Thessaloniki-GREECE 2007

4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1522

RESULTS FROM SINGLE-STATION AND ARRAY MICROTREMOR MEASUREMENTS IN BUCHAREST, ROMANIA

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ABSTRACT

The records obtained in the Capital city of Romania, Bucharest, during the strong Vrancea subcrustal earthquakes of March 4, 1977 (moment magnitude Mw=7.5) and August 30, 1986 (Mw=7.2) displayed an acceleration response spectra with important amplifications at long periods (1÷2s). The long period ground motion is considered to be the effect of source characteristics and of site effects. In the frame of the Japan International Cooperation Agency seismic risk reduction Project in Romania, experts from Tokyo Institute of Technology and Tokyo Soil Research Co., Ltd., together with staff of National Center for Seismic Risk Reduction (NCSRR), Bucharest, performed array and single station microtremor measurements at three sites in the northern half of Bucharest. A first set of array measurements was done in 2004 (recording pattern and data analysis according to SPAC methodology), and a second one in 2005 (as for F-K methodology). Both sets of measurements contained small, medium and large size arrays, with station-to-station distances up to about 3 km. The observed phase-velocities were then inverted by a genetic-algorithm methodology (Yamanaka and Ishida, 1996). Preliminary results from array data analysis were given in Aldea et al., 2006a. In 2006 were performed ten single stations microtremor measurements and some small array measurements. The H/V spectral ratio method was applied in order to investigate the characteristics of site response within the city. The present paper presents an alternative velocity profile at INCERC site, based on more geological constrains, and comments on the new model in correlation with H/V results.

Keywords: microtremors, array, velocity profile, genetic-algorithm, H/V, NCSRR

INTRODUCTION

Seismic activity in Romania is governed by Vrancea intermediate depth (60÷170km) source, and by several crustal sources. Vrancea source dominates the seismic hazard not only in Romania but also in Republic of Moldova and affects large areas in Bulgaria and Ukraine.

Until the strong earthquake of March 4, 1977 (*Mw*=7.5) no strong ground motions for engineering purposes were recorded in Romania. The INCERC seismic network recorded the earthquake in Eastern Bucharest. Even the record was not impressive in terms of peak values, it's frequency content (narrow frequency band and a predominant period of ground vibration of ~1.3÷1.5s) and response spectra attracted international attention. "It is indeed fortunate that at least one reliable observation of the ground motion was made in Bucharest. It appears to be a very interesting one which may modify the concepts of standard response spectra." (Berg, EERI, 1977).

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Such special ground motion as the Bucharest 1977 record was explained by a combination of source effects and site effects. Studies on the Vrancea source and on the site effects in Bucharest became of interest for national and international efforts/projects.

In 2002 the National Center for Seismic Risk Reduction (NCSRR, Bucharest, Romania) was created under the Ministry of Transports, Construction and Tourism, in order to implement the Japan International Cooperation Agency (JICA) Technical Cooperation Project with Romania entitled "Seismic risk reduction for buildings and structures". In the frame of this project NCSRR performed array and single station microtremor measurements in Bucharest as a joint work of Romanian staff and Japanese short-term experts. The array microtremor measurements focused the northern half of Bucharest, where a dense seismic network was installed within the same project (Aldea et al., 2004, 2006b). The single station microtremor measurements were performed all around the city.

The present paper presents results from the analysis of the microtremor data at INCERC, trying to contribute to the understanding and modeling of site response in Eastern Bucharest.

ARRAY MICROTREMOR MEASUREMENTS IN BUCHAREST

Three sites were investigated by the use of array microtremor measurements, (Figure 1): INCERC in eastern Bucharest, EREN in north-western Bucharest and Civil Protection (PRC) in northern Bucharest. At all the sites borehole data are available and down-hole tests were also performed within the JICA project. INCERC and EREN areas are also of interest because of the significantly different ground motion records during the strong Aug.30, 1986 Vrancea earthquake (Lungu et al., 1997).

