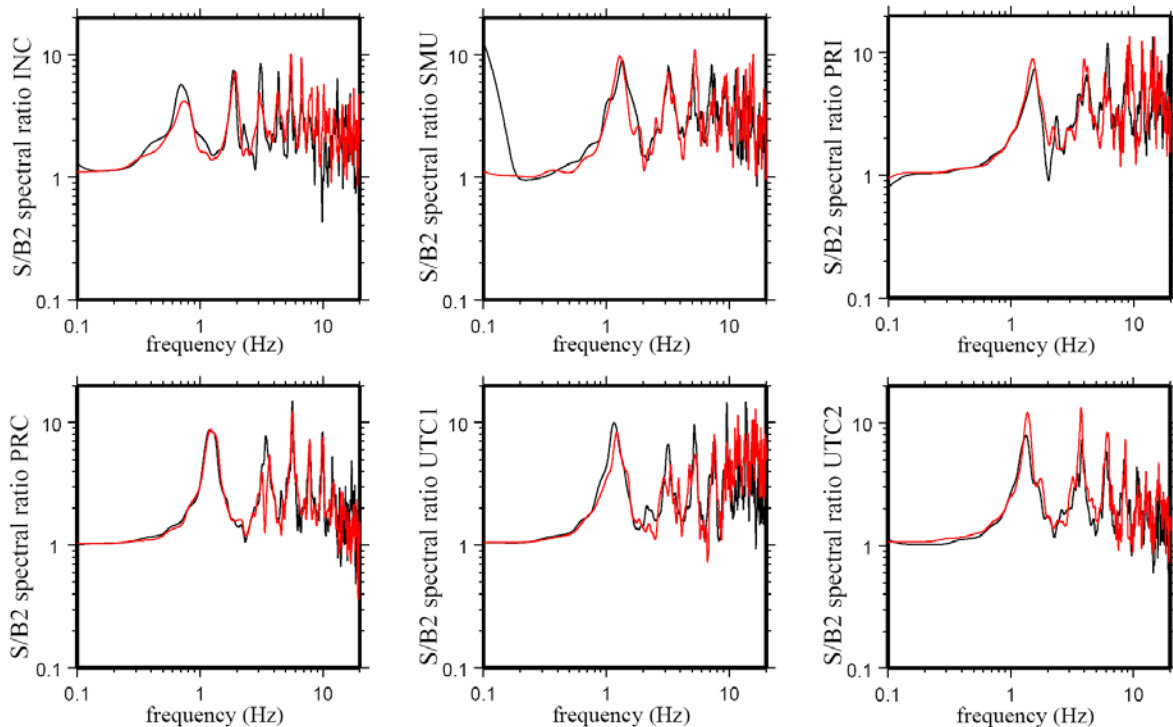


Figure 10: SBSR at *NCSR*R seismic stations in Bucharest (27/10/2004 earthquake)

Table 7: First frequency peak identified from SBSR (27/10/2004 earthquake)

Station	PRI	UTC2	PRC	SMU	UTC1	INC
B2 borehole depth	-52 m	-66 m	-68 m	-70 m	-78 m	-153 m
f_1 (Hz) from SBSR	1.53	1.35	1.21	1.32	1.19	0.7

It can be observed that, in general, deeper the borehole sensor lower the frequency corresponding to the first spectral peak. In case of sites with deep sediments (as in the case of Bucharest), the site response and the site conditions should be analysed by considering the whole thickness of sediments until the bedrock, and not only the top 30m. INCERC site gives an instrumental proof that the soil category and the design spectrum selected by using only the upper 30 m of soil can be a misleading approach, the strong earthquakes of 1977 ($M_w=7.5$) and 1986 ($M_w=7.2-7.3$) having response spectra with large values at long periods, much larger than those from EC 8 spectra (corresponding to the site category based on the top 30m of soil). The long-period phenomenon was explained by the contribution of two factors: the source characteristics in case of strong Vrancea events and the site conditions (thick sediments with probably non-linear behaviour during strong earthquakes). Even the SBSR presented in Figure 4 are characterising the soil column response between the two sensors in elastic range, they show that soil thickness has an important contribution in the site response, and that the ground vibration fundamental period tends to be closer or even higher than 1 sec.

