MODERN URBAN SEISMIC NETWORK IN BUCHAREST, ROMANIA

A. Aldea[1), T. Kashima [2), D. Lungu[3), R. Vacareanu[4), S. Koyama[5), C. Arion[6)

1) Lecturer, Technical University of Civil Engineering, Bucharest &
Chief of Division, National Centre for Seismic Risk Reduction, Bucharest, Romania
2) Senior Researcher, Building Research Institute, Tsukuba, Japan
3) Professor, Technical University of Civil Engineering, Bucharest &
General Director, National Building Research Institute, Bucharest, Romania
4) Associate Professor, Technical University of Civil Engineering, Bucharest &
Director, National Centre for Seismic Risk Reduction, Bucharest, Romania
5) Senior Researcher, National Institute for Land and Infrastructure Management, Tsukuba, Japan
6) Chief of Division, National Centre for Seismic Risk Reduction, Bucharest, Romania
aldea@mail.utcb.ro, kashima@kenken.go.jp, lungud@mail.utcb.ro, vradu@mail.utcb.ro, koyama@nilim.go.jp

Abstract: The paper presents the main characteristics of ground motions recorded in Bucharest during strong and moderate earthquakes from the intermediate depth Vrancea seismic source, and the existing seismic instrumentation in Bucharest, Capital City of Romania, with emphasis on the recently installed seismic network (2003) of the *National Centre for Seismic Risk Reduction NCSRR* in the frame of the Technical Cooperation Project "Seismic Risk Reduction for Buildings and Structures" with *Japan International Cooperation Agency*. This new network with digital instruments has three components: stations for ground motion attenuation analysis (6 stations outside Bucharest), stations for site effects assessment in Bucharest (7 sites instrumented with free field and borehole sensors at 2 depth levels, between 25m and 153m), and stations for structural monitoring in Bucharest (4 instrumented buildings). The paper also presents preliminary site response assessment based on seismic records from the new network, and building characteristics derived from building records.

1. INTRODUCTION

Located in the alluvial Romanian Plain and crossed by two rivers, Bucharest, the capital city of Romania suffers from earthquakes originating from Vrancea intermediate depth (focal depth 60÷170km) earthquakes. There is a significant variability of ground shaking characteristics within the city, and it is considered that deep sediments of variable thickness and composition are responsible for the site effects observed in Bucharest.

The main characteristic of ground motions in Bucharest is the long predominant period of soil vibration, the city being characterised in international scientific literature as "Large city with Mexico-city effect" (The World Map of Natural Hazards, *Munich Re*, 1998). The relatively high seismic hazard, the peculiarities of ground motion, the existing building stock with many pre-code vulnerable buildings, the concentration of economical, political, administrative and cultural activities, all of these make Bucharest as one of the cities with the highest seismic risk in Europe.

Seismic instrumentation is essential for the proper establishment of input ground motion for design of new buildings and for seismic evaluation and retrofitting of existing buildings. 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.

2. SEISMIC GROUND MOTIONS RECORDED IN BUCHAREST

The history of strong ground motions recorded in Bucharest started with the March 4, 1977 (moment magnitude M_W=7.5) earthquake. The 1977 earthquake killed 1,424 people and injured 7,598 in Bucharest, most of them in the 31 buildings that collapsed. One accelerogram was recorded on a SMAC-B Japanese instrument from *INCERC (National Building Research Institute)* seismic network. The record was digitised and processed by the *Observational Committee of Strong Motion Earthquake of the Building Research Institute*, Japan, 1978. The main characteristic of the record was the large spectral amplification at long periods. "The field study of the Romanian earthquake of 1977 suggests that strong ground motions, for engineering purposes, may differ considerably from those currently adopted for design on the basis of US West Coast-type of recordings." (Ambraseys, 1977). Fig.1 presents the spectral acceleration *SA* - spectral displacement *SD* spectra of the record.