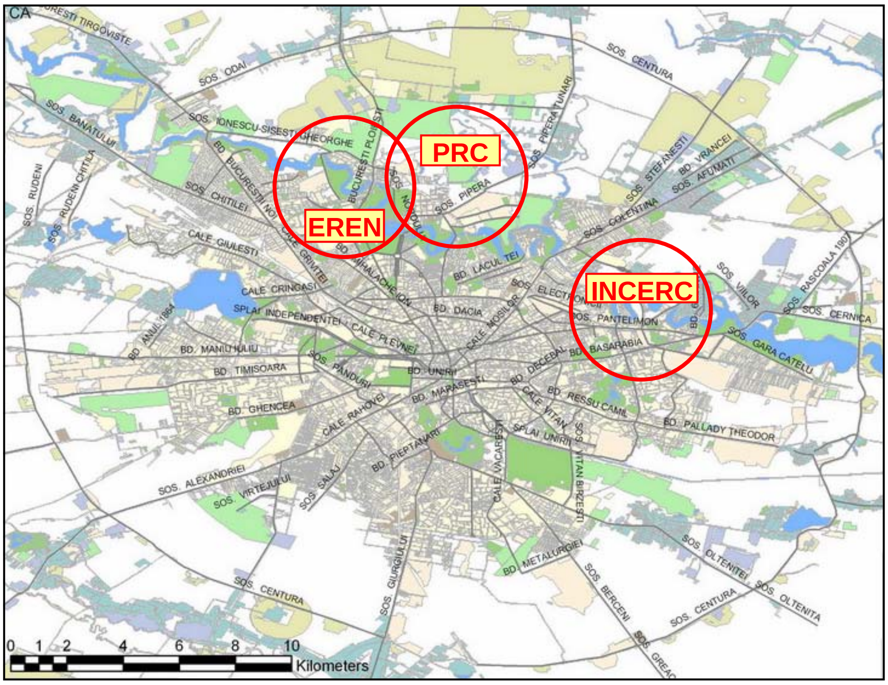

Figure 1. Location of the arrays for microtremor observation in Bucharest

Array microtremor measurements in 2004

A first set of measurements was performed in 2004 in cooperation with Tokyo Soil Research Co., Ltd: small (radius 40m) and medium size (radius 153m, Fig.2, left) arrays at INCERC site, and small, medium and large size arrays at EREN. The disposal of sensors was according to the requirements of spatial autocorrelation method (SPAC): a circular array consisting of 4 stations, arranged in an equilateral triangle corners and in its centre. The use of SPAC method with only 4 points produce satisfactory results, not significantly different compared with an array with more stations on a circle (Okada, 2001). This allows a reduction of effort and costs. However, the absence of high quality digital maps and the real urban situation (obstacles, private properties, noisy sites, etc.) proved that the perfect equilateral triangle sensor disposal is quite hard to reach. The instruments were portable stations (equipped with Global Positioning System GPS for ensuring time synchronisation) and feedback type velocity sensors made by Tokyo Hokushin Corp. For each array were recorded 2 sets of 30 min each.

Array microtremor measurements in 2005

In 2005 a second set of measurements was performed in cooperation with Tokyo Institute of Technology: a large array at INCERC site (Figure 2, right), and medium & large size arrays at PRC site. Each array was composed by 7 observation points, disposed in a somehow triangular shape and in the center of the triangle, for applying the frequency-wave number (F-K) method. The F-K method gives more freedom in the disposal of sensors and consequently seems to be more adapted to the urban environment. The largest distance between two points was of ~2.5km for the INCERC large size array. The Tokyo Institute of Technology instruments were portable Hakusan Corp. recorders and acceleration sensors with over damping (period range up to 5-6s). The internal clock was corrected with GPS signal 2 minutes before the scheduled starting time of recording, for ensuring time synchronization. For each array were recorded 2 sets of 27 min. each, with 100Hz sampling frequency.

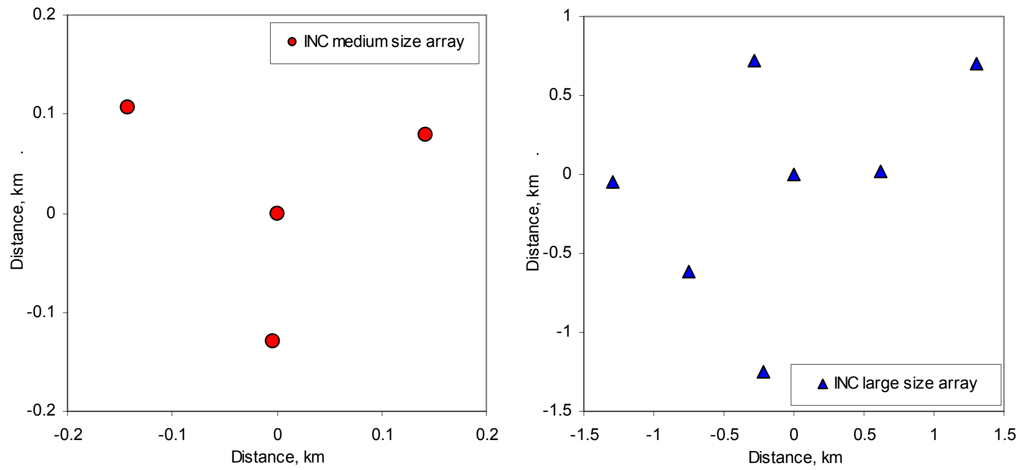

Figure 2. Arrays for microtremor observation at INCERC site: medium (left) and large (right)

ARRAY MICROTREMOR DATA ANALYSIS

Phase velocities at INCERC site

The array microtremor data acquired at in 2004 was processed with the SPAC method (Aki, 1957) in order to obtain the phase velocity dispersion curves. The SPAC coefficients (averaged spatial covariance function normalized with the power spectrum of microtremors) averaged azimuthally, for a fixed distance between two stations, at various frequencies, are used to obtain the phase velocities as function of frequency by fitting the Bessel function using the least-squares method. The computations were done with software developed at Tokyo Soil Research Co.,Ltd.

The array microtremor data acquired in 2005 was processed with the F-K method. In the frequency-wave number power spectral density method (Capon, 1969) the phase velocities can be extracted for each period value, together with their corresponding standard deviations. It is assumed that microtremors consists of plane waves propagating horizontally, and can be regarded as a stochastic process. The stochastic process of microtremors has an auto-correlation function that depends on time and location vector. The frequency-wave number spectrum (F-K spectrum) is the auto-correlation function Fourier-transformed with respect to time and space. The phase velocity and propagation direction are then obtained from the peak wave number of F-K spectra. The processing of data was done with software developed at Tokyo Institute of Technology.