As an example, in Figure 11 is presented the evolution with depth of the accelerograms recorded at INC station (EW components). In Figure 12 are presented the evolutions with depth of acceleration and velocity response spectra, of Fourier amplitude spectra and of H/V Fourier amplitude spectral ratios. In higher frequency domain the upper 24m have a significant impact. In the low frequency domain, the impact of the upper 24 m becomes insignificant, except for the velocity spectra. It should be noticed that even at 153m depth there is an important content of low frequencies, and a clear peak appears around 0.4-0.5Hz.

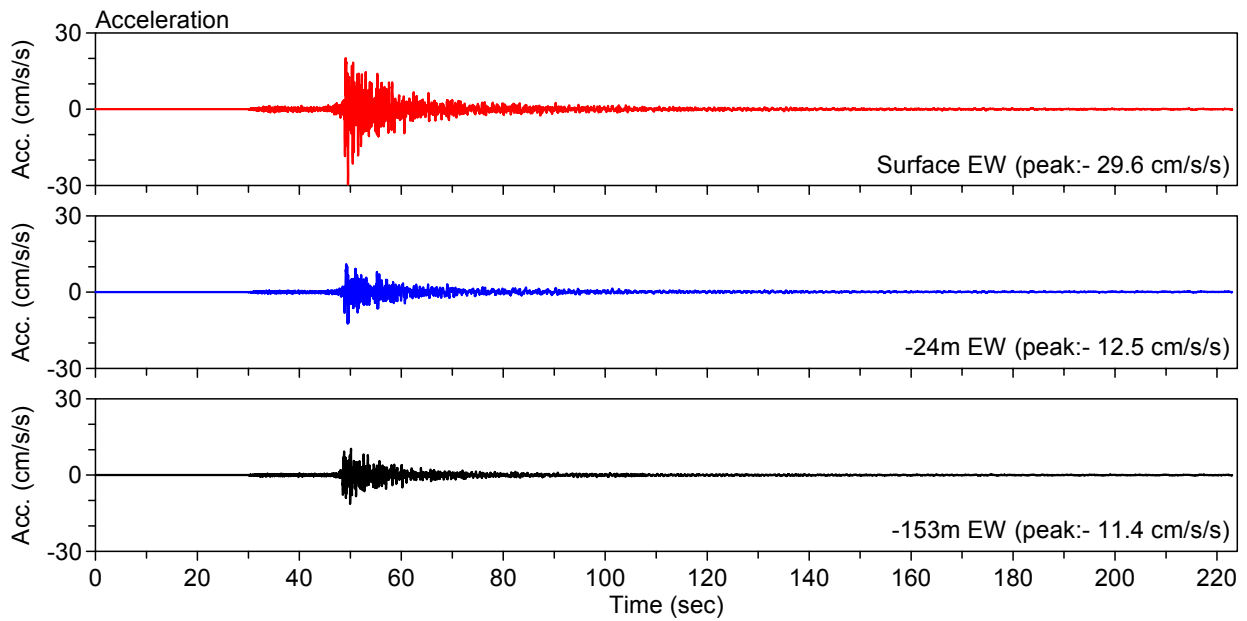


Figure 11: Evolution with depth of the accelerograms recorded at INC station (EW comp.), 27 Oct. 2004

