In Situ Investigation for Microzonation of Bucharest Surface Geology

15 WCEE
LISBOA 2012

C. Arion, C. Neagu, R. Văcăreanu
Technical University of Civil Engineering, Bucharest

E. Călăraşu
Urban-Incerc, Bucharest

SUMMARY:
The modern codes for earthquake resistant design classify the local site conditions based on qualitative and quantitative indicators (average shear wave velocity, Standard Penetration Test results, etc.). The borehole data and the experimental research performed in the last 10 years in Bucharest indicate a clear correlation between city superficial geology and the frequency contents of seismic records during 1986 and 1990 Vrancea events recorded in more than 10 seismic stations within the city. The paper contains data obtained from seismic investigations (down-hole prospecting and surface-wave methods) and geotechnical in situ investigations (Standard Penetration Test) in Bucharest. Technical University of Construction Bucharest specialists and the colleagues form Building Research Institute, Japan and Tokyo Soil Research, Japan performed the tests in the framework of the JICA Technical Cooperation Project on the Reduction of Seismic Risk for Buildings and Structures in Romania (2004-2008).

Keywords: microzonation, shear waves, SPT, spectral values, Bucharest

1. INTRODUCTION

The experience of the strong ($M_W = 7.5$) Vrancea 1977 record on Japanese SMAC – B instrument in Bucharest proved the long predominant period of ground vibration, T_p = 1,4 - 1.6s, for ground vibration within the city. The period has been also confirmed during the next 1986 Vrancea event ($M_W = 7.2$). According to Munich Re public documents, the Bucharest and Lisbon are the only capital cities of Europe characterized by specific long periods of ground vibration.

The characterization of local soil conditions using in situ prospecting for establishing the superficial geology and to determine the values of dynamic parameters is an essential element for seismic design of constructions and urban planning. The use of those prospecting techniques represents an important stage in the implementation of modern codes for seismic design (EC8, EC7, ASCE and UBC).

Bucharest city is located in the central part of the Moesian Sub-plate (age: Precambrian and Paleozoic), in the Romanian Plain. Over Cretaceous and Miocene deposits (having the top at about 1000 m depth) a Pliocene shallow water deposit (~700m thick) was settled. The surface geology consists mainly of Quaternary alluvial deposits. Later loess covered these deposits and rivers shaped the present landscape. The surface geology can be divided in seven lithological formations, from surface to bottom (Liteanu, 1951): (i) backfill (thickness h up to 3 m) and (ii) sandy-clay superior deposits (loess and sand, h=3÷16 m), both formations from Holocene, and other formations from Pleistocene: (iii) "Colentina" gravel (gravel and sand, h=2÷20 m); (iv) Intermediate cohesive deposits of lacustral origin (80% clay and some sand, h=0÷25 m); (v) "Mostistea" banks of sands (mainly sand, sometimes lenses of clay, h=10÷15 m); (vi) lacustral deposits from (clay and sands, h=10÷60m), and (vii) "Fratesti" gravel (gravel & sands separated by clay, h=100÷180 m). Site effects were firstly observed on the basis of damage pattern within the city. When strong ground motions were recorded, they provided instrumental proofs of site effects and of the long predominant period of soil vibration that characterize Bucharest.

The strong November 10, 1940 Vrancea earthquake (moment magnitude $M_W=7.7$) represents the starting point of earthquake engineering in Romania. The earthquake triggered liquefaction at many sites including Bucharest, the water blowing out up to 1m height. During March 4, 1977 Vrancea strong earthquake ($M_W=7.5$), the most destructive earthquake ever experienced in Romania, not only man-made structures and buildings suffered, but also geological and hydrological elements were disturbed at many sites in Romania. Permanent ground settlement in Bucharest measured after 1977 event was uniform of 0.2-2.5cm for 11-12 storeys buildings. The characterisation of ground conditions from the seismic point of view requires the knowledge of local geology and, if possible, of the dynamic soil properties, especially of the shear wave velocity that is used by many codes for ground type classification. For each ground type (soil category), the codes specify compatible design spectra.

