13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1800

DEVELOPMENT OF STRONG GROUND MOTION NETWORK IN ROMANIA AND BUCHAREST INSTRUMENTATION FOR SITE EFFECTS ASSESSMENT

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SUMMARY

The paper presents a short history of strong ground motion records and seismic instrumentation in Romania. Some data recorded during past strong and moderate earthquakes are presented using GIS technology. Emphasis is putted on the recent enlargement of the National Building Research Institute (INCERC) seismic network. A special chapter is devoted to the newly created seismic network of the National Center for Seismic Risk Reduction (NCSRR) in the frame of a Technical project of cooperation [1] with Japan International Cooperation Agency (JICA). NCSRR seismic network 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 two depth levels), and stations for structural monitoring (4 instrumented buildings in Bucharest). A synthesis of the first data obtained from NCSRR network and of their analysis is presented.

INTRODUCTION

Romania is an earthquake prone country, its seismic activity being dominated by Vrancea intermediate depth source, and by several crustal sources (Banat, Fagaras, Maramures, etc.), Figure 1. Vrancea source dominates seismic hazard not only in Romania but also in Republic of Moldova and also affects large areas in Bulgaria and Ukraine. Strong Vrancea earthquakes have been felt on areas of about 2 millions km^2. Gutenberg & Richter [2] classified Vrancea seismic source as a separated seismic region inside the Division 8 “Alpine-Asian Arch”: the region number 51.
Seismic instrumentation is essential for the proper establishment of input ground motion for design, and for the seismic evaluation and retrofitting of existing buildings. United States of America and Japan are the major examples of countries understanding the need for a proper seismic instrumentation.

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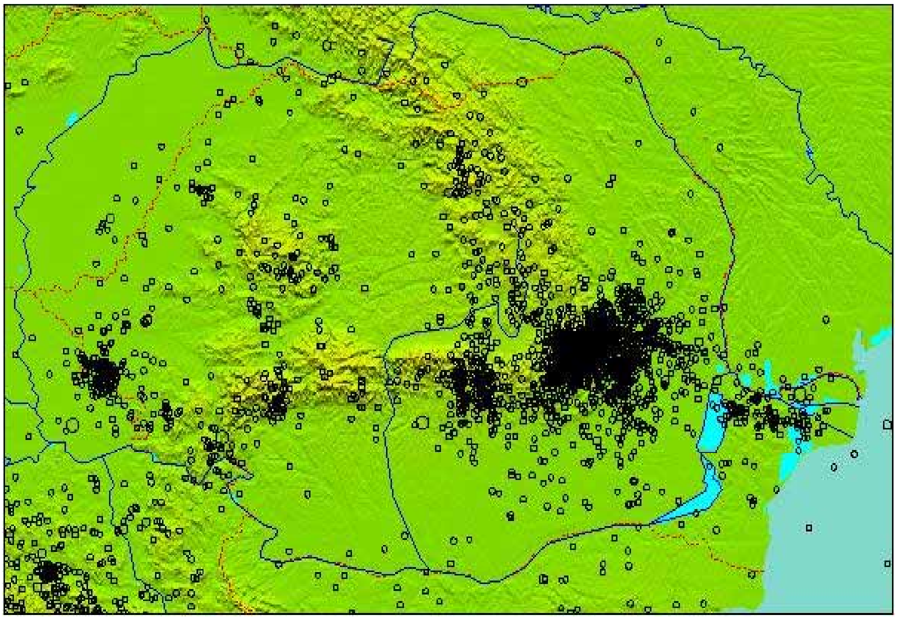

Figure 1. Seismicity of Romania (Geoscience Interactive Databases - Cornell Univ./INSTOC)

The USA approach is self-explanatory (USGS [3]): "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".

Japanese case is also conclusive. Earthquake records are judged as fundamental data for improving earthquake protection, and not only that there are large and dense national seismic networks as Japan Meteorological Agency network and K-NET network (of National Research Institute for Earth Science and Disaster Prevention), but local authorities and education and research institutions also developed their own seismic networks. K-NET (Kyoshin Net [4]) is one of the most impressive in the history of seismic instrumentation worldwide. After 1995 Great Hanshin Earthquake, 1000 free field stations were deployed all over Japan, with an average station to station distance of about 25km. Each station has a digital strong-motion seismograph, the records obtained being acquired at the control centre by telemetry. At each site the soil conditions, including P and S-waves velocity structures, have been obtained by downhole measurement. Data is available via Internet.

In 1997 was held in Bucharest the First International Workshop on Vrancea Earthquakes [5], and the working group "Strong Ground Motion" chaired by Professor B.Bolt made the following recommendation: "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.

HISTORY OF SEISMIC GROUND MOTION RECORDING IN ROMANIA

The history of the seismic stations and records in Romania (Radu, [6]) begins with the Bucharest seismic station founded in 1889, which was among the first ones in Europe. At that time, at the initiative of

S.Hepites, director of the Romanian Meteorology Institute, two Brassart Italian seismoscopes were installed at the Bucharest-Filaret station. Later followed a Guzzanti seismoscope and a Tacchini seismometer (1895) and an Agamennone seismoscope (1898). All these instruments worked until 1914 and they allowed the recording of 39 Romanian, 2 Turkish and 7 Bulgarian earthquakes. In 1892 Hepites creates the national network for macroseismic data collection. In 1902 Hepites installed two Bosch seismometers that entered in the history of modern seismology with the recording of November 1st, 1929 intermediate depth Vrancea earthquake, which was one of the five earthquakes that seismologist H.Jeffreys used to prove the existence of intermediate depth earthquakes. Bosch seismometers also recorded the strong shallow earthquakes from April 10th, 1904 in Bulgaria and from January 26th, 1916 in Romania. In 1902 a seismic station was installed in Timisoara, and in 1911 another one in Cluj.