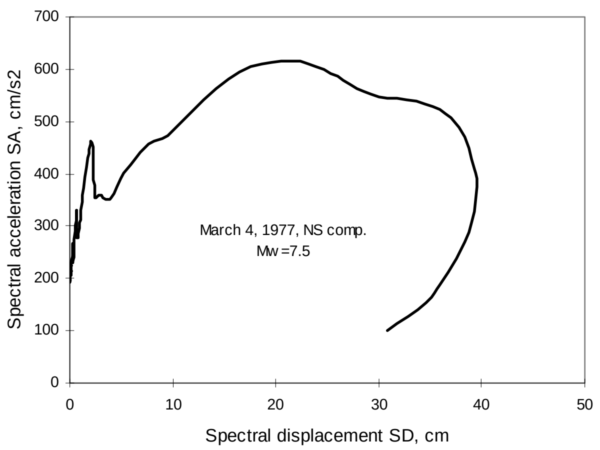

Fig.1 *SA-SD* spectra of 1977 *INCERC* record

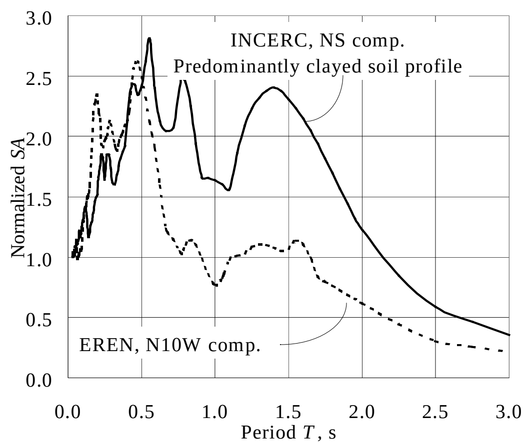

Fig.2 Normalised *SA* spectra for 1986 event recorded at *INCERC* station (East of Bucharest) and *EREN* station (North of Bucharest)

Three other important earthquakes were later recorded in Bucharest: August 30, 1986 (M_W=7.2) and May 30&31, 1990 (M_W=7.0&6.4) Vrancea earthquakes. The records were obtained in three seismic networks: *INCERC* – 24 records, *INFP (National Institute for Earth Physics)* – 2 records and *GEOTEC (Institute for Geotechnical and Geophysical Studies)* – 3 records.

These records indicated that there is a significant difference in the ground shaking characteristics within the city and from one earthquake to another (mobility with magnitude). For exemplification, in Fig.2 is presented the variation of normalised acceleration response spectra at two sites during 1986 earthquake (Lungu *et al*., 1997), and in Fig. 3 is presented the microzonation of Bucharest in terms of peak ground acceleration *PGA* for 1986 earthquake (Lungu *et al*., 2000). There is a clear difference between the Eastern, Central and Southern Bucharest and the rest of the city. In this part of Bucharest the *PGA* has lower values and the control period has higher values in comparison with North and Western side where *PGA* reaches the highest values and the control period is lower. This is explained by the difference in the subsoil conditions. The long control period of response spectra is a characteristic of Bucharest and it appears just in case of moderate and strong Vrancea earthquakes (Lungu *et al*., 1997, 2000). The quite large spectral values at long periods are not just a local phenomenon, the microzonation of *SA* for 1986 event showing in the city a practically uniform distribution of the *SA* ordinates at $T=1.5s$ at values of about $200cm/s^2$ (Aldea *et al*., 2003).

HAZUS 99 underlines that it's demand spectrum does not apply for the combinations of source and site conditions characterised by significant amplifications at periods larger than 1 second, case in which *HAZUS* spectrum over-estimate the spectral acceleration at low periods and under-estimate it at long periods. Mexico-city and Bucharest city (Figure 1) are such special cases.