2. IN SITU PROSPECTING METHODS USED BY UTCB AT VARIOUS SITES IN ROMANIA

2.1. In Situ P and S-Wave Measurements

The dynamic response of a site depends strongly on the dynamic properties of the soil. One direct method to obtain the elastic properties in depth is borehole logging using elastic waves. The down-hole technique has become indispensable for determining values of dynamic parameters and Poisson's ratio of soils at relatively small strain levels. Low-strain tests are based on the theory of wave propagation in the materials. One of the low-strain field tests is PS Logging, a seismic down-hole technique. In the down-hole method the sensors are placed at various depths in the borehole and the source of energy is above the sensors - usually at the surface. This technique does not require as many boreholes as the cross-hole method, but the waves travel through several layers from the source to the sensors. Thus, the measured travel time reflects the cumulative travel through layers with different wave velocities, and interpreting the data requires sorting out the contribution of the layers. Since S and P wave velocities are calculated from the slope of a depth/travel time curve, the velocities are obtaining not for each incremental interval but for a velocity layer that has a certain thickness including many measuring points as an average values. Hitting a wooden pile with a large wooden hammer (as shows in the left of Figure 1) generates the P-wave, and hitting the end of a plank horizontally with the same hammer (as shows in the right of Figure 1) generates S-wave. Examples of the measured sited in Bucharest are showed in Figure 2.

The analysis of travel-time data coordinated with the site stratigraphy revealed the seismic velocity profiles and other related parameters as Young's modulus (E_{din}), shear modulus (G_{din}) and Poisson's ratio (υ_{din}). The average shear wave velocity at the site is the fundamental tool for site classification in present codes.

Figure 1. Generation of P and S waves

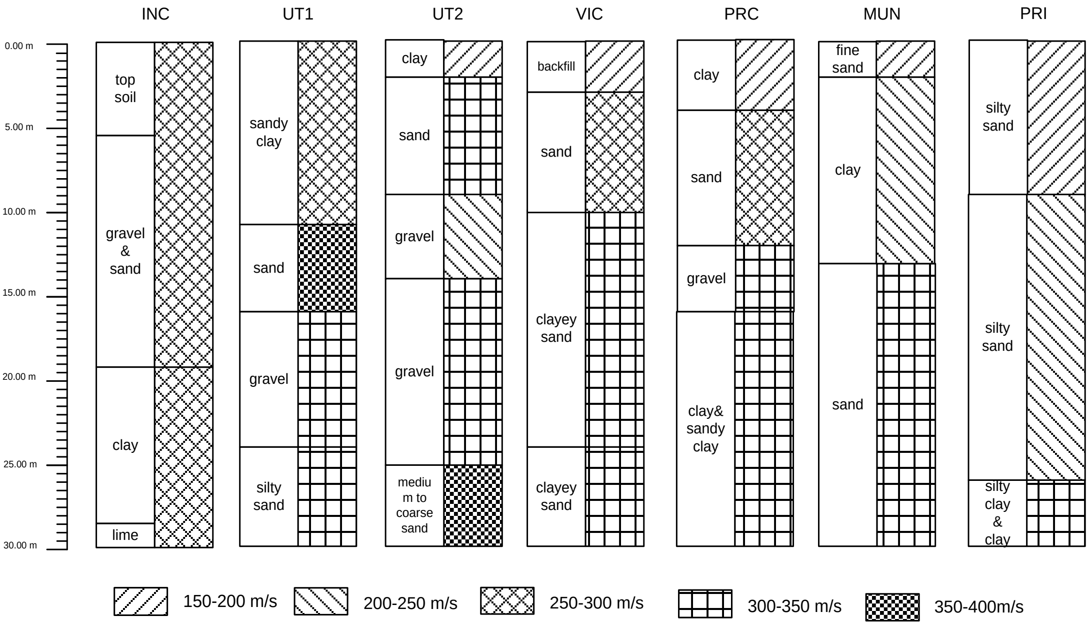

Figure 2. Results of in situ S-wave measurements at various sites in Bucharest area