In 1935 the Bucharest Seismic Observatory was created. The Observatory was equipped with Mainka-Demetrescu seismographs. In 1937, two Galitzin seismographs were installed followed in 1940 by an Alfani seismograph. The November 10th, 1940 earthquake gave an impulse to the development of the national seismic network. Seismic stations were installed in Focsani and Bacau in 1942 and in Campulung in 1943. In 1943 construction works began at the Vrancioaia station, but also it stopped because of the unfavourable situation in the country. The stations in Focsani and Bacau were stopped in 1944. After the World War II, the stations in Focsani and in Bacau resumed their activity. In 1951 Vrancioaia station and in 1952 Iasi station were installed. All the stations were equipped with Mainka-Demetrescu seismographs, made in Bucharest.

In the year 1967 the National Building Research Institute INCERC seismic network was created with the acquisition of modern recording instruments: a Japanese SMAC-B accelerograph and an American WILMOT seismoscope. March 4, 1977 earthquake was recorded at INCERC Bucharest seismic station (in the basement of the INCERC building, East of Bucharest). After the 1977 earthquake the Romanian seismic network developed rapidly. For the INCERC seismic network, 75 SMA-1 accelerographs and 14 WILMOT seismoscopes (products of Kinemetrics) were purchased between 1978-1980 (Danci, [7]).

The status of seismic instrumentation in the beginning of the ‘80s was described by Radu & Grecu [8]: “Romanian strong motion network consists of 78 instruments - 66 accelerographs and 12 seismoscopes - placed in 42 locations. The distribution of the instruments is as follows: (i)INCERC: 39 accelerographs (SMA-1, MO-2, SMAC-B, SMAC-E, RFT-280) and 12 seismoscopes (WM-1); (ii) CFPS, Center of Earth Physiscs and Seismology: 19 accelerographs (SMA-1, SSRZ); (iii) ISPH, Institute for Hydroelectrical Studies and Design: 5 accelerographs (SMA-1); (iv) ICH, Institute for Hydrotechnical Research: 3 accelerographs (SMA-1). In the majority of cases (84%), the ground conditions are represented by alluvia and only a small part (16%) by rock - granite, limestone.
The data obtained till now consists of 6 accelerograms for 3 Vrancea intermediate earthquakes: 1977 March 4 (Gutenberg-Richter magnitude M = 7.2), 1978 Sept. 5 (M = 4.0) and 1978 Sept. 30 (M= 4.5.)”.

In the beginning of the ‘90s, the Romanian seismic network disposed of over 250 strong ground motion recordings (Danci, [7]), Table 1:

Table 1. Strong ground motion records available in the beginning of the ‘90s (Danci [7])

Network	Event		
	Aug 30, 1986	May 30, 1990	May 31, 1990
INCERC	60	63	43
INFP[1)]	10	8	7
GEOTEC[2)]	5	3	2

1) INFP-National Institute for Earth Physics, Bucharest

2) GEOTEC-Institute for Geotechnical and Geophysical Studies, Bucharest

March 4, 1977 earthquake record

The March 4, 1977 earthquake (moment magnitude M_W=7.5) killed 1,424 people and injured 7,598 in Bucharest, most of them in the 32 tall RC buildings that collapsed. The INCERC Bucharest record was digitised and processed by the Observational Committee of Strong Motion Earthquake of the Building Research Institute, Japan [9]. International community was impressed by the characteristics of the motion recorded in Bucharest. Some of the opinions expressed in international reports are herein presented.

“Indeed, geologists and seismologists have a fascinating earthquake to study. This accelerogram is so different from those obtained from other destructive earthquakes that one is at first tempted to say something must be wrong with the record. Chris Rojahn inspected the instrument and says it was properly installed and maintained, and he sees no reason to doubt the record. I believe him.” Berg [10].

“The record, unlike most obtained from other destructive earthquakes, is characterised by a single strong pulse with a period of about 1.4 seconds. It’s spectrum intensity exceeds that of the 1940 El Centro earthquake, which has long served as something of a benchmark for strong ground motion.” NBS [11].

"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 [12].

Figure 2 presents the accelerogram (BRI [9] digitisation) and the spectral acceleration SA - spectral displacement SD spectra of NS component of the 1977 record. Table 2 presents peak ground acceleration values for 1977 INCERC Bucharest record.

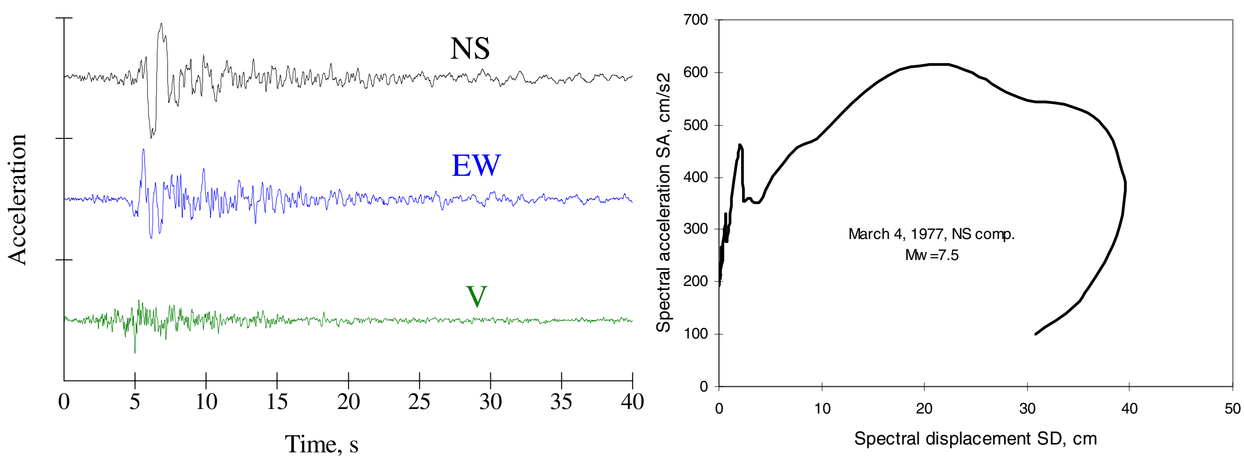

Figure 2. March 4, 1977 record at INCERC station in Bucharest & SA-SD spectra (NS comp.)