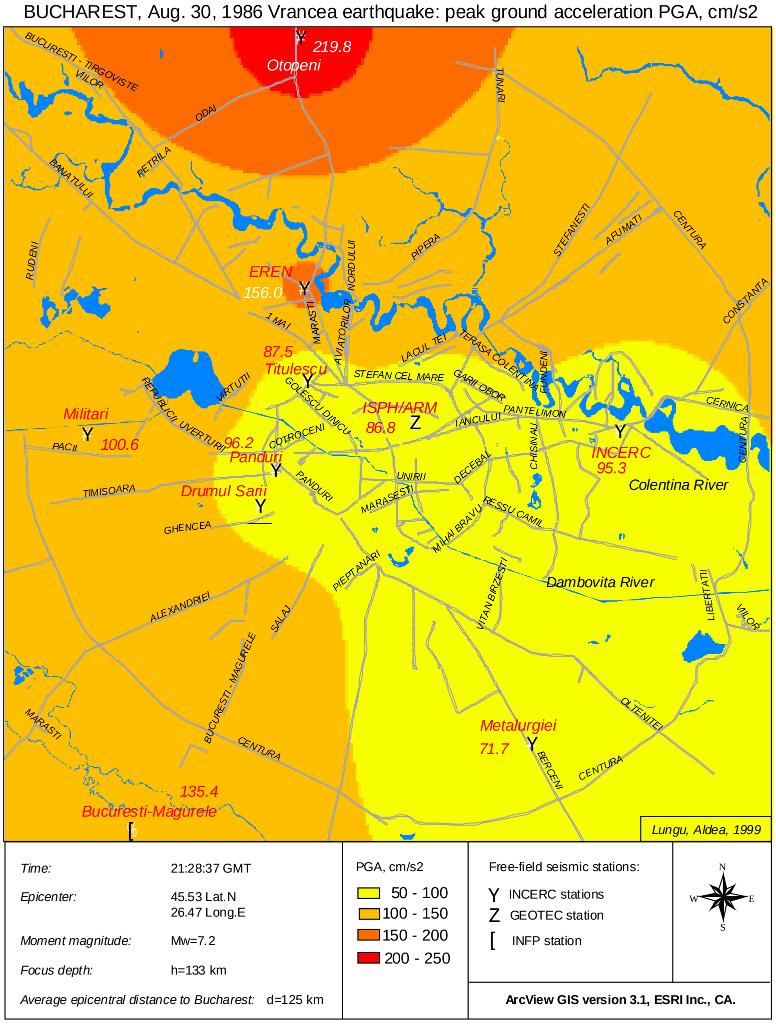

Fig.3 Bucharest – August 30, 1986 Vrancea earthquake: microzonation of *PGA*

3. SEISMIC NETWORKS IN BUCHAREST

The three networks with analog instruments of *INCERC*, *INFP* and *GEOTEC* continue to function in Bucharest and a significant effort for developing a digital network was done by all institutions. *INCERC* installed 9 Romanian digital instruments in the '90s, and in 2003, with the support of *State Inspectorate for Construction* also installed 7 *Etna Kinemetrics* instruments. In the frame of the *SFB 461 German Science Foundation Project* at *Karlsruhe University* with *Technical University of Civil Engineering UTCB, INFP* and *INCERC*, *Karlsruhe University* installed in the last decade 15 *K2 Kinemetrics* instruments that are operated by *INFP*. In 2003 a new seismic network was created: in the frame of the *Japan International Cooperation Agency JICA* Technical Cooperation Project "Reduction of Seismic Risk for Buildings and Structures", the *National Centre for Seismic Risk Reduction NCSRR* installed in Bucharest 7 free field stations and instrumented 4 buildings with *K2 Kinemetrics* instruments. The total number of stations in Bucharest is now 56. The distribution within the city of these instruments is presented in Fig.4.

4. NCSRR SEISMIC NETWORK IN BUCHAREST

The *National Centre for Seismic Risk Reduction NCSRR* seismic network was installed in 2003 by staff from *OYO* Japan, *NCSRR* and *UTCB*. The *Kinemetrics* equipment was donated by JICA. All the stations are *K2 Kinemetrics* and, for the moment, they are stand-alone stations.