2.2 Standard Penetration Test (SPT)

Starting with 2003, NCSRR received, as a donation from JICA, drilling equipment FRASTE Rig Type Multidrill XL, which has as attachments an automatic device used for Standard Penetration Test. The purpose of the Standard Penetration Test is to identify the soil stratification and the layer thickness in order to estimate the geological and hydrogeological conditions and other engineering properties of soil layers as relative density of sands, the resistance and rigidity soil characteristics to penetration. During the drilling, it was possible to take disturbed and undisturbed samples (using double core barrel-sampler), which were used for further laboratory tests. In many countries, Standard Penetration Test remains the subsurface investigation technique of choice for geotechnical engineers. The results of the SPT measurements are quantified in the number of blows required to affect that segment of penetration, NSPT. The SPT equipment, SPT split-barrel sampler and the drill rods used for soil penetration test are shown in Figure 3 (left), and the soil sampling is presented in Figure 3 (right).

The relative firmness or consistency of cohesive soils or density of cohesionless soils can be estimated from the blow count data. The resistance to penetration is obtained by counting the number of blows required to drive a steel tube of specified dimensions into the subsoil to a specified distance using a hammer of a specified weight (mass). The test is well established in practice, provides a soil sample, and a vast amount of local experience and correlation data have been collected by researchers.

Figure 3. Standard Penetration equipment of CNRRS

2.3 Cone Penetration Test (CPT)

The Cone Penetrometer Technology (CPT) provides cost-effective, real-time data for use in the characterization of the subsurface. The cone penetrometer consists of a steel cone that is hydraulically pushed into the ground while in situ measurements are continuously collected and transported to the surface for data interpretation and visualization. The cone penetration test is used for cohesive and cohesionless soils, especially for sandy soils; the maximum depth of the static penetration can be established between 25.00 to 30.00 meters. The purposes of the cone penetration test is to evaluate the soil type, geological and hydrogeological conditions, soil stratification, layers limits, thickness and inclination of the soil layers in the lithological profile, shear strength parameters, soil density and in situ stress condition. During the static penetration, the cone resistance (q_c) and the friction sleeve (f_s) are measured. In July 2004, the CPT equipment from Geomil, Holland, was received by NCSRR as donation from JICA. The Cone Penetration Test equipment from Geomil and the electrical piezocone are presented in Figure 4.

Figure 4. CPT equipment and the electric piezocone

2.4 Surface Wave Method

The surface-wave method can be carried out from ground surface non-destructively. The surface wave method is the seismic exploration method in which the dispersion character of the surface-waves is analysed. Figure 5 shows the schematic view of a surface-wave method. A 10 kg sledgehammer or 50 kg weight drops are used as a source. The sources are placed with 1 to 4m intervals; 12 to 48 geophones (4.5Hz) are deployed with 0.5 to 2m intervals. The result of measurements at UTCB Tei is presented in Figure 6.