In Figure 3 is presented the phase velocity dispersion curve at INCERC site, with the values selected for being used in the inversion procedure and their corresponding standard deviation. In case of the measurement from 2005 for which the f-k method was applied, for each phase velocity there is also a corresponding standard deviation, while in the case of the measurements from 2004 for which the SPAC method was applied, the standard deviation was considered as 20% from the phase velocity.

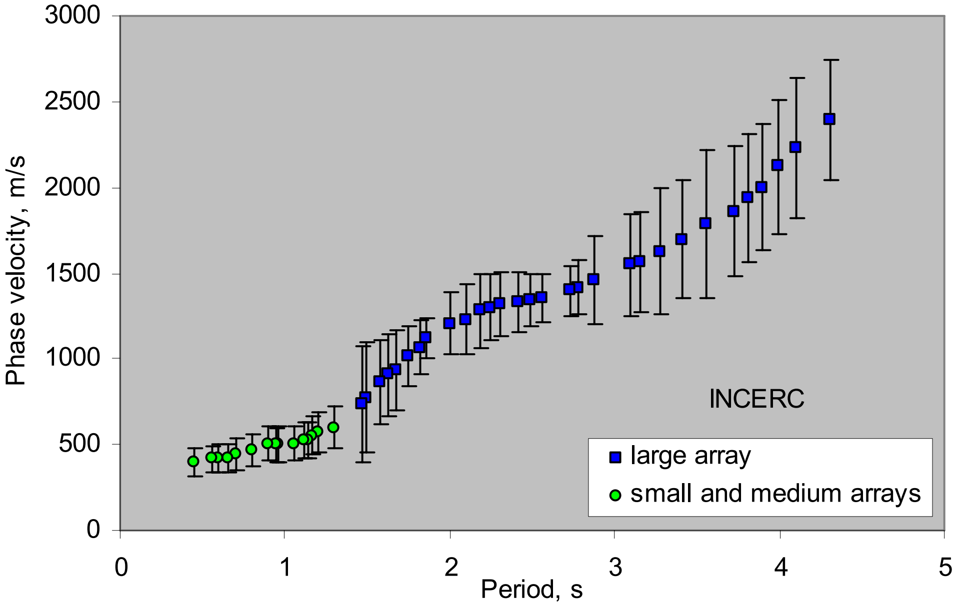

Figure 3. Selected observed phase velocity at INCERC site

Inversion procedure

The phase velocity curve was inverted using Genetic Algorithms (G.A.). The G.A. method consists of selection, crossover and mutation of individuals in a population. In order to facilitate the convergence to an optimal solution, an elite selection was added for ensuring that the "best" individual with the smallest misfit values is not excluded from the succeeding generation, together with a dynamic mutation which contains a generation-variant mutation probability (Yamanaka and Ishida, 1996). The genetic algorithm inversion has been successfully applied in inversion of phase velocity from microtremor array exploration (details in Yamanaka et al., 2000).

Preliminary results

Preliminary results of GA inversion of phase velocity were given in Aldea et al., 2006b (Table 1).

Table 1. Share wave velocity (Vs) and thickness (h) obtained by GA-based inversion of microtremor phase-velocities. Preliminary results (Aldea et al., 2006)

	INCERC		Density
	Vs (m/s)	h (m)	ρ (t/cm^3)
Layer 1	455	268	1.8
Layer 2	917	449	2.0
Layer 3	1493	979	2.2
Seismic bedrock	2948	∞	2.5
Good models for averaging the final model	195		
Total number of models	31649		
Tolerance (min. misfit + 5%)	0.23		

The layer model was selected in a simple form, i.e., 3 macro-layers over the bedrock, in order to identify the significant changes of velocity. The share wave velocity of the seismic bedrock was assumed to be around 3000m/s, thus the search limits for this layer were constrained between 2900m/s and 3100m/s. For the 3 soil layers considered in the analysis the share wave velocity and thickness were set free. The density of the soil layers was fixed at proposed values in a regular range of values. The compression wave velocity Vp is considered in the inversion procedure by the Kitsunezaki et al. (1990) formula: $Vp=1.11Vs+1.29$.

These results were considered as preliminary. Several ways of improvement were considered for future computations: a) use of geology data in order to better constrain the geometric model and if possible the density, b) use of the measured seismic wave velocities (by down hole tests), and c) further microtremor array measurements. In what follows only the first two items are detailed, since no new measurements were performed.

Use of geological data for constraining the inversion model

Liteanu studied a long period and in detail the quaternary deposits from Romanian Plain and from Bucharest. In one of his studies (Liteanu, 1961) he draw the map of the depth of the bottom of quaternary deposits in Romanian Plain, (part with Bucharest area in Figure 4). The map indicates that in Bucharest region the thickness of quaternary deposits is between 200m and 300m. The results from Table 1 are in agreement with Liteanu's estimations.

Figure 4. Map of the separation limit between quaternary and tertiary deposits (Liteanu, 1961)

Since the array microtremor method is applied here for estimating the shear wave velocity of "macro-layers" (thick geologic units/formations), some published geologic cross-sections were used for proposing geometrical (thickness) constrains in the inversion procedure.