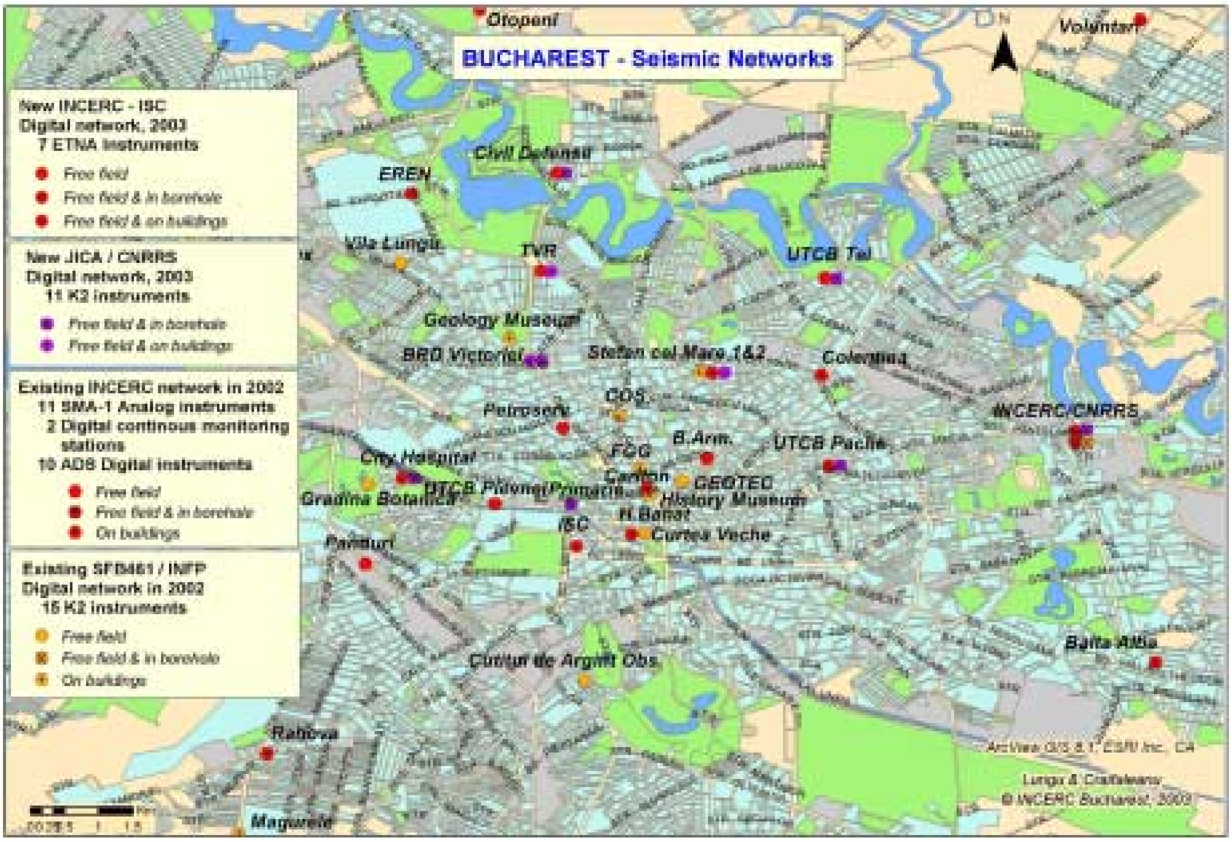

Fig.4 Bucharest – existing seismic networks in 2003

The *NCSRR* network has 2 components in Bucharest: (i) free-field instrumentation for site effect assessment (7 sites with sensors at ground surface and in two boreholes) and (ii) building instrumentation (4 buildings). A brief description of the network is presented in Table 1 and Table 2. At all the free-field stations the soil profile of the boreholes is known. Down-hole tests were performed by *NCSRR* and *Tokyo Soil* and their results will be soon published. Laboratory tests are underway. All these data will allow the numerical modelling of site response.

Table 1 *NCSRR* seismic stations for site effect assessment

No.	Site	Station ID	Surface sensor location	Depth of sensor in shallow borehole, m	Depth of sensor in deep borehole, m	Type of equipment
1	UTCB Tei	UTC1	free field	-28	-78.4	K2 + FBA-23DH
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	

Table 2 *NCSRR* seismic stations in buildings

No.	Site	Station ID	Station & sensor 1 location	Sensor 2	Sensor 3	Sensor 4	Bldg. data	Type of equipment
1	Stefan cel Mare 1	BLD1	11th floor	12th floor	5th floor	1st floor	RC frame '80s	K2 + Episensor ES-T
2	Stefan cel Mare 2	BLD2	Basement	7th floor	4th floor	Free field	RC frame '60s	
3	National Television	TVR	14th floor	15th floor	basement	-	RC frame '60s	
4	BRD-SG Tower	BRD	19th floor	3rd basement	-	-	RC dual 2003	

4.1 Available data

Ambient vibration measurements were performed at all sites using the *Kinemetrics* equipment. Some outputs of these measurements are herein presented.