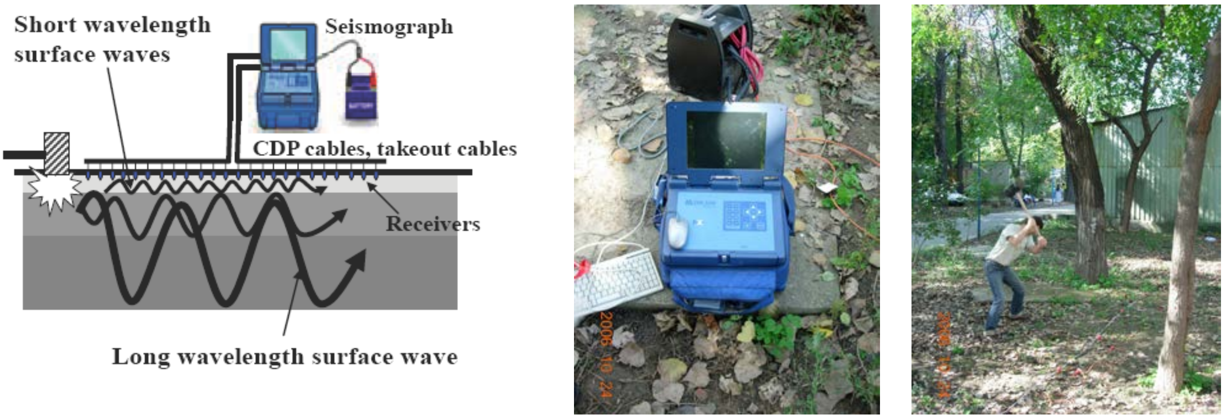

Figure 5. Schematic diagram of a surface-wave method

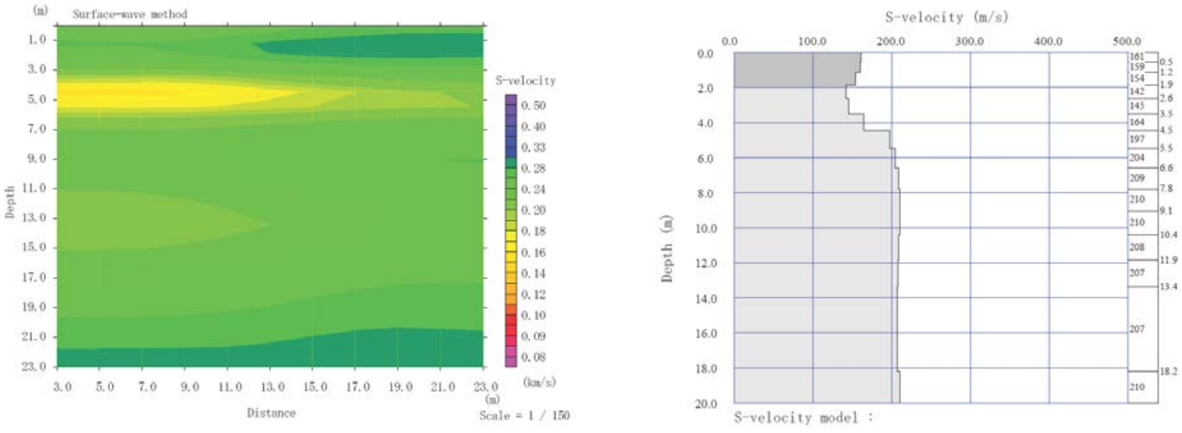

Figure 6. Shear-wave velocity models for the UTCB site obtained through the surface-wave method

2.5 LABORATORY INVESTIGATION FOR ESTIMATION OF LOW AMPLITUDE MODULI

Laboratory measurements of soil properties can be used to supplement or confirm the results of field measurements. They are necessary to establish values of damping and modulus at strains larger than those that can be obtained in the field or to measure the properties of materials that do not exist in the field, such as soils to be compacted. The dynamic deformation characteristics of the soil are used in order to calculate seismic response of ground, earth structures and structure-ground response.

During the last years we conduct series of dynamic triaxial tests especially on the clay soils. Though soil deformation under seismic loading is relatively small, its modulus is dependent on dynamic stress or strain level. Soil modules such as Young's modulus and shear modulus decrease as the level of stress or strain increases. Therefore nonlinearity of dynamic deformation characteristics is significant in seismic response analysis. All the moduli E, ν, G, h depends on strain range but the dependency of ν is considered rather small. The evaluation of shear modulus of soils at very small levels of strains was a main concern of researchers. This modulus is called maximum shear modulus, initial shear modulus, or low amplitude shear modulus and is noted by G_{max} or G_0. In the Figure 7 are represented relations of shear modulus ratio G/G_O versus shear strain and the strain dependent damping for the laboratory samples. Also the strain-dependent modulus and damping curves quoted in the literature are represented.