The Geology and Geophysics Institute of Romania published a series of geologic cross-sections (scale 1:200000) covering all regions. One cross-section crosses Bucharest. Several useful data could be extracted for the vicinity of Colentina river in Bucharest (INCERC site is nearby the river): the top of the superior Jurassic deposits (about 500m thick) is at about 1500m depth, the top of the Cretacic deposits (about 500m thick) is at about 1000m depth; the thickness of quaternary deposits is of about 300m. Due to the scale of the drawing the thickness of the other layers could not be estimated.

The Geologic map of Romania (map no.44, Bucharest region, scale 1:200000) also presents a useful cross-section from which in the vicinity of Colentina river: the top of Jurassic deposits is at about 1600m depth, the top of the Cretacic deposits (about 600m thick) is at about 1000m depth, the top of Neogene deposits is at about 300m depth (the ~700m thickness of these deposits is divided in ~300m Miocene deposits and ~400m Pliocene ones), the thickness of the quaternary layer being of ~300m.

At the beginning of 20th century, a 1000m depth borehole was drilled in central Bucharest at Filaret (Oncescu, 1957). The Cretacic was not reached, the bottom 500m are Miocene deposits, followed by 500m Pliocene and Quaternary deposits.

Based on these geologic data, the following two soil profiles were selected for inversion, Table 2. The quaternary layer was divided in two parts, according to Liteanu's study (1951) that identified a quite homogenous lower part called "Fratesti gravels complex".

Table 2. Soil profiles proposed for INCERC site, based on geologic data

Model 1

Layer No.	h (m) search limits	Vs (m/s) search limits	ρ(g/cm^3)	Geologic description	
1	100-150	100-500	1.9	Top layers	Quaternary
2	100-150	300-800	2.0	Fratesti gravels	
3	300-400	700-1100	2.1	Pliocene	Neogene
4	400-500	1000-2000	2.3	Miocene	
5	∞	2800-3200	2.6	Bedrock	Cretacic

Model 2

Layer No.	h (m) search limits	Vs (m/s) search limits	ρ(g/cm^3)	Geologic description	
1	100-150	100-500	1.9	Top layers	Quaternary
2	100-150	300-800	2.0	Fratesti gravels	
3	300-400	700-1100	2.1	Pliocene	Neogene
4	400-500	1000-2000	2.3	Miocene	
5	450-500	1500-2500	2.6		Cretacic
6	∞	2800-3200	2.7	Bedrock	Jurasic

New results from inversion of phase velocity dispersion curve

Using the soil models in Table 2, the phase velocity dispersion curve in Figure 3 and the Genetic Algorithms inversion, the following results were obtained, Table 3.

Table 3. Share wave velocity (Vs) and thickness (h) obtained by GA-based inversion of microtremor phase-velocities. Present study results

Model 1	INCERC		Density
	Vs (m/s)	h (m)	ρ (t/cm^3)
Layer 1	427	136	1.9
Layer 2	474	135	2.0
Layer 3	872	352	2.1
Layer 4	1218	464	2.3
Seismic bedrock	2877	∞	2.6
Good models for averaging the final model	276		
Total number of models	32246		
Tolerance (min. misfit + 5%)	0.247		

Model 2	INCERC		Density
	Vs (m/s)	h (m)	ρ (t/cm^3)
Layer 1	431	132	1.9
Layer 2	464	132	2.0
Layer 3	858	399	2.1
Layer 4	1276	448	2.3
Layer 5	1765	509	2.6
Seismic bedrock	2934	∞	2.7
Good models for averaging the final model	356		
Total number of models	32325		
Tolerance (min. misfit + 5%)	0.239		

As it can be observed, the first three layers are very similar in both models, in terms of both velocity and thickness. The Quaternary layer resulted with a thickness of 260-270m, the Pliocene layer with 350-400m and the Miocene layer with 450-460m. The Cretacic depth resulted at 1087m in Model 1 and at 1051m in Model 2. The Jurassic depth resulted at 1560m (in Model 2). The seismic bedrock was at 1696m in the preliminary results (Table 1). When comparing Table 1 and Table 3, one may notice that the top (quaternary) layer has almost the same thickness and similar velocity. Also the second (Pliocene) layer has comparable values. Both models are characterised by quite similar tolerance and GA statistics, and these values are close to the ones in Table 1.

The theoretic phase velocity curves corresponding to the preliminary model (Table 1) and to the new models (Table 3) are comparatively compared in Figure 5. The three curves are almost identical, the models explaining in a satisfactory way the observed data.