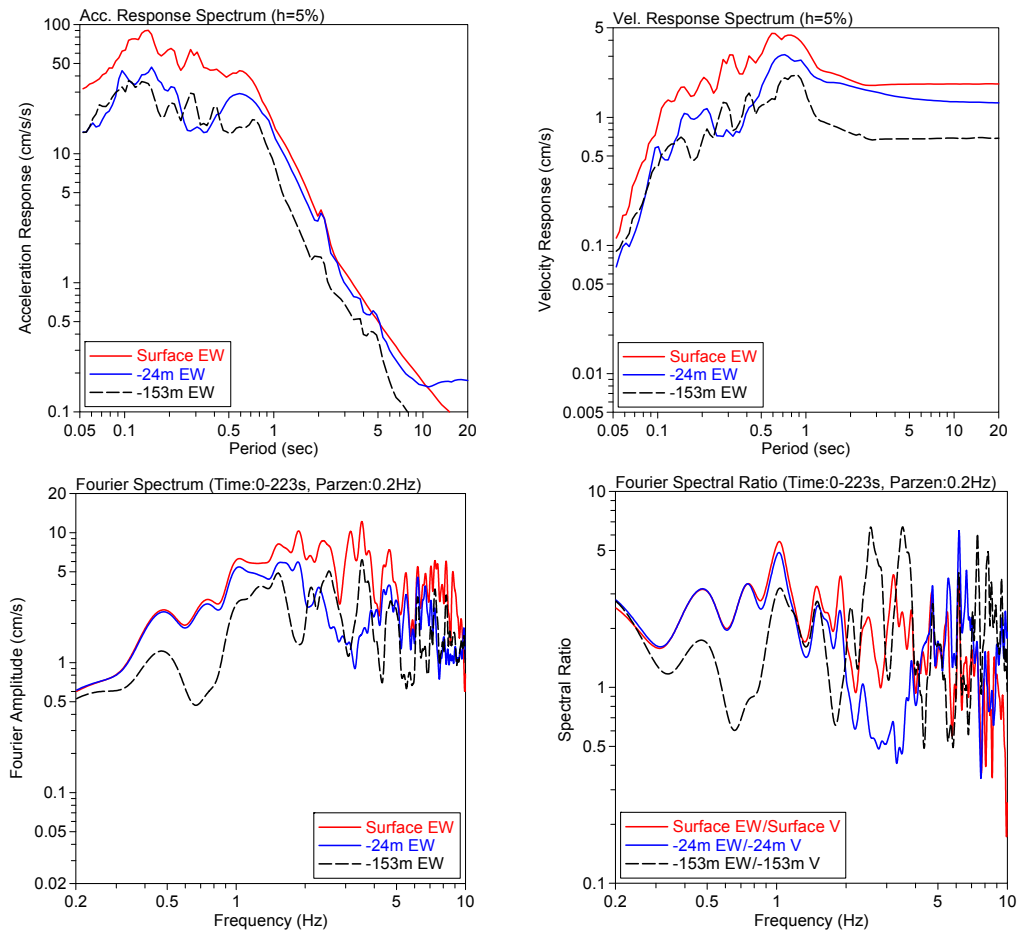


Fig.12: INC: evolution with depth of acceleration & velocity response spectra, of Fourier spectra & H/V ratio

Since a reference nearby rock site is not available in Bucharest area, a non-reference site technique (the single station H/V Fourier amplitude spectral ratio) can be used for estimating the site response characteristics. Despite a lack in theoretical justification, the single station spectral ratio was tested successfully for soil sites by an increasing number of authors [example Lermo and Chavez-Garcia, 1993]. In Figure 13 are comparatively presented the H/V spectral ratios at ground surface, at the shallow sensor B1 (-24m) and at the deep sensor

B2 (-153m), computed using the whole record, the S-wave part, the coda/surface-wave part and the P-wave part. A first peak (not of largest amplitude) appears constantly around $0.4-0.5\text{Hz}$, when using the whole record, the S-wave part and the coda/surface-wave part.