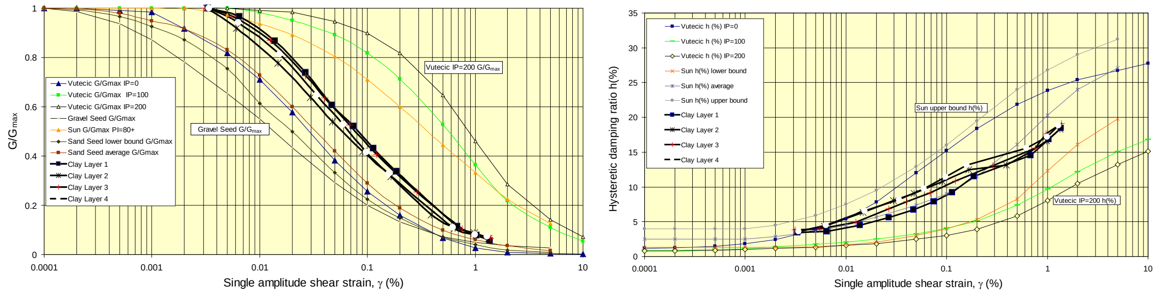

Figure 7. Test results for cohesive soils from Bucharest and comparison with analytical model curves

3. THE PREDOMINANT PERIOD OF RESPONSE SPECTRA IN BUCHAREST

The predominant period of response spectra is $T_C = 2\pi \frac{EPV}{EPA}$, where EPA and EPV the invariant to frequency content of ground motions definitions of the peak ground acceleration PGA and peak ground velocity PGV, [Lungu *et al.*, 1997]. Based on the analysis of frequency contents of recorded ground motions in 12 location in Bucharest during the 1977, 1986 and 1990 Vrancea earthquakes versus soil profiles at recording sites (stations) the following conclusion has been established [Lungu, 1999, Aldea et al., 2002]: the relatively short control period of response spectra $T_C \leq 0.8$s corresponds to the sandy and gravely soil profiles, mainly located in the Northern part of Bucharest (EREN seismic station) and the long predominant period Tp = 1.4÷1.6s of soil vibration during the 1977 and 1986 events corresponds to clayed soil profiles, mainly located in the Eastern (INCERC seismic station), Southern and Central parts of Bucharest. Microzonation maps for control period of response spectra T_C for 1986 earthquake are presented in Figure 8 [Lungu et al., 1999].

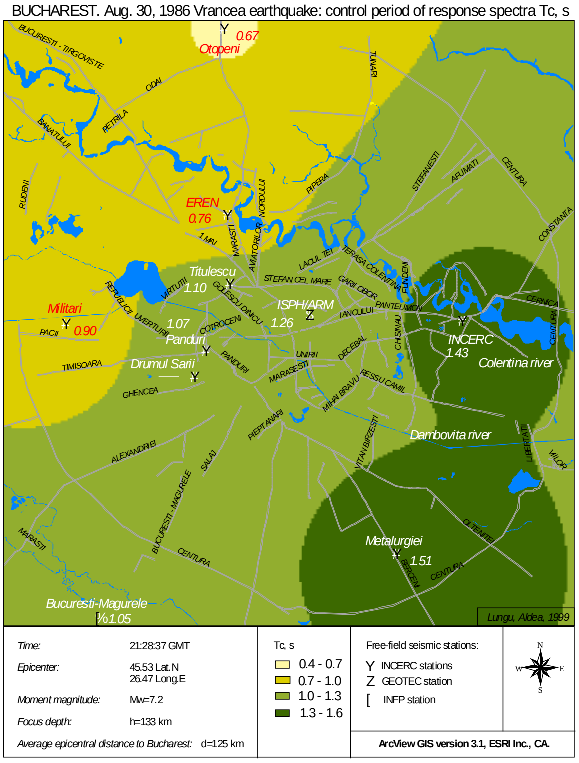

Figure 8. Bucharest - Aug.30, 1986 event: microzonation T_C [Lungu et al., 1999]

As it can be noticed, there is a clear difference between the Eastern, Central and Southern Bucharest and the rest of the city. In this part of Bucharest the control period has higher values in comparison with northern and western sides where the control period is lower. A similar pattern was noticed on the microzonation maps for May 30, 1990 event.