Table 2. Values of peak ground acceleration from different digitisations of the INCERC Bucharest accelerogram from March 4th, 1977 Vrancea earthquake

Comp.	Digitisation			
	BRI [9]	Hartzel [13]	INCERC (1996)	Ambraseys *et al.* (2000)
NS	194.9	221	207.6	197.7
EW	162.3	187	181.3	168.1
Z	105.8	100	121.9	102.6

Strong ground motion records in Romania

The August 30, 1990 (M_W=7.2) and May 30&31, 1990 (M_W=7.0&6.4) Vrancea intermediate depth earthquakes were recorded at about 70 seismic stations in Romania (including Bucharest). The geographic distribution of parameters and the zonation maps were prepared using Geographic Information Systems technology (i.e., ArcView 3.2 software, ESRI, California), Lungu et al. [14], Aldea [15].

In Figure 3 is presented the zonation map of maximum horizontal peak ground acceleration recorded during 1977, 1986 and 1990 events. The distribution of PGA confirms the pattern of the macroseismic intensity isolines observed during past earthquakes, showing a clear directivity NE-SW.

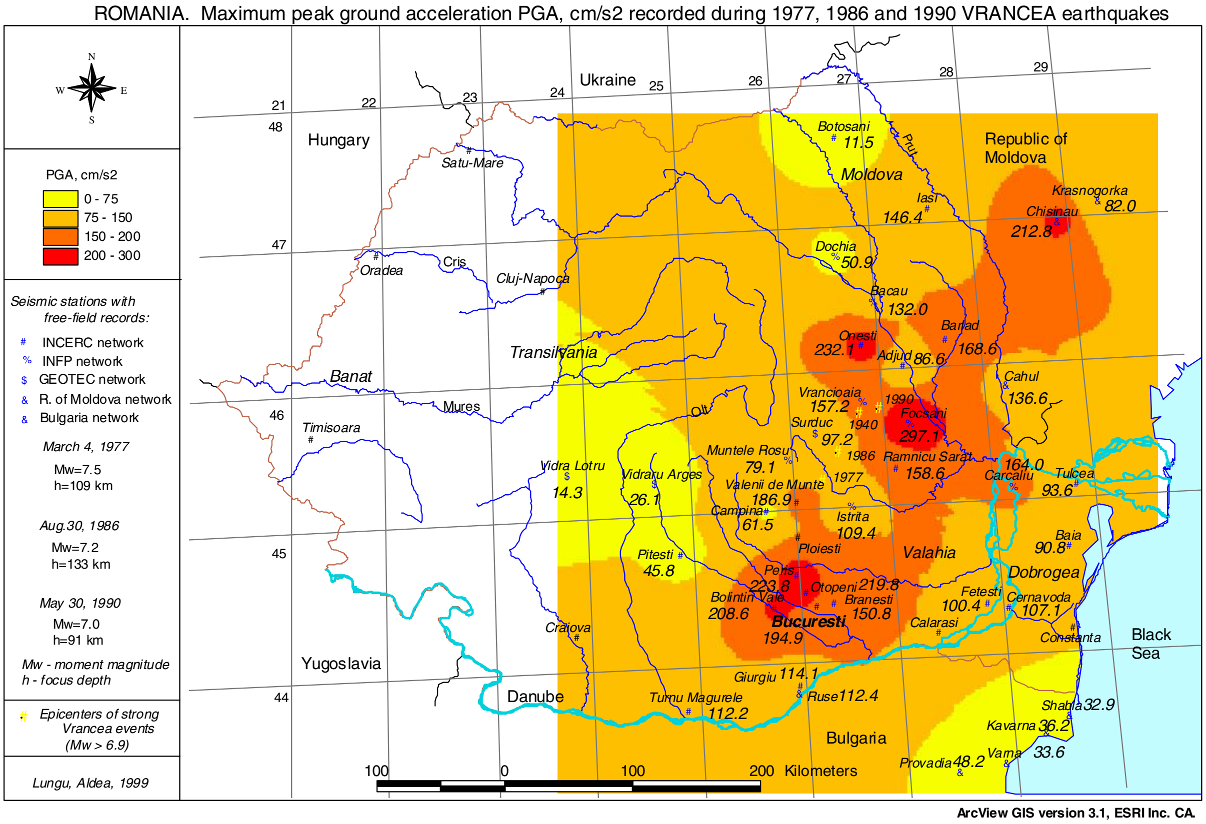

Figure 3. Zonation of maximum horizontal peak ground acceleration for 1977, 1986 & 1990 events

Strong ground motion records in Bucharest

After 1977 event, three other important Vrancea earthquakes were recorded in Bucharest in 1986 and 1990. The records were obtained in three seismic networks: INCERC – 24 records, INFP– 2 records and GEOTEC– 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 Figure 4 is presented the variation of normalised acceleration response spectra at two sites during 1986 earthquake (Lungu et al. [16]).

In Figure 5 is presented the microzonation of Bucharest in terms of peak ground acceleration PGA for 1986 earthquake (Lungu et al. [14]). There is a clear difference between the Eastern, Central and Southern Bucharest and the rest of the city. In this part of Bucharest 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 was explained by the difference in the subsoil conditions.

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 [17]). The long control period of response spectra is also characteristic for Bucharest ground motions and it appears just in case of moderate and strong Vrancea earthquakes, Lungu et al. [14]&[16].