At all the free-field stations sites microtremor measurements were done with velocity sensors and equipment made by *Tokyo Soil* and *Buttan Service*, Japan, donated by *JICA* to *NCSRR*. Microtremor velocity data is under analysis.

Four small earthquakes were recorded by *NCSRR* network, three originating from Vrancea source: October 5, 2003 (M_W=4.6, h=143km), December 24, 2003 (M_D=3.8, h=86km) and January 21, 2004 (M_b=4.7, h=111km), and one from Bulgaria: December 17, 2003 (M_D=4.5, h=10km), and a total of 14 records were obtained.

4.2 Preliminary site response assessment

Using earthquake records, the H/V spectral ratio technique was compared with the borehole top/bottom spectral ratio technique. Both techniques are commonly used nowadays for the assessment of site response, especially for identifying the predominant periods of ground vibration.

H/V spectral ratio has to be tested in Bucharest, since the classical and reliable spectral ratio that uses a reference rock site is not applicable. In Bucharest area there is no outcropping bedrock, and the bedrock is believed to be at about 800÷1000m depth, the city being located on deep sediments. The H/V single station spectral ratio, despite a lack in theoretical justification, was tested successfully by an increasing number of authors (for example Lermo *et al*. 1993). The basic assumption is that the vertical component of ground motion is not affected by site effects.

The technique that uses borehole records (Surface-Borehole Spectral Ratio SBSR) is considered by some authors as the most reliable (Atakan, 1995), while others do not recommend it since "the downhole sensors records not only the incident waves coming from the source, but also waves reflected from the surface" (Safak, 1997). In our case, the method is used only for comparison, the main limitation coming from the fact that the borehole sensor is not located on the bedrock, and consequently the spectral ratio may characterise just the response of the soil profile corresponding to the borehole depth.

In Fig. 5 are presented the H/V ratio and the SBSR for NCSRR/INCERC site, for Dec.17, 2003 event, and in Fig.6 the same ratios for Jan.21, 2004 earthquake. The borehole sensor (B2) is located at –153m. Majority of the ratios indicates a first major peak around 0.8Hz. The SBSR are more clear and show a similar pattern for both earthquakes, identifying also the higher vibration modes. These results are in agreement with previous studies indicating for INCERC site a predominant frequency of ~0.75Hz in case of March 4, 1977 earthquake (Lungu *et al*., 1997) and 0.87 Hz as a mean of H/V ratio for several small earthquakes (Aldea, 2001).

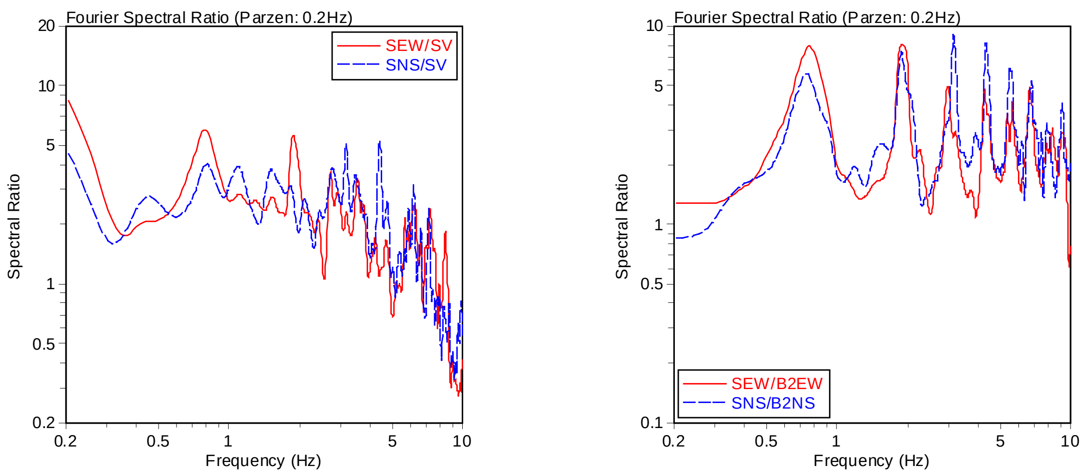

Fig.5 NCSRR/INCERC site, Dec.17, 2004 event: H/V ratio (left) and SBSR (right)