3.1 Microzonation of Spectral Values

The acceleration response spectrum is of major engineering interest and seismic hazard assessment is often made in terms of spectral values. The city of Bucharest has a specificity in terms of acceleration response spectra SA due to it's soil condition characterized by a long control period of response spectra. This long control period appears just in case of moderate and strong Vrancea earthquakes. The quite large spectral values at long periods are not just a local phenomenon in some parts of the city, the microzonation of SA for 1986 event, Figure 9, showing a practically uniform distribution of spectral values at the level of about 200cm/s^2 at T=1.5s.

Figure 10 presents the microzonation of normalized acceleration response spectra for T=1.5s, underlining the high dynamic amplification factor (β value in Romanian P100-1-2006 seismic design code) for the eastern, central and southern Bucharest in comparison with the rest of the city [Aldea et al., 2002, Arion, 2003].

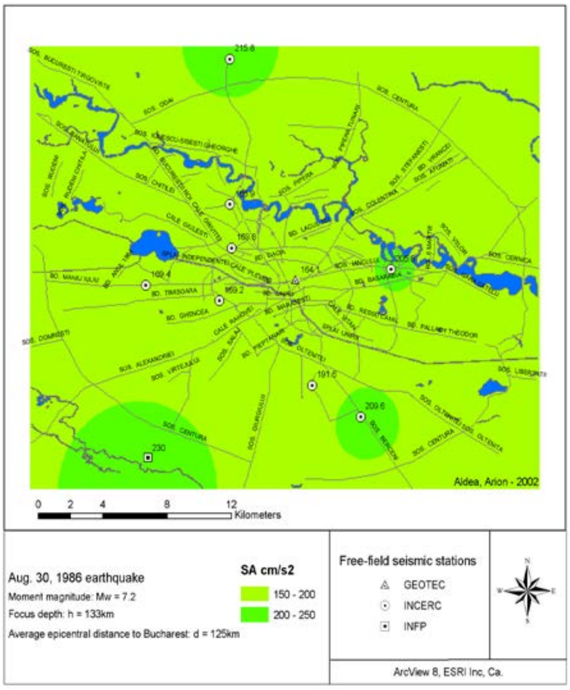

Figure 9. Bucharest - Aug.30, 1986 earthquake: microzonation of SA values at T=1.5s

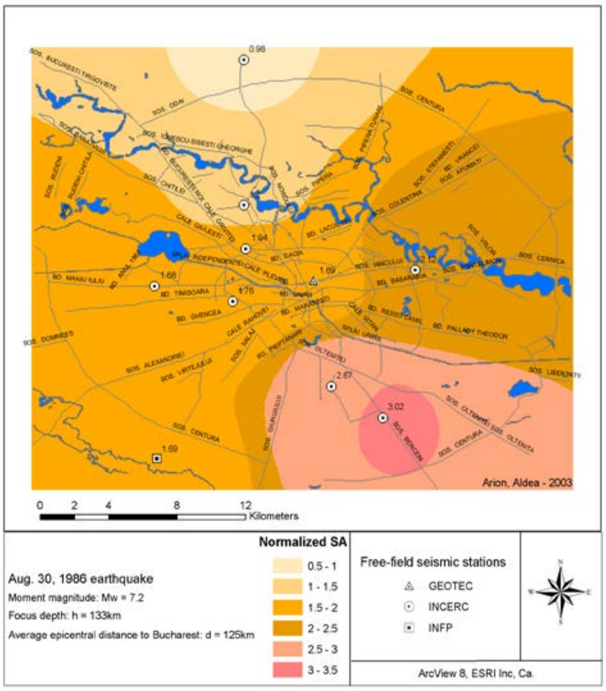

Figure 10. Bucharest - Aug.30, 1986 event: microzonation of normalized SA at T=1.5s

3.2 Microzonation of Shear Wave Velocity

The microzonation of averaged shear wave velocity for Bucharest shows a relative uniformity of the values in the range between 210m/s and 310m/s.