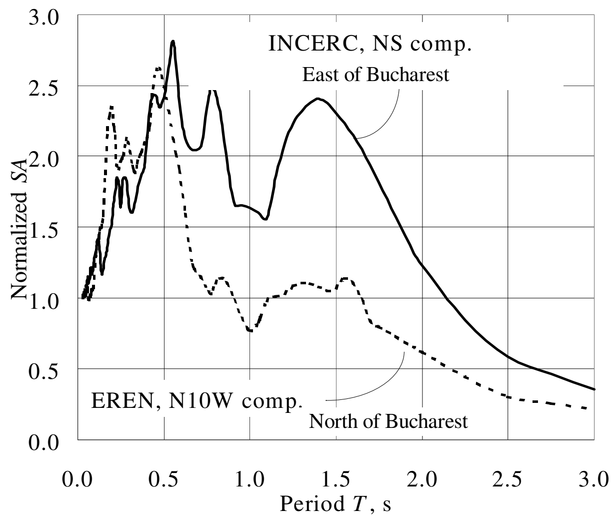

Figure 4. Normalised SA spectra for 1986 event at INCERC and EREN stations in Bucharest

BUCHAREST, Aug. 30, 1986 Vrancea earthquake: peak ground acceleration PGA, cm/s2

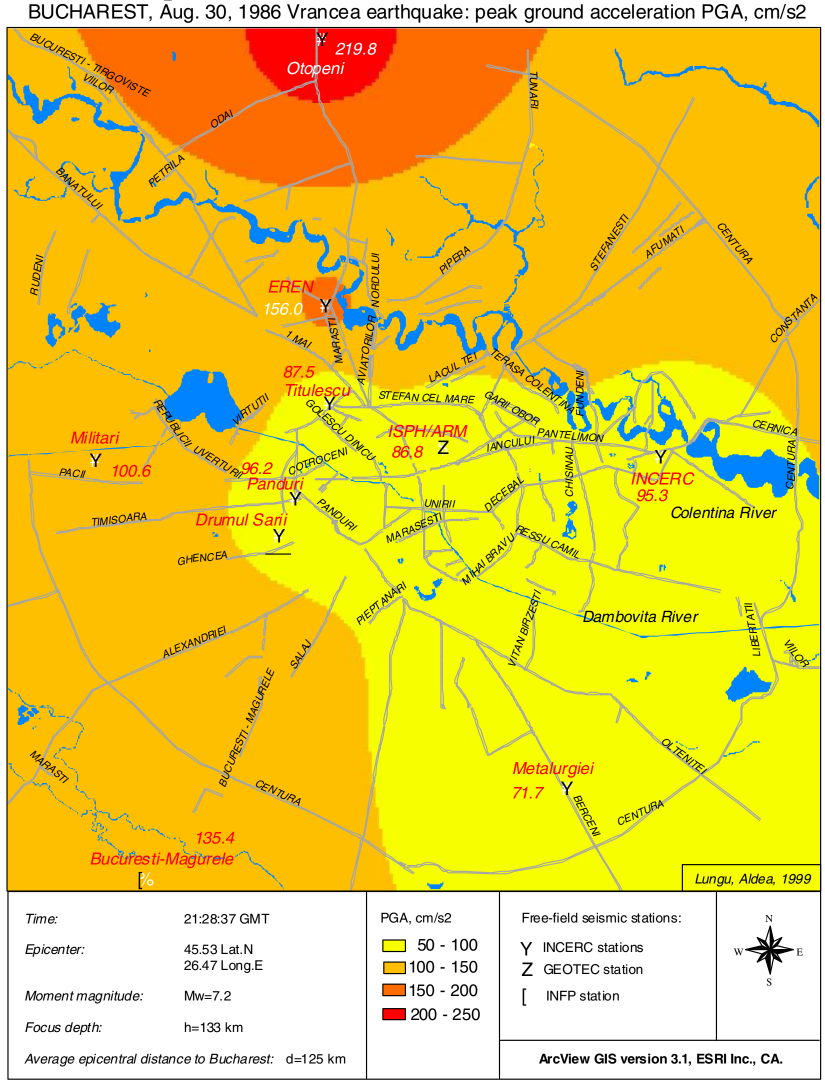

Figure 5. Bucharest – August 30, 1986 Vrancea earthquake: microzonation of PGA

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. [18]). HAZUS [19] 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 are such special cases.

EXISTING SEISMIC NETWORKS IN ROMANIA

The three networks with analog instruments of INCERC (National building Research Institute), INFP (National Institute for Earth Physics) and GEOTEC (Institute for Geotechnical and Geophysical Studies) continue to function and a significant effort for developing digital networks 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 30 Etna Kinemetrics instruments. In the frame of the SFB 461 German Science Foundation Project [20] at Karlsruhe University with INFP, Technical University of Civil Engineering UTCB and INCERC, Karlsruhe University installed in the last decade 41 K2 Kinemetrics instruments that are operated by INFP. In 2003 the National Centre for Seismic Risk Reduction (NCSRR) seismic network was created. In the frame of the Japan International Cooperation Agency JICA Technical Cooperation Project [1] "Reduction of Seismic Risk for Buildings and Structures".
The present seismic instrumentation in Romania is summarized in Table 3 and in Figure 6 (Lungu et al. [21]). In Figure 7 are presented the existing seismic networks in Bucharest (Lungu et al. [21]).

Table 3. Seismic networks in Romania, 2004

	Network	**Bucharest**	**Romania (including Bucharest)**
New digital networks, installed in 2003	*INCERC & ISC, State Inspectorate for Construction*[1)]	7 ETNA	31 ETNA
	NCSRR & JICA, Japan International Cooperation Agency[2)]	11 K2	17 instruments: -11 K2; - 6 ETNA
Existing seismic networks, in 2002	*INCERC*[1)]	21 instruments: -10 SMA-1 (analog) -9 ADS (digital) -2 digital stations for continuous monitoring	70 instruments: -58 SMA-1(analog) -9 ADS (digital) -3 digital station for continuous monitoring
	INFP[3)]	1 SMA	18 SMA (analog) & upgraded SMA (digital) including 1 broad band digital station for continuous monitoring
	SFB 461 German Science Foundation Project at *University of Karlsruhe* jointly operated with *INFP*[1)]	15 K2	41 ETNA & K2
	GEOTEC[4)]	1 K2	~ 20 SMA (analog) and 6 K2
TOTAL		**56 instruments**	**203 instruments**

Source of data 1) Lungu et al [21], 2) JICA Project [1], 3) INFP [22] and 4) Moldoveanu [23]