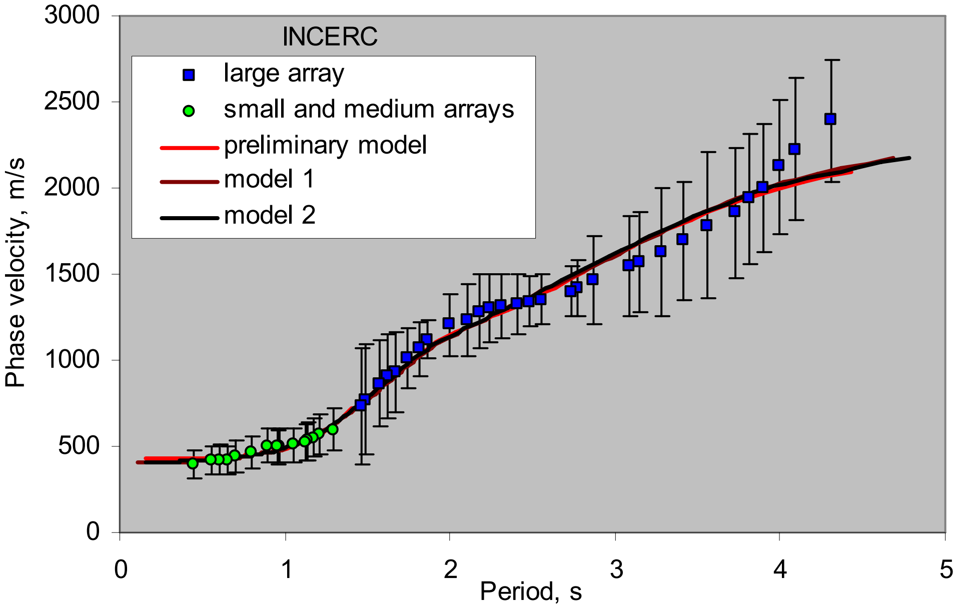

Figure 5. Observed and theoretic phase velocities at INCERC site

Wave velocities measured by down hole tests

At all the NCSRR seismic stations with borehole instrumentation 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.*, 2006c). In Table 2 is presented the velocity profile at INCERC site (as obtained from down-hole measurements).

Table 4. Velocity profile at INCERC site, as obtained from down-hole measurements

h (m)	Vs (m/s)	Vp (m/s)	ρ(g/cm^3)
5.5	260	490	1.75
1.5	260	490	2.00
12	260	850	2.00
9.5	280	1640	2.00
7.0	350	1640	2.00
7.5	350	1640	2.05
12	380	1740	2.01
19	380	1740	2.07
20	400	1740	2.00
20	440	1740	2.04
21	440	1740	2.05
5.0	440	1740	2.03

The total investigated depth is 140 m. The weighted average shear wave velocity over the top 30m of soil is 270 m/s (corresponding approximate vibration period 0.45 s). The weighted average shear wave velocity over the whole borehole depth (140m) is 364 m/s (corresponding approximate vibration period 1.54 s). One may notice the slow increase with depth of velocity, and the significant change of the approximate vibration period when considering a thinker package of soil layers. Also it can be observed that the Vs=455m/s for the top layer in Table 1 is realistic, considering the slowness of velocity increase and the limitation of the low period phase velocity data used in the inversion. It is obvious that the fundamental period of ground vibration at INCERC site is even longer, depending on the depth at which a significant shear wave velocity is found. If we consider the first layer in Table 1 (268m with 455m/s shear wave velocity), the corresponding period would be 2.36s.

If the first layer from the genetic algorithms obtained models presented in Table 3 is replaced with the down-hole test results from Table 4, new models are constructed (called here "GA + PSlog"). The theoretical phase velocity curve of these new "GA+PSlog" model 2 is compared with that of the GA model 2 (from Table 3) in Figure 6.

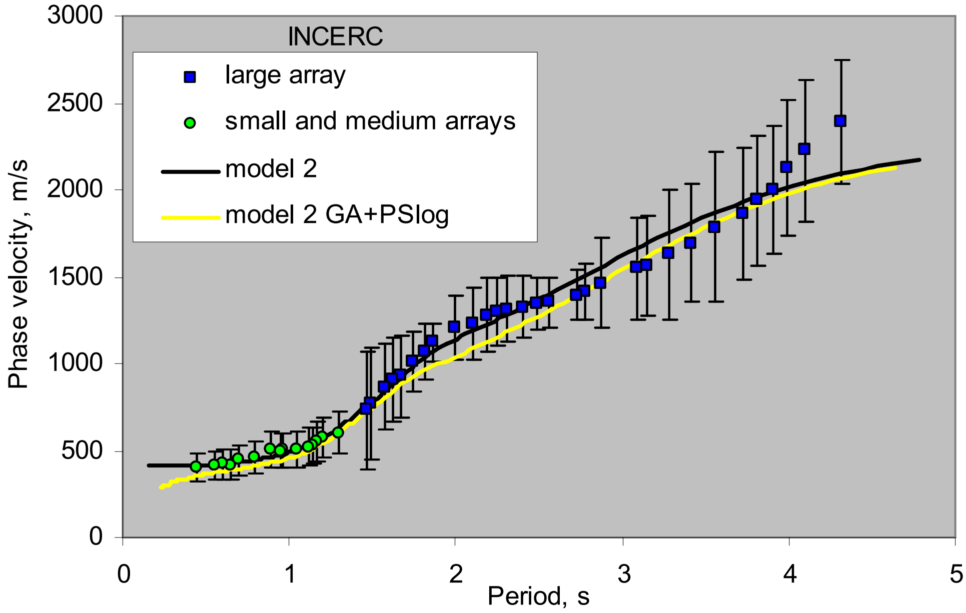

Figure 6. Observed and theoretic phase velocities for different models at INCERC site

As expected, there is a small reduction of phase velocities when including in the computation the results from down-hole tests. In future, a check should be done by fixing the top soil layer properties with the values from down-hole test (Table 4), and then performing the genetic algorithm inversion.