$V_{S,30}$ is the average shear wave velocity over the top 30 m, computed according to the following expression:

$$V_{s,30} = \frac{30}{\sum_{i=1}^{N} \frac{h_i}{V_i}} \qquad (3.1)$$

where h_i and V_i denote the thickness (in m) and shear-wave velocity (at shear strain level of 10^{-6} or less) of the i-th formation or layer, in a total of N, existing in the top 30 meters, [EC8].

Using the V_i, the fundamental natural period of ground T_G, can be evaluated as:

$$T_G = 4 \cdot \sum_{i=1}^{n} \frac{h_i}{V_i} \qquad (3.2)$$

The mapping of recent results of in situ S-wave measurements averaged on the first 30m at various sites in Bucharest area using GIS technology is represented in Figure 11. The GIS ArcGIS software package was used to analyze the results.

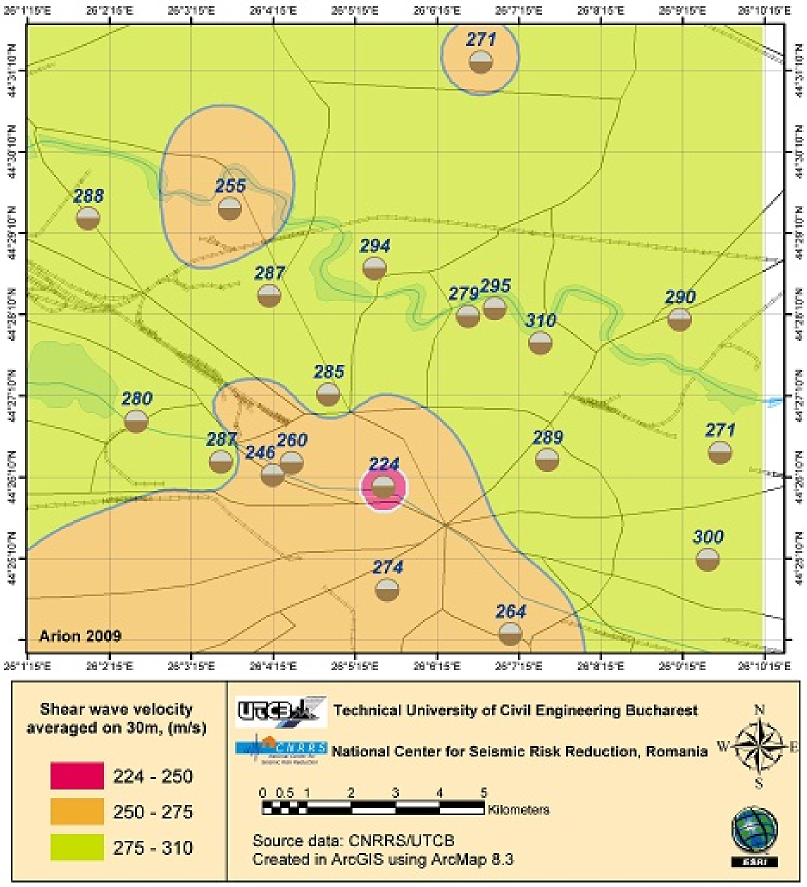

Figure 11. Bucharest. Microzonation map for shear wave velocity (m/s) averaged on 30m

CONCLUSIONS

Ground motions are significantly influenced by local soil condition. The different local soil conditions in Bucharest area lead to a variability of the soil seismic response, which can occur at small distances and can be observed even for the same city area. This is the reason why in the case of the large urban areas microzonation studies must take into account the mapping of the soil profile and the soil parameters.

Bucharest city is characterized by long periods of ground vibration (1.4-1.6s) during moderate and strong Vrancea earthquakes. Intensive work is needed for obtaining dynamic soil properties up to significant depths within the city. Further investigations and research are necessary for modeling ground response during earthquakes and for establishing predictive microzonation maps.

The extended soil investigation will provide valuable data that must be correlated with prior data concerning seismic data processing; the complete data set should be analysed in the future in order to establish the microzonation parameters to be used for urban planning and earthquake risk reduction.