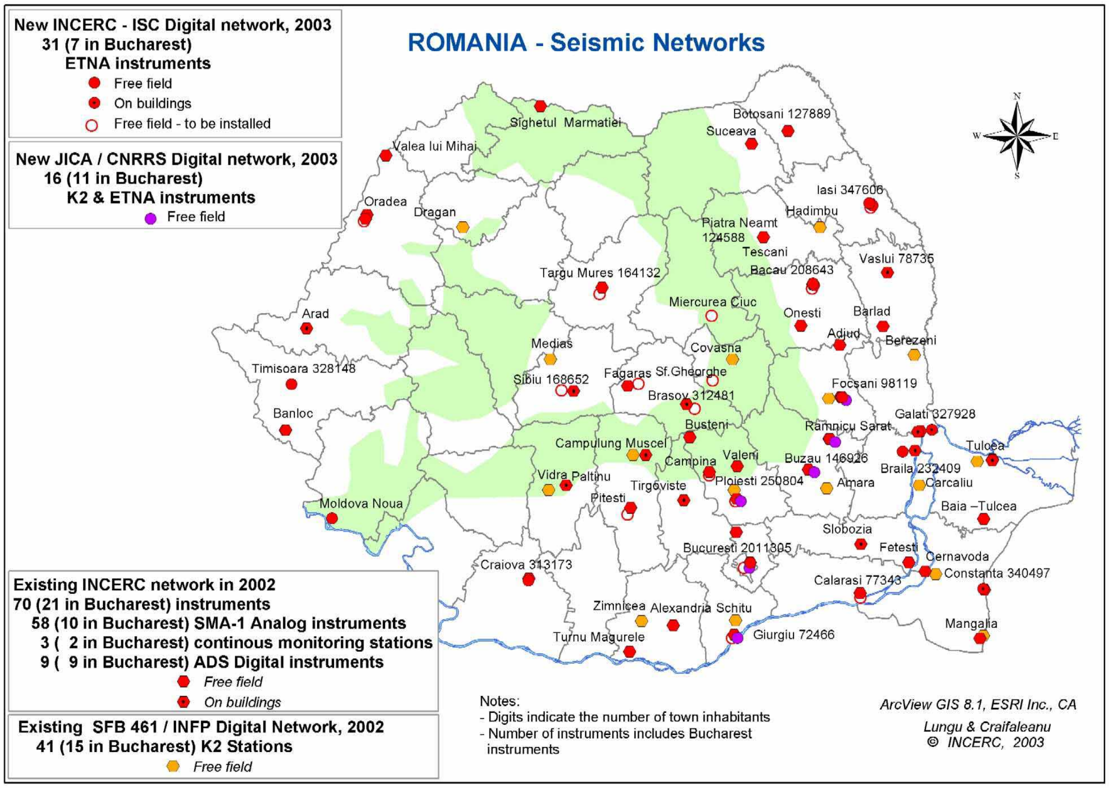

Figure 6. Seismic networks in Romania (Lungu et al. [21])

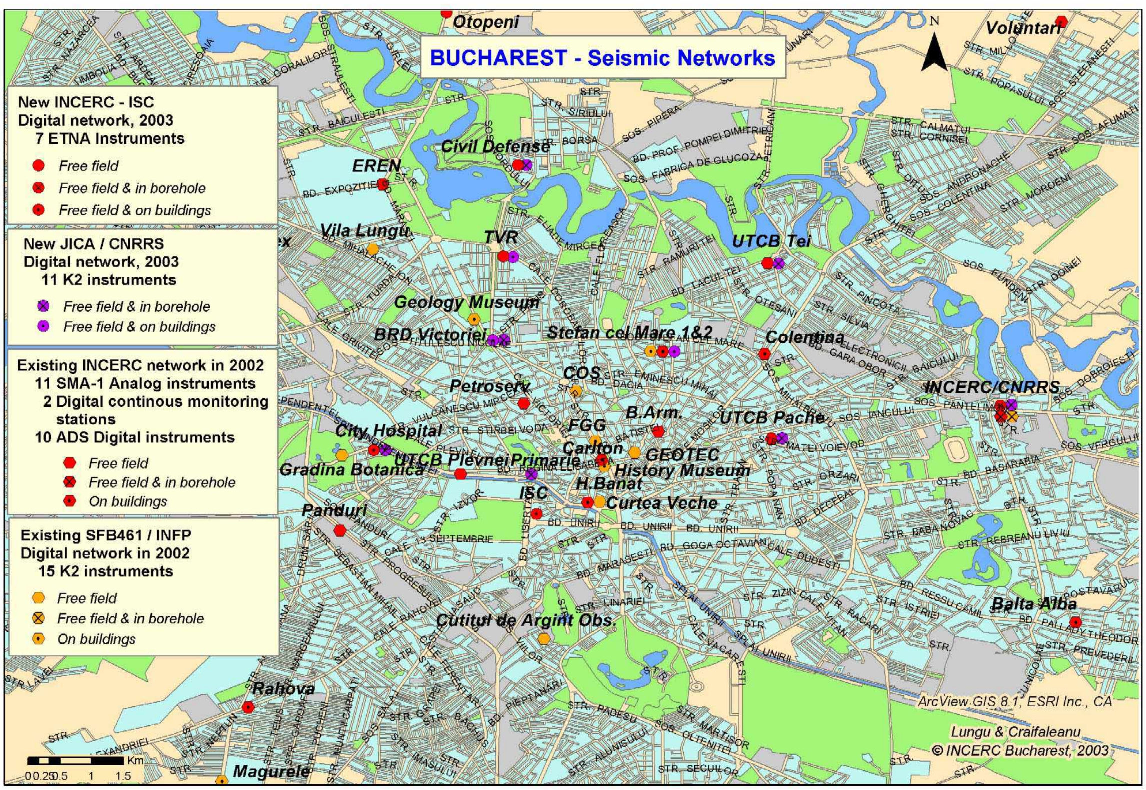

Figure 7. Seismic networks in Bucharest (Lungu et al. [21])

NCSRR SEISMIC NETWORK

The National Centre for Seismic Risk Reduction NCSRR seismic network (Aldea et al. [24]) was installed in 2003 by staff from OYO Japan, NCSRR and UTCB. The Kinemetrics equipment was donated by JICA. All the stations are K2 and ETNA instruments from Kinemetrics and, for the moment, they are stand-alone stations.