Other velocity profile from literature

Constantinescu and Enescu (1985) indicate the following velocity profile at INCERC site, Table 5.

Table 5. Soil profile at INCERC site (Constantinescu and Enescu, 1985)

Layer No.	h (m)	Vs (m/s)	ρ(g/cm³)	Geologic description	
1	4	104	1.9	Top layers	Quaternary
2	28	174	1.9		
3	15	367	1.9		
4	17	444	1.9		
5	198	694	2.1	gravels, sands, clays	
6	470	933	2.2	Pliocene	Neogene
7	430	1150	2.3	Miocene	
8	∞	3120	2.6	Bedrock	Cretacic

The top 5 layers (the quaternary part) have a total thickness of 262m and a weighted average shear wave velocity of 465m/s, which is very close to the results from Table 1 and Table 3. However, the model in Table 5 shows a quite significant velocity contrast between layers 4 and 5 (at 64 m depth), contrast that is not identified in the inversion results and/or in the down hole test results (Table 2). The Pliocene layer in Table 5 is somehow "stronger" than the one in Table 3 (it has larger thickness and velocity), and the Miocene one is slightly "weaker" (smaller thickness and velocity), but overall the values are quite close. The seismic bedrock in Table 5 has a larger velocity than the one from inversion of observed phase velocity. In Figure 7 is represented the theoretical phase velocity curve corresponding to the profile in Table 5, comparatively with the observed data and with the curves from GA inversion models (Table 1 and Table 3).

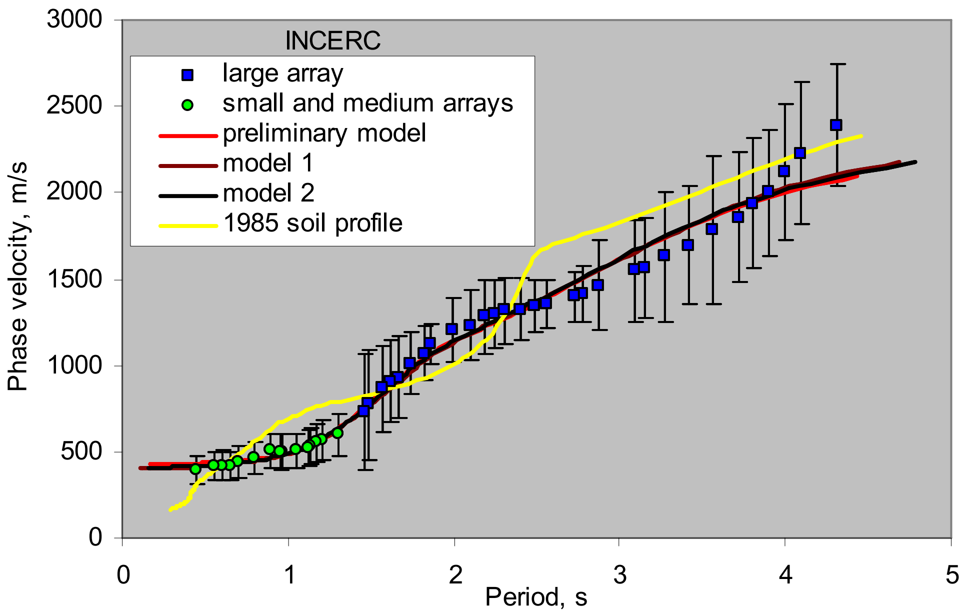

Figure 7. Observed & theoretic phase velocities for different models of INCERC site soil profile

Even in appearance the soil profiles are looking quite similar, their corresponding phase velocity curves differ. The curve of 1985 model follows the tendency of the observed data, but the match of the models from inversion is superior. However, it should be noticed that the soil profiles from inversion do not model satisfactory the observed data in the long period domain.

MICROTREMOR MEASUREMENTS

In 2006 single-station microtremor measurements were performed by NCSRR and Tokyo Soil Research Co., Ltd., at several sites in Bucharest (including INCERC site), Figure 8.

Each single station microtremor observation consisted of 30 minutes of measurement, and horizontal to vertical Fourier amplitude spectral ratio ("H/V Nakamura ratio", Nakamura, 1989) was computed for the undisturbed data segments. FFT was computed with 32,778 points and 50% overlapping of each selected time-window. In general, all over the city two main peaks were observed on the H/V ratio, one at 1-2s and another one at 4-6s.

The H/V ratio was compared with the theoretical elipticity of Rayleigh waves. The two main peaks of the H/V ratio were explained by the contribution of the fundamental and the first higher modes of the theoretical elipticity of Rayleigh waves.. The comparison between the observed H/V ratio and the theoretical transfer functions corresponding to the two models in Table 4 is presented in Figure 9. The first H/V peak is well fitted by the first higher mode. The longer peak (due to the deeper geology) has a certain shift toward lower periods in the theoretical curve. Improvement of models and more single station microtremor measurements (for confirming the H/V shape) may allow better results.