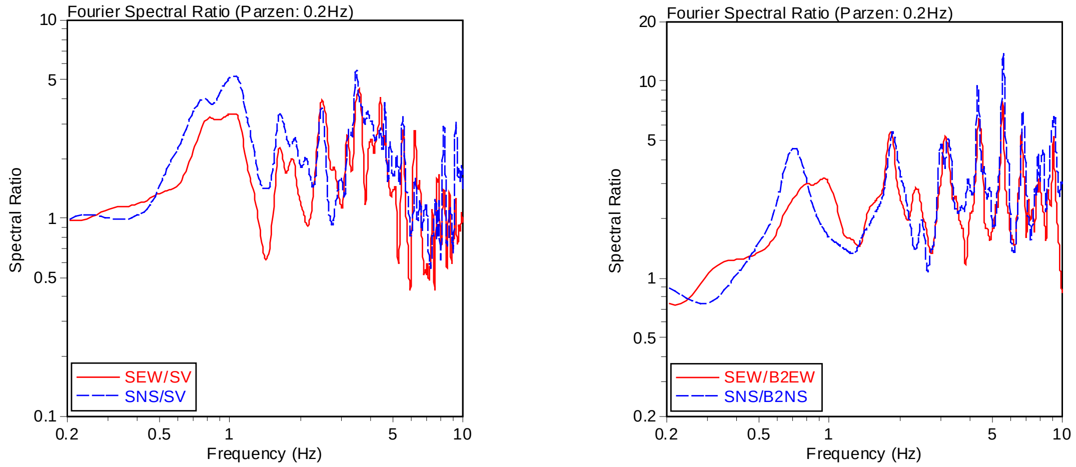

Fig.6 NCSRR/INCERC site, Jan.21, 2004 event: H/V ratio (left) and SBSR (right)

In Fig. 7 are presented the H/V ratio and the SBSR for UTC2 site, for Dec.17, 2003 event, and in Fig.8 the same ratios for Jan.21, 2004 earthquake. The borehole sensor (B2) is located at –70m.

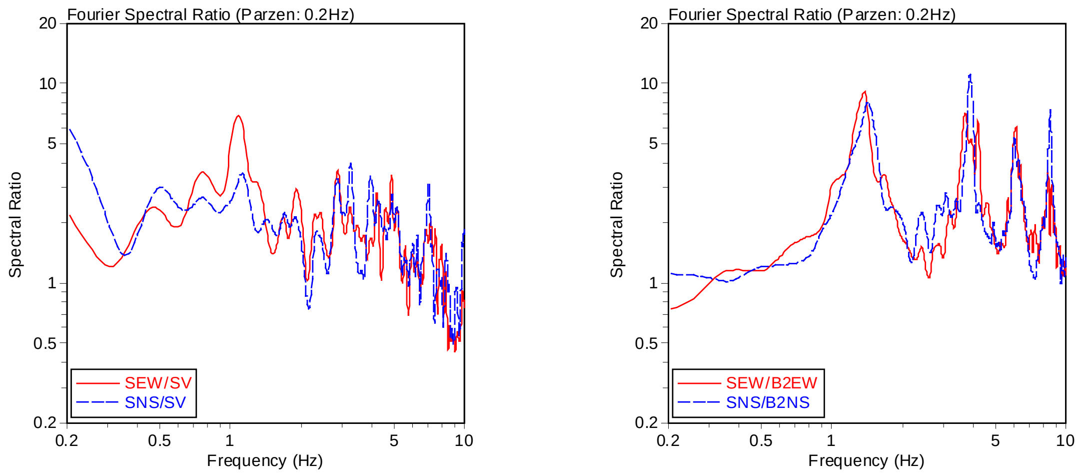

Fig.7 UTC2 site, Dec.17, 2004 event: H/V ratio (left) and SBSR (right)