Seismic stations for ground motion attenuation analysis

Six ETNA stations were installed on the SW direction starting from Vrancea epicentral area toward Bucharest, in order to obtain data for ground motion attenuation analysis. All of them are in buildings with 1 or 2 storeys, that is considered as a free field condition. Ground conditions are not known yet, but NCSRR will perform soil and geotechnical investigations at each site. The stations are briefly presented in Table 4.

Table 4. NCSRR Seismic Network - Free field stations in Romania

No.	Site	Station ID	Sensor location	Type of equipment
1	Giurgiu	GRG	Ground Floor of 2 storey bldg.	ETNA
2	Ploiesti	PLO	GF of 2 storey bldg.	
3	Focsani	FOC	GF of 1 storey bldg.	
4	Buzau	BUZ	GF of 1 storey bldg.	
5	Ramnicu Sarat	RMS	GF of 1 storey bldg.	
6	Urziceni	URZ	GF of 1 storey bldg.	

Seismic stations for site effects assessment

Inside Bucharest, NCSRR installed 7 stations with sensors at ground surface (free field conditions) and in boreholes at two levels of depth: the first at about –30m and the second between –50m and –153m, Table 5.
At all the stations the soil profile of the boreholes is known. NCSRR and Tokyo Soil (Japan) performed down-hole tests at all the boreholes that were instrumented and the results will be soon published. Laboratory tests are underway.

Table 5. 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	

Seismic stations for structural monitoring

Two residential buildings of different structural types located one near the other were instrumented in Central Bucharest. Two representative public buildings were also instrumented: The National Television Headquarters (that needs to be retrofitted) and the Headquarters of BRD-Société Générale Bank (a modern high-rise dual RC structure). Details about building instrumentation are given in Table 6.

Table 6. 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	

PRELIMINARY RESULTS FROM NCSRR SEISMIC NETWORK RECORDS

Five small earthquakes were recorded by NCSRR network, four originating from Vrancea source and one from Bulgaria, and a total of 15 records were obtained, Table 7.

Table 7. Earthquakes recorded by NCSRR seismic network

Date (dd/mm/yyyy)	Region	origin time (UTC)	coordinate lat (°N)	coordinate lon (°E)	depth (km)	magnitude		Nr. of stations with records
05/10/2003	Vrancea	21:38:18	45,57	26,46	143	m_b = 4,7 (USGS)	M_W = 4,6 (INFP)	4
17/12/2003	Bulgaria	23:15:15	43,19	27,44	60	M_D = 4,5 (INFP)		3
24/12/2003	Vrancea	13:44:59	45,06	26,08	86	M_D = 3,8 (INFP)		1
21/01/2004	Vrancea	05:49:10.4	45,6	26,4	111	m_b = 4,7 (EMSC)		5
07/02/2004	Vrancea	11:58:22	45,72	26,64	146	m_b=3,9 (EMSC)		2

Ambient vibration measurements were performed at all seismic station sites using the Kinemetrics equipment. At all the free-field stations sites (outside and inside Bucharest) microtremor measurements were done with velocity sensors and equipment made by Tokyo Soil and Buttan Service (Japan), donated by JICA to NCSRR. Microtremor data is under analysis.

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 used 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 earthquake 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. [25]). The basic assumption is that site effects do not affect the vertical component of ground motion.

The technique that uses borehole records (Surface-Borehole Spectral Ratio SBSR) is considered by some authors as the most reliable (Atakan [26]), 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 [27]). In our case, the method is used only for comparison. One important limitation of the comparison is 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 Figure 8 are presented the H/V ratio and the SBSR for NCSRR/INCERC site, for Dec.17, 2003 event, and in Figure 9 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 clearer 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 1977 event (Lungu et al. [16]) and 0.87 Hz as a mean of H/V ratio for several small earthquakes (Aldea [28]).

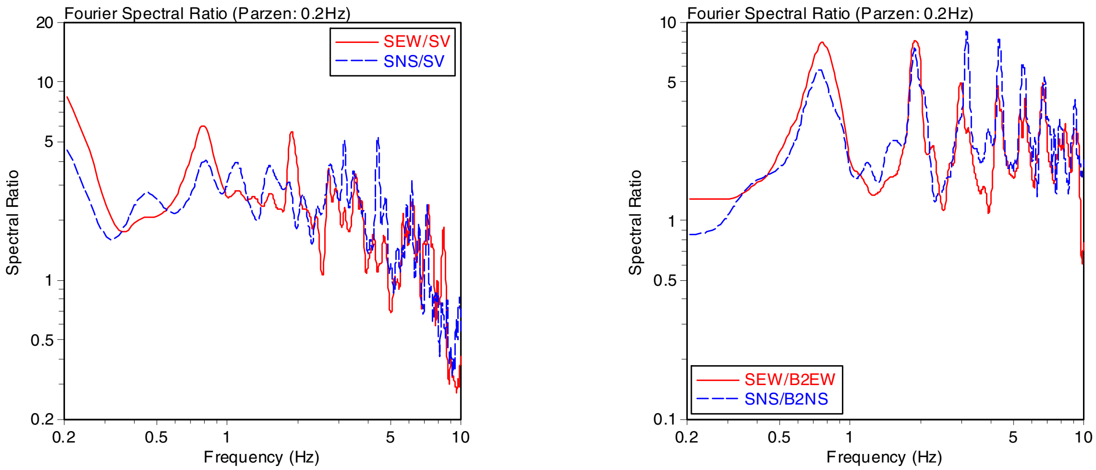

Figure 8. NCSRR/INCERC site, Dec.17, 2004 event: H/V ratio (left) and SBSR (right)