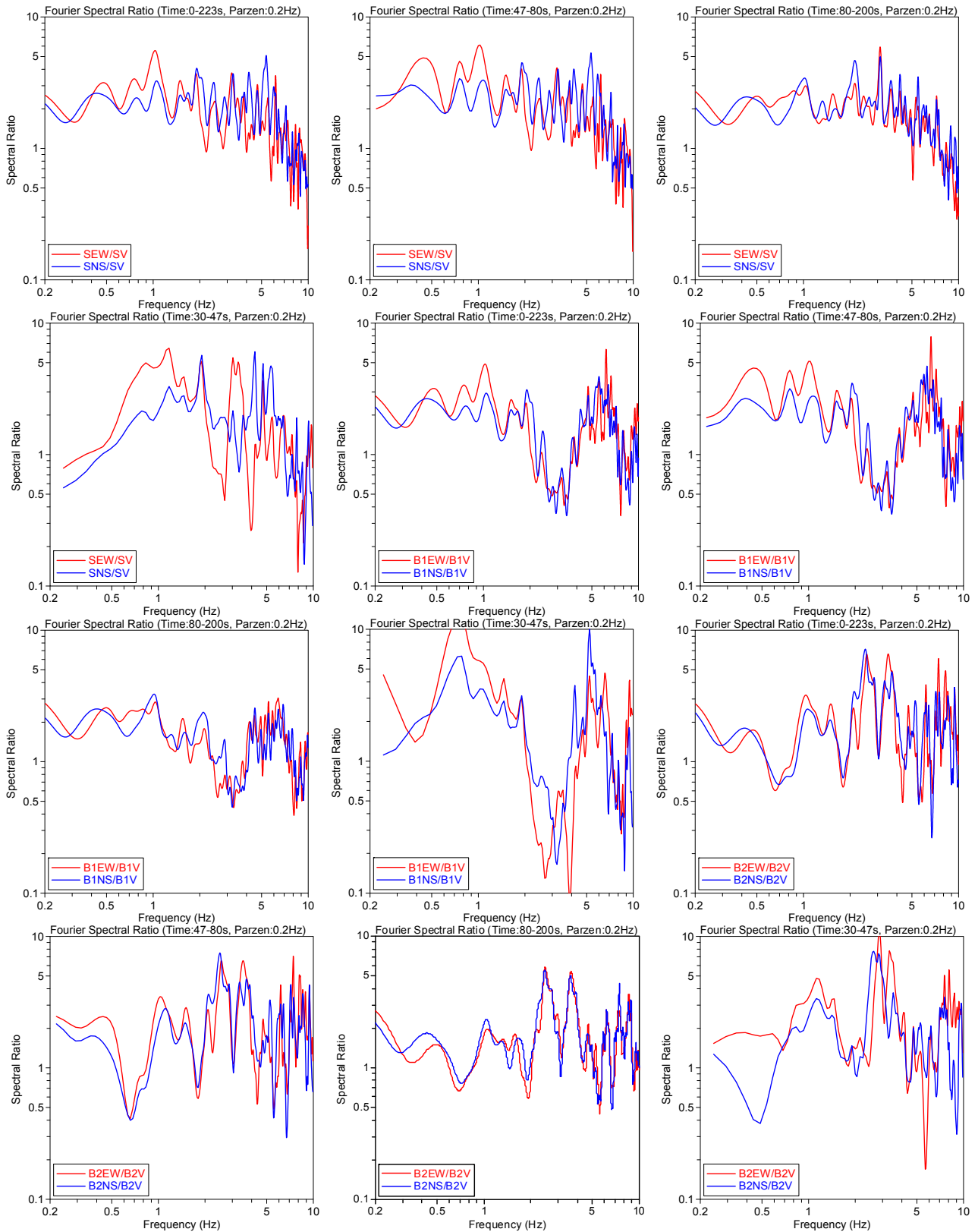


Figure 13: INC (27/10/2004): H/V spectral ratios at ground surface, at the shallow sensor B1 (-24m) and at the deep sensor B2 (-153m), computed using the whole record, the S-wave part, the coda/surface-wave part and the P-wave part of the record.

PS LOGGING TESTS AT THE SEISMIC STATION SITES

At all the stations the soil profile/stratigraphy of the boreholes is known, and *NCSRR* and *Tokyo Soil Research Co., Ltd.* performed in 2003 down-hole tests for the estimation of the seismic velocities profiles at all sites (Aldea *et al.*, 2006b).