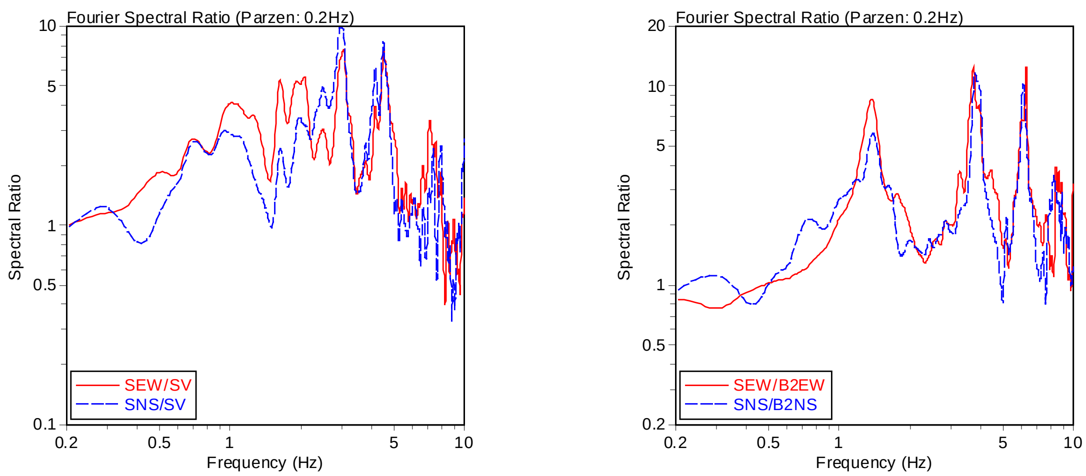

Fig.8 UTC2 site, Jan.21, 2004 event: H/V ratio (left) and SBSR (right)

The SBSR ratios are very much similar for both earthquakes, clearly identifying a predominant frequency of 1.5Hz at UTC2. The H/V spectra are less clear, and the predominant peak is at 1-1.2Hz.

The analysis of more data, completed by numerical modelling and by H/V Nakamura (1989) method (for microtremors) will allow an improved assessment of site response in Bucharest.

4.3 Preliminary building response assessment

In the case of instrumented buildings, the ambient vibration at bottom/basement represents an input signal that is amplified by the building. The top vibration includes the building vibration and, if soil-structure interaction exists, it also includes the contribution of rocking and sway. A soil-structure interaction assessment for the instrumented buildings has not yet been performed, and in the followings, the identified frequencies are considered as the frequencies corresponding to the vibration modes of the building.

In Fig.9 are presented the Fourier spectra of ambient vibration records at the top of the *Romanian National Television TVR* (14 storeys). The spectra indicate clearly the main period of vibration for each direction of the building, and also the higher modes of vibration can be identified: 0.85Hz, 3Hz, 5Hz for NS direction, and 0.75Hz, 2.9Hz, 5Hz for EW direction.

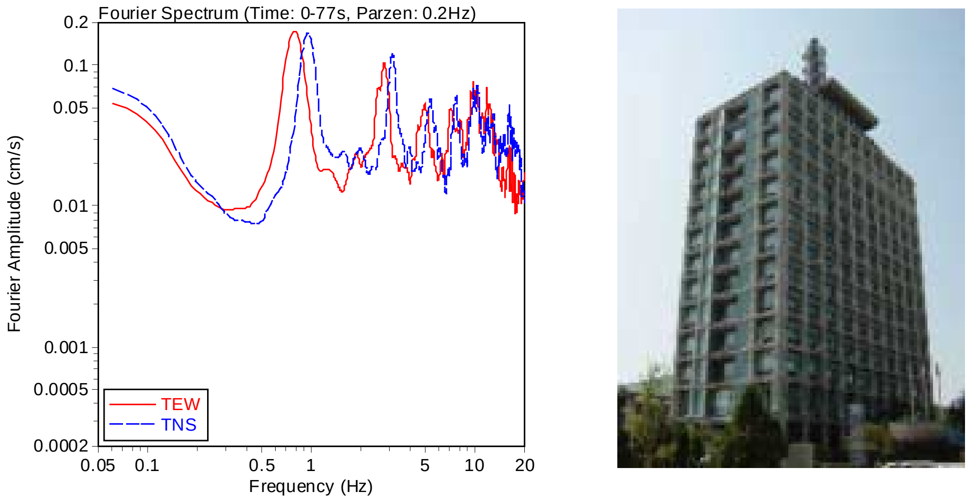

Fig.9 Fourier spectra of ambient vibration at *TVR* building

In Fig.10 are presented the Fourier spectra of ambient vibration records at the top of the *BRD-SG* Tower (20 storeys). The spectra indicate clearly the main period of vibration for each direction of the building: 1.5Hz for NS direction and 1Hz for EW direction. These values are in agreement with a previous microtremor study done at *UTCB* for the *BRD-SG* building in 2002.