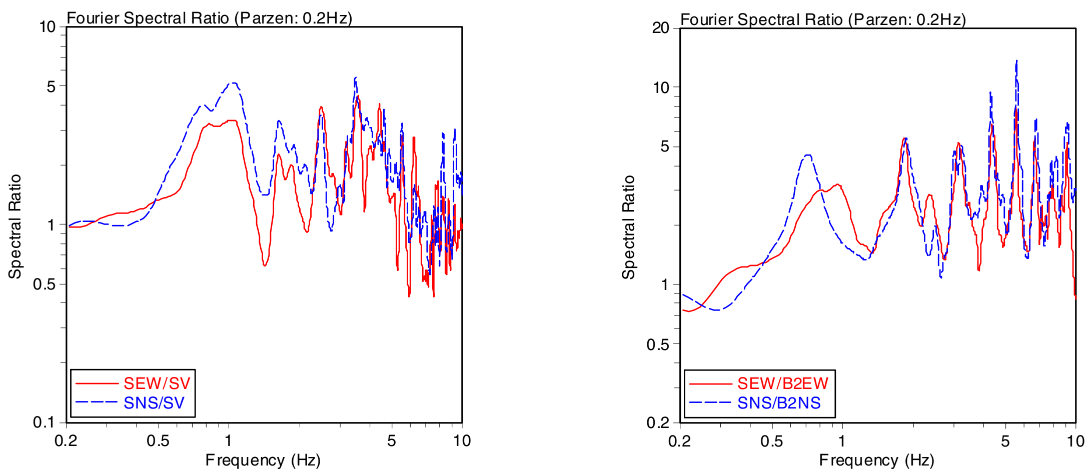

Figure 9. NCSRR/INCERC site, Jan.21, 2004 event: H/V ratio (left) and SBSR (right)

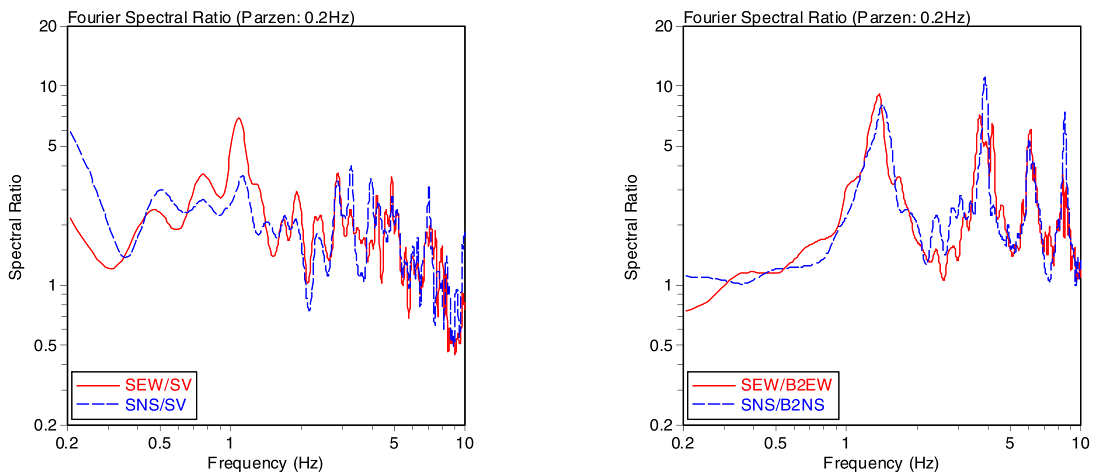

Figure 10. UTC2 site, Dec.17, 2004 event: H/V ratio (left) and SBSR (right)

In Figure 10 are presented the H/V ratio and the SBSR for UTC2 site, for Dec.17, 2003 event, and in Figure 11 the same ratios for Jan.21, 2004 earthquake. The borehole sensor (B2) is located at –70m.

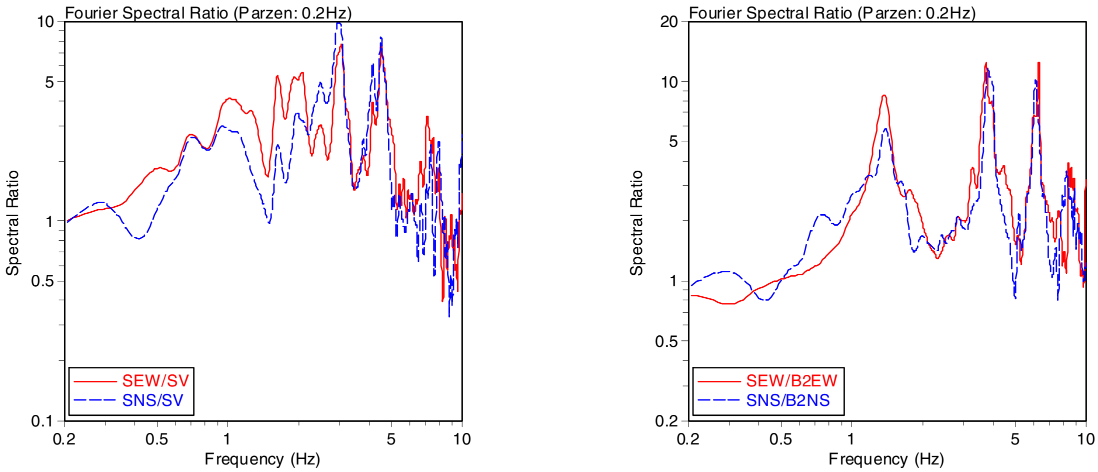

Figure 11. UTC2 site, Jan.21, 2004 event: H/V ratio (left) and SBSR (right)

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 [29] method (for microtremors) will allow an improved assessment of site response in Bucharest.

Preliminary building response assessment

In the case of instrumented buildings, the ambient vibration recorded at the top of the building is amplified at the eigen frequencies. 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 only to the building vibration.
In Figure 12 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 fundamental frequency of vibration for each direction of the building, and also the higher modes can be identified: 0.85Hz, 3Hz, 5Hz for NS direction, and 0.75Hz, 2.9Hz, 5Hz for EW direction.