In Table 8 are presented the weighted average (*UBC* formula) shear wave velocity (V_s) for seven sites (using the upper 30m, the upper 52 m and the whole investigated depth). It can be observed that the differences between the sites are not significant when looking at the average on 52m and some differences (up to 50%) exists at the average on 30m. The sites are classified as "hard soil"-class D according to *UBC 1997*, and "Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of m" class C according to *Eurocode 8*. In the mentioned codes, these ground classes are associated with a control period of response spectra $T_c \approx 0.6s$, which is not in agreement with the real situation in Bucharest, where during August 30, 1986 Vrancea earthquake the values of T_c were higher than $0.6s$ all over the city (Lungu *et al.*, 1997, Aldea, 2002). In the future editions of the Romanian earthquake resistant design code, the ground categories may also be related to the predominant period of the site, supplementary to the characteristics of the upper 30m of soil profile, since the important thickness of medium-to-hard sediments can also induce long periods motions with high spectral amplifications beyond 1 second. The influence of soil thickness on the predominant periods in Table 8 is self-explanatory.

Table 8: Average shear wave velocity at NCSRR stations based on down-hole tests

Station	PRI	UTC2	PRC	SMU	UTC1	INC	VIC
Average (30m) V_s , m/s	219	288	293	245	309	270	284
Predominant frequency (30m), Hz	1.83	2.40	2.44	2.04	2.58	2.25	2.37
Average (52m) V_s , m/s	258	318	309	281	326	302	310
Predominant frequency (52m), Hz	1.24	1.53	1.49	1.35	1.57	1.45	1.49
Average V_s , m/s (whole borehole depth, m)	258 (52m)	332 (66m)	324 (68m)	303 (69m)	349 (78m)	364 (140m)	354 (110m)
Pred. freq. (whole investigated depth), Hz	1.24	1.26	1.19	1.10	1.12	0.65	0.81
f_1 (Hz) from SBSR (27/10/2004 event)	1.53	1.35	1.21	1.32	1.19	0.7	-

In Table 8 are also computed the predominant frequencies using an approximate formula (average V_s over four times the total considered thickness). When estimating the predominant frequency by using the whole investigated depth, the predominant frequency values start to be similar to those obtained from SBSR ratio (Table 7).

The H/V ratios of the ground surface records from Oct.27, 2004 indicate in Bucharest a ground vibration rather rich in low frequencies, all the ratios displaying significant amplitudes around $1Hz$ and/or below [Aldea *et al.*, 2007b]. A first peak (not of largest amplitude) appears constantly around $0.4-0.5Hz$, a second one around $0.7-0.8Hz$, and a third one again quite constantly around $1Hz$. In a rough approximation, considering a quaternary layer with $h=300m$ thickness and $V_s=450m/s$ shear wave velocity, the vibration frequency $f=V_s/4h=0.38Hz$.

Bonjer *et al.* (1999) indicated for all over the city a peak of $\sim 0.7Hz$ obtained from microtremor measurements, and also reported a $0.5Hz$ peak using records from May 30, 1990 Vrancea event. It should be noticed that at INCERC site (INC station) a peak at $0.7Hz-0.8Hz$ was reported by Lungu *et al.*, [1997] using power spectral density H/V ratio for March 4, 1977 earthquake records. Also, at INCERC site the same $0.7Hz-0.8Hz$ peak was obtained from H/V Fourier spectral ratios and H/V displacement response spectra ratios for 1977 earthquake records, (Aldea and Okawa, 2000).

CONCLUSIONS

The development of seismic monitoring in Romania is an important achievement of *JICA* Project in Romania, creating the premises for a better understanding and modelling of earthquake ground motion attenuation, site effects and building response. In future, it is necessary to characterise site/soil conditions at all the seismic stations sites (from all networks in Romania) in order to establish the link between site/soil conditions and

ground motion characteristics used for design. The remarkable borehole instrumentation now available in Bucharest, together with the increasing number and quality of soil data will allow an improved understanding and predictive modelling of site response within the city. The functioning and development of the existing Romanian seismic networks should be continuously supported, since recorded ground motions are fundamental for improving the seismic input for design of new buildings and for evaluation and rehabilitation of existing ones, items that finally contribute to the reduction of seismic risk.

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