Creating a database concerning the characteristics of superficial geology of Bucharest is the basis for determining the correlation between seismic velocities, SPT and CPT results and seismic soil parameters. The resulted information is useful for the characterization of local site conditions from the geological and geotechnical point of view and will provide the background information for the future improvements of the Romanian earthquake resistant design codes, harmonized with the European and international codes.

ACKNOWLEDGEMENT

The authors would like to acknowledge the cooperation of Japanese specialist during JICA Project as well as the generous funding provided by Japan International Cooperation Agency (JICA). We kindly acknowledge the support of late Dr. M. Tamura from BRI, Japan. Parts of this work were supported by the research projects 31-031, 31-023 and 31-005 funded by CNMP Romania that we kindly acknowledge.

REFERENCES

Aldea, A., Arion C., Okawa, I. (2001). Microzonation of Bucharest soil response, *JICA International Seminar: Earthquake Hazard and Countermeasures for Existing Fragile Buildings*, Bucharest, November 23-24, 2000, Lungu, D., Saito, T. editors, Independent Film, Bucharest, p.67-80.

Aldea, A., (2002). Vrancea source seismic hazard assessment and site effects, PhD thesis Technical University of Civil Engineering Bucharest, Bucharest, 256p.

Arion, C., (1999). Soil amplification factors, *Bulletin of the International Institute of Seismology and Earthquake Engineering IISEE*, Tsukuba, Japan, **Vol.35**, 307- 320.

Arion, C., (2003). Seismic Zonation of Romania considering the soil condition and seismic sources. PhD Thesis UTCB, Bucharest, 181p.

Arion, C., (2004). Report on soil tests and investigations (laboratory and field experiments), JICA/CNRRS/BRI.

Boulanger, R.W., Seed R.B., (1995). Liquefaction of Sand Under Bidirectional Monotonic and Cyclic Loading, *Journal of Geotechnical Engineering* **121(12)**: 870-878.

Comptes Rendus des Séances de l'Académie des Sciences de Roumanie. Numéro consacré aux recherches sur le trem-blement de terre du 10 Novembre 1940 en Roumanie, 1941, Tome V, Numéro 3, Mai-Juin, Cartea Romaneasca, Bucuresti, p. 177-288

Eurocode 8, 2004: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings. Document EN 1998-1:2004, European Standard, Stage 64, 229p

Hayashi, K, and Suzuki, H., (2004). CMP cross-correlation analysis of multi-channel surface-wave data, *Exploration Geophysics,* **Vol 35:** 7-13.

March 4, 1977 Earthquake in Romania, (1982). Monograph, Ed.Academiei, 516p. (in Romanian)

Liteanu, E., (1951). Geology of Bucharest city zone, St.Tehn.Econ., E, 1, Bucharest (in Romanian)

Lungu, D., T.Cornea, A.Aldea, C.Nedelcu, A.Zaicenco, (1997). Seismic microzonation of the city of Bucharest-Romania. Technical Rep. for Association Française du Génie Parasismique, 2Vol., 91p.+69p.

Lungu, D., Aldea, A., Arion, C., Demetriu, S., Cornea, T., (2000). Microzonage Sismique de la ville de Bucarest - Roumanie, *Cahier Technique de l'Association Française du Génie Parasismique,* **No.20**: 31-63

Lungu, D., Arion, C., Aldea, A., Cornea, T., (2001). City of Bucharest Seismic profile: from Hazard estimation to risk mitigation, *JICA International Seminar,* Bucharest, November 23-24, 2000, Lungu, D., Saito, T. editors, Independent Film, Bucharest, p.43-66

Lungu, D., Aldea, A., (2002). Earthquake engineering and site effects, *12th Danube-European Conference of Geo-technical Engineering,* Passau, 27-28 Mai, 10p.

Lungu, D., Arion, C., Aldea, A., Vacareanu, R., (2004). Representation of seismic action in the new Romanian code for design of earthquake resistant buildings P100-2003, *13th World Conference on Earthquake Engineering*, Vancouver, Canada, 15p., CD-ROM

PHRI, (1997). Handbook on Liquefaction Remediation of Reclaimed Land.A.A. Balkema Publ., Brookfield.