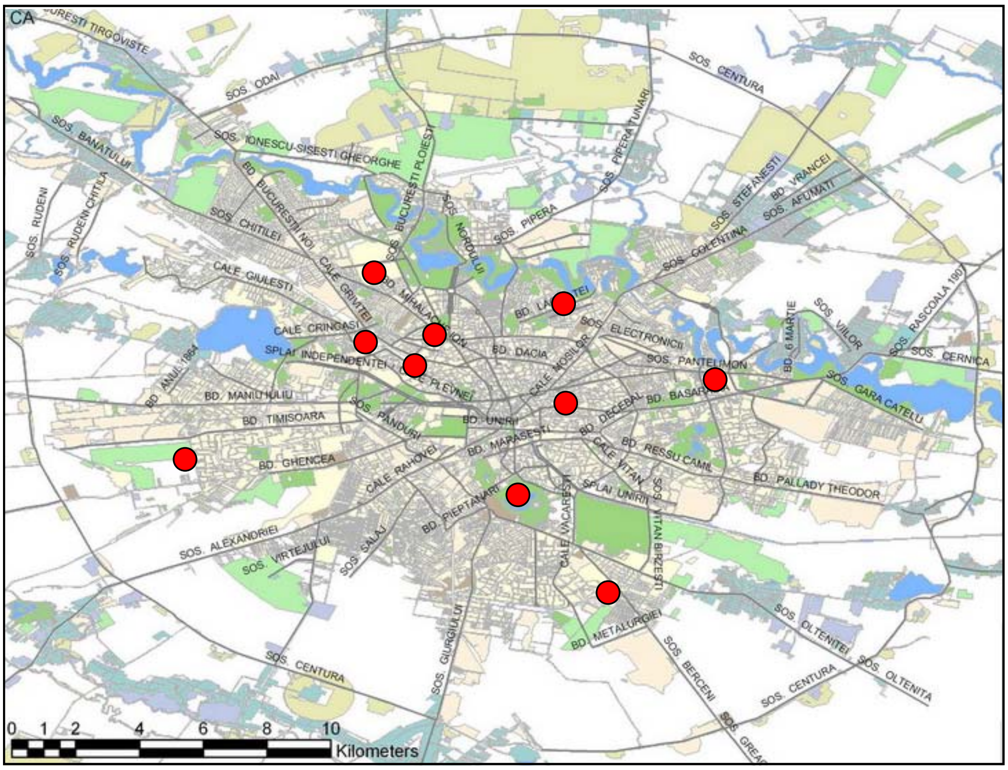

Figure 8. Location of sites with single station microtremor measurements

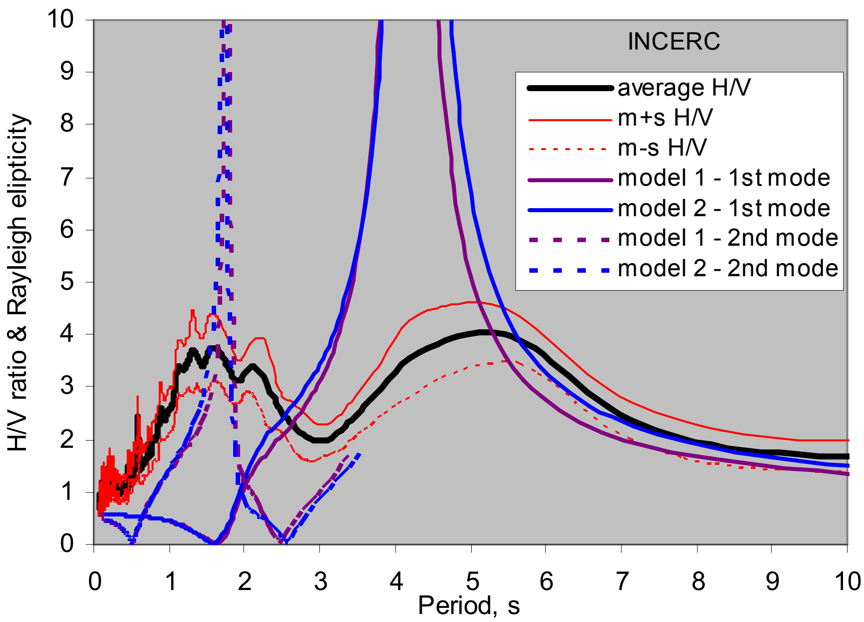

Figure 9. Comparison between H/V spectral ratio and theoretical Rayleigh transfer functions

CONCLUSIONS

The analysis of single station and array microtremor observations is a versatile, cheap and efficient method for estimating the velocity profile and evaluating the main characteristics of site response. The frequency-wave number approach that allows a less rigid disposal of acquisition stations is more appropriate for urban environment. The Genetic Algorithms are a power tool for the inversion of phase velocities.

The preliminary results obtained in a previous study were confirmed by the new models in what concerns the upper geology. The new models follow closely the published geologic data. Two soil profiles were found to quite satisfactory model the observed phase velocities, but the decision on a final model needs further investigations. The studies will continue not only for the INCERC site but also for the other locations were microtremors were measured within the JICA project in Romania. The establishment of a reliable velocity profile for Bucharest area is considered to be essential, and the basis for other studies (ground motion simulation, seismic microzonation, etc.). The results obtained confirmed the long periods of ground vibration in Bucharest revealed during strong subcrustal Vrancea earthquakes and responsible for the damage of high-rise flexible buildings.