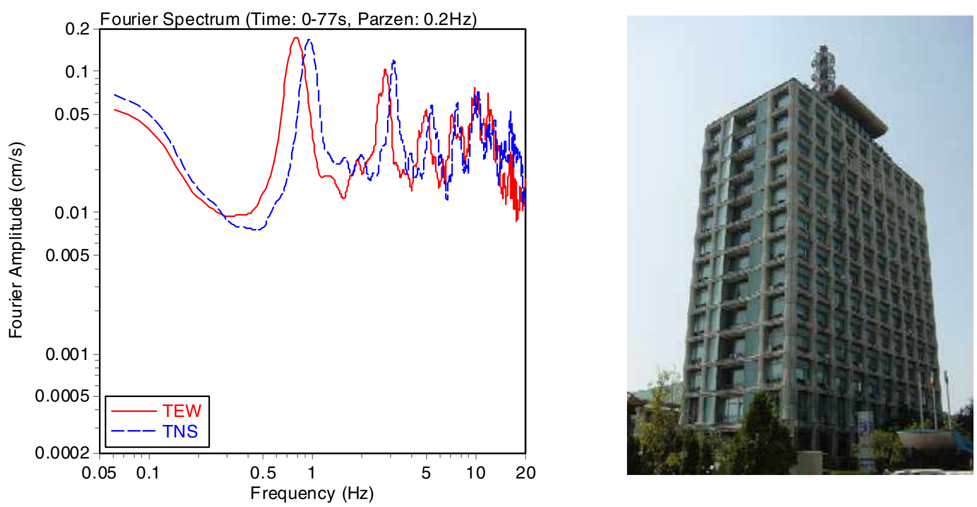

Figure 12. Fourier spectra of ambient vibration at TVR building

In Figure 13 are presented the Fourier spectra of ambient vibration records at the top of the BRD-SG Tower (20 storeys). The spectra indicate clearly the fundamental frequency 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.

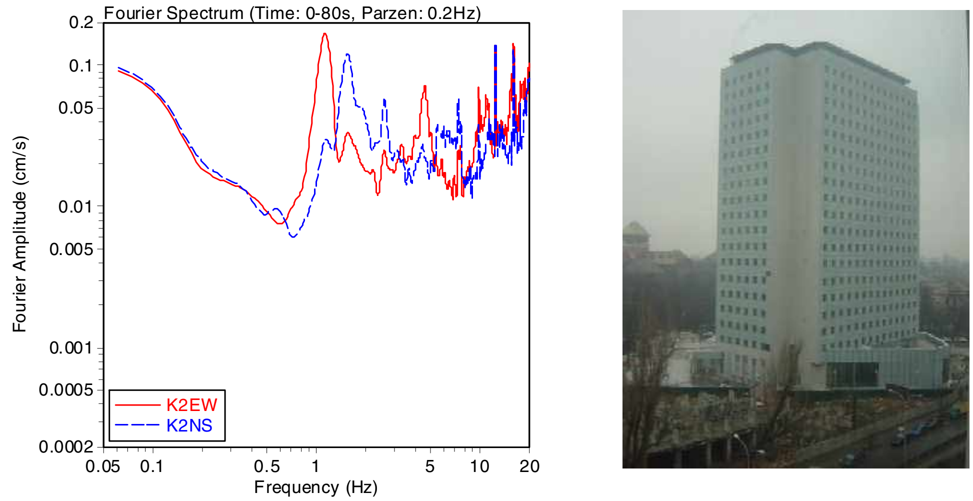

Figure 13. Fourier spectra of ambient vibration at BRD-SG building

Figure 14 presents the top/basement Fourier spectral ratios for earthquake records at BLD 2 station, indicating the fundamental frequencies of vibration: 2.2Hz for NS direction and 2.5Hz for EW.

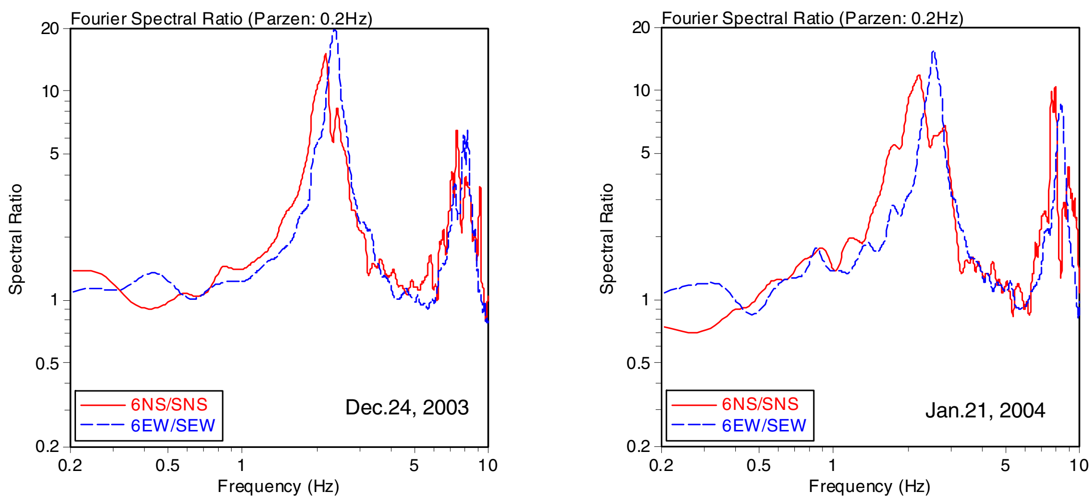

Figure 14. Top/basement Fourier spectral ratio for earthquake records at BLD2 seismic station

CONCLUSIONS

Romania is a country making continuous efforts for the development of seismic instrumentation. Attention should be putted on creating a modern communication system for the 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 7 sites in Bucharest.

ACKNOWLEDGEMENTS

The authors acknowledge Japan International Cooperation Agency JICA for supporting seismic risk reduction efforts in Romania by establishing the Project "Reduction of Seismic Risk for Buildings and Structures" that includes the donation of seismic observation equipment.

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