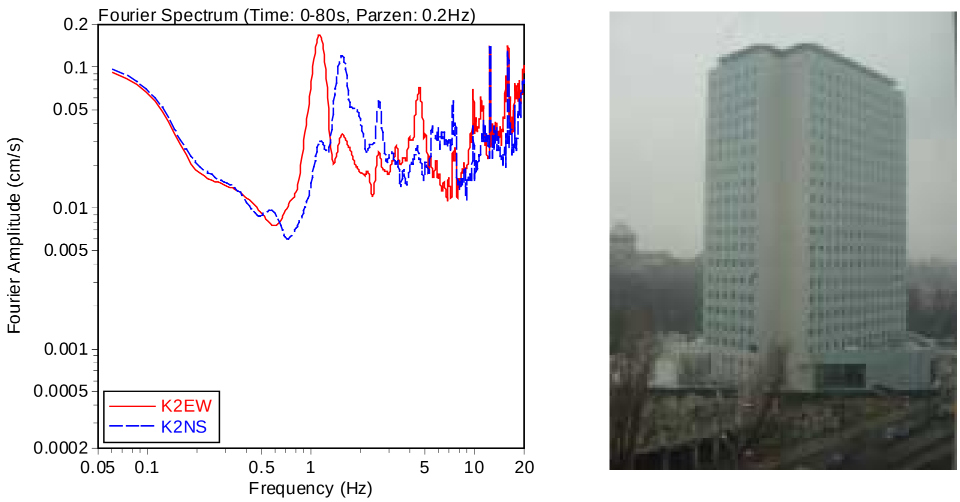

Fig.10 Fourier spectra of ambient vibration at *BRD-SG* building

Fig. 11 presents top/basement Fourier spectral ratios for earthquake records at BLD 2 station, indicating the main periods of vibration of the building: 2.2Hz for NS direction and 2.5Hz for EW.

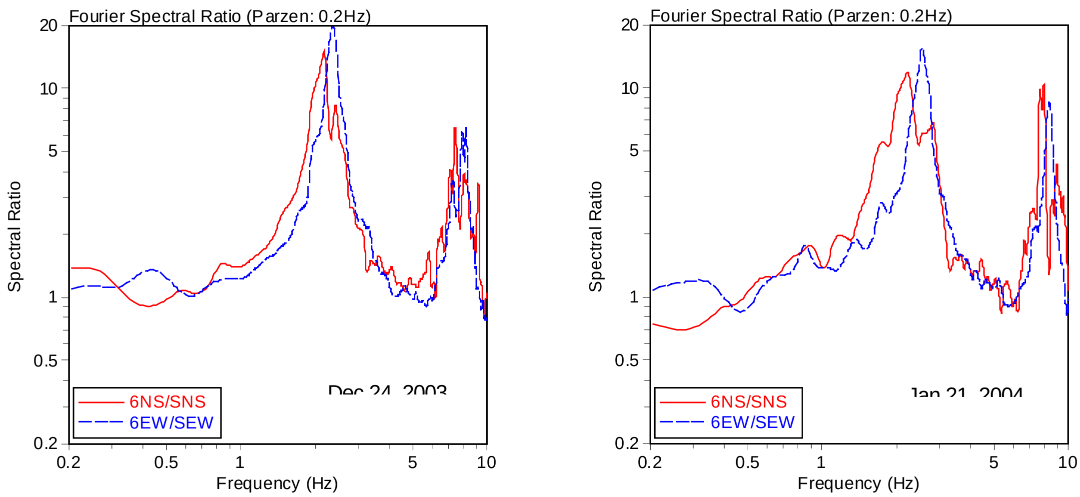

Fig.11 Top/basement Fourier spectral ratio for earthquake records at BLD2 seismic station

5. CONCLUSIONS

Bucharest city is one of the well instrumented cities in Europe, but efforts are still needed for having an entirely digital network, for a better distribution of seismic stations and for a modern communication of recorded data allowing in the future the development of near-real time shake maps. The *NCSRR* seismic network offers remarkable conditions for a better understanding of site response by providing seismic data in 14 boreholes at seven sites with the city. The network will also help the understanding of RC structures behaviour during earthquakes.

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