AKNOWLEDGEMENTS

Japan International Cooperation Agency (JICA) is gratefully acknowledged for supporting the Japanese authors work in Romania as short-term experts within the JICA project, and for supporting the training of the Romanian author in Japan. The activities of Japanese authors in Romania were also supported by T.Kaminosono, N.Furukawa and S.Koyama (BRI, Japan), and R. Vacareanu (NCSRR). The activity of the Romanian author in Japan was also supported by I.Okawa (BRI, Japan). Their help and support is kindly acknowledged. The authors also gratefully acknowledge the effort and contribution of T. Takahasi from Tokyo Soil Research Co., Ltd., of the staff from NCSRR and of the students from Technical University of Civil Engineering Bucharest that participated to the measurements.

REFERENCES

***Geology and Geophysics Institute, "Geologic profiles at scale 1:200000 for completion of geologic imaging of Romanian territory, Section Nr.20", (in Romanian), 198?

***State Geologic Committee, Geologic Institute, "Geologic map, Bucharest region, map nr.44", 25p + 1 map, (in Romanian), 1966

Aldea, A., Yamanaka, H., Takahashi, T., "Microtremor array measurements in northern Bucharest for estimation of site response", *Proceedings of First European Conference on Earthquake Engineering and Seismology*, Geneva, Switzerland, 3-8 Sept., 10p., CD, 2006a

Aldea, A., Kashima, T., Poiata, N., Kajiwara, T., "A New Digital Seismic Network in Romania with Dense Instrumentation in Bucharest", *Proceedings of First European Conference on Earthquake Engineering and Seismology*, Geneva, Switzerland, 3-8 September 2006, 10p., CD, 2006b

Aldea, A.,Yamanaka, H., Negulescu, C., Kashima, T., Radoi, R., Kazama, H., Calarasu, E., "Extensive seismic instrumentation and geophysical investigations for site-response studies in Bucharest, Romania", *ESG 2006 Third International Symposium on the Effects of Surface Geology on Seismic Motion*, Grenoble, France, 30 Aug.-1 Sept., Paper Number: 69, 10p, CD-ROM, 2006c

Aldea, A., Kashima, T., Lungu, D., Vacareanu, R., Koyama, S., Arion, C., "Modern Urban Seismic Network in Bucharest, Romania", *Proceedings of the First International Conference on Urban Earthquake Engineering*, March 8-9, 2004, Tokyo Institute of Technology, Yokohama, 8p., 2004

Aki, K., "Space and time spectra of stationary stochastic waves with special reference on microtremors", *Bull.Earth. Res.Inst.*, 35, p.415-456, 1957

Berg G.V., "Earthquake in Romania, March 4, 1977". A preliminary report to *Earthquake Engineering Research Institute*, 52 p., 1977

Capon, J., "High-resolution frequency-wavenumber spectrum analysis", *Proc. of IEEE*, 57, 1408-1418, 1969

Constantinescu, L., Enescu, E., "Vrancea earthquakes from scientific and technologic point of view", Editura Academiei, 230p., (in Romanian), 1985

JICA Technical Cooperation Project "Reduction of Seismic Risk for Buildings and Structures" with Romania, 2002-2007, Ref.#7241011E0

Kitsunezaki, C., Goto, N., Kobayashi, Y., Ikawa, T., Horike, M., Sait, T., Kurota, T., Yamane, K., Okozumi, K., "Estimation of P- and S- wave velocities in deep soil deposits for evaluating ground vibrations in Earthquake Journal of natural Disaster Science, Vol. 9-3, 1-17, (in Japanese), 1990

Liteanu, E., "Geology of the city of Bucharest", *Technical studies*, Series E, *Hydrogeology*, No.1, (in Romanian), 1951

Liteanu, E., "On the quaternary/tertiary limit in Romanian Plain", *Economic and technical studies*, Series E, No.5, *Hydrogeology*, Geologic Committee, Geologic Institute, 12p., (in Romanian), 1961

Lungu, D., Cornea, T., Aldea, A., Nedelcu, C., Zaicenco, A., "Seismic microzonation of the city of Bucharest". Technical Report at Technical University of Civil Engineering Bucharest prepared for Association Française du Génie Parasismique, Vol.1&Vol.2, 91p.+69p., 1997

Nakamura, Y., "A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface". *QR Railway Technical Research Institute,* Vol.30. No.1, p.25-33, 1989

Okada, H., "Remarks on the efficient number of observation points for the spatial auto-correlation method applied to array observations of micro tremors", *Proc. of the 104th SEGJ Conf. Society of Exploration Geophysicists*, Japan (in Japanese), 2001

Oncescu, N., "Geology of Romania", Ed.,Tehnica, Bucuresti, (in Romanian), 278p., 1957

Yamanaka, A., Ishida, H., "Application of Genetic Algorithms to an Inversion of Surface-Wave Dispersion Data", *Bull. of the Seismological Society of America*, Vol.86, No.2, pp.436-444, 1996

Yamanaka, H., Yamada, N., Sato, H., Oikawa, S., Ogata, Y., Kurita, K., Seo, K., Kinugasa, Y. , "Exploration of basin structure by microtremor array technique for estimation of long-period ground motion", *12 WCEE*, CDROM, paper No.1484, 2000