

## PHYSICAL AND DYNAMIC PROPERTIES OF THE QUATERNARY SEDIMENTARY LAYERS IN AND AROUND BUCHAREST CITY

ANDREI BALA<sup>1</sup>, ION ZIHAN<sup>2</sup>, VIORICA CIUGUDEAN<sup>3</sup>, VICTOR RAILEANU<sup>1</sup>,  
BOGDAN GRECU<sup>1</sup>

<sup>1</sup> National Institute of Research and Development for Earth Physics, Bucharest-Magurele,  
bala@infp.ro

<sup>2</sup> SC "Prospectiuni" SA, Bucharest

<sup>3</sup> SC "Metroul" SA, Bucharest

(Received )

*Abstract.* New seismic measurements are performed in Bucharest area with the purpose of defining better physical and dynamic properties of the shallow sedimentary rocks. Downhole seismic measurements were performed in 10 cased boreholes drilled in the Bucharest Metropolitan area. Processing and interpretation of the data lead to the conclusion that shallow sedimentary rocks can be considered weak in the area, down to 150–200 m depth.

Seismic wave velocity values and bulk density values presented in the paper associated with local geology are useful primary data in the seismic microzonation of Bucharest City. They are used as 1D models to derive transfer functions and response spectra for the stack of sedimentary rocks in several parts of Bucharest area, leading to a better knowledge of the local site amplification and associated frequency spectra.

This paper was presented in the symposium "Thirty Years from Romania Earthquake of March 4, 1977", 1–3 March 2007, Bucharest, Romania.

*Key words:* physical properties, quaternary sedimentary layers, seismic measurements, geological conditions.

### 1. GEOLOGICAL CONDITIONS IN AND AROUND BUCHAREST CITY

From the geological point of view, Bucharest is situated in the central part of the Moesian Platform, in the Romanian Plain, which represents a major depressionary unit. The Romanian Plain appears as a flat area, which lies between the Sub-Carpathians hills to the north, the pre-Balkan Platform to the south, the Dobrogea and the Moldavian Platform to the east.

During the Paleogene period, the area was acting as a sedimentary deposit continued in Miocene epoch. Thus, Miocene deposits represented by the Sarmatian and Tortonian are added on a slowly folding fundament. These deposits are in a

facies of deep water and include especially clayey and clayey-marley deposits. Gradually, the connection with the Sarmatian Sea is closed and over the Sarmatian deposits new Pliocene ones are added, in a not so deep sea facies, characterized by the presence of sands and gravels.

The Pliocene is represented through all its stages: Pontian, Dacian, Romanian. During the Pliocene epoch, detrital materials, such as sands and gravels, got significant thicknesses due to a process of subsidence, which led to a continuous descent of the sediments. Pliocene deposits do not have continuity along the entire Romanian Plain because during some stages, the deposit of the detrital material overcame the sinking rhythm of the support/fundament and land areas were formed by clogging. These main lands created stratigraphic gaps through Pliocene formations. Pliocene has a thickness of 700 m around Bucharest area. At the end of the Romanian and the beginning of the Quaternary, the area of the Romanian Plain had been completely silted, the entire region became mainland.

The silting/clogging of the Quaternary Lake was a slow process, with swamps and rivers with irregular route and flows, with large alluvial deposits. This is the explanation for the entire irregularity of these deposits. The lithological succession in Bucharest up to the Quaternary period is made of alternating lithological complexes that contain either non-cohesive soil, such as sands with gravels, or only sands or cohesive clayey layers. The thickness of the Quaternary is around 250 m and it is formed by different alluvial deposits as piedmont, deltaic, alluvial cones, terrace, waterside and lacustrine deposits, but also wind deposits which cover totally the older deposits where rivers dug the present relief.

Quaternary geology of Bucharest City is characterized by 7 distinct sedimentary complexes, with different peculiarities and large intervals of thicknesses. These shallow Quaternary complexes were first identified and separated by Liteanu (1951) and then cited by different authors with minor changes (Aldea and Arion, 2001; Ciugudean and Stefanescu, 2005; Hannich *et al.*, 2005, Bala *et al.*, 2005 and 2006).

**Type 1 stratum: Recent surface sediments**, made up of vegetal soil and clayey sediments, with a thickness locally reaching 15 m.

**Type 2 stratum: Upper Sandy-Clayey Complex**, is constituted of loess formations, often moisture sensitive, with sand layers and overall thickness of 16 m in the north and less than 1m on the river side. There are two lithological types of deposits: typical loess and loess-loam.

Loess has two different layers, an upper one-darker as colour (yellow brown) it is corresponding for a leaching area of meteoric waters and a lower layer, white yellow, with a dense network of limestone inclusions which correspond to accumulation area of washed carbonate, where appear frequently concretions and powdered limestone. As granularity, loess is corresponding to a silty clay, with 20% of clay fraction and about 50% of silt fraction.

Loess loams are brown-grayish and generally plastic stiff-plastic consistent. They are not limy/calcareous at all and contain iron-manganese black pigmentations and grains. As granularity, these deposits have a clay fraction larger than loess.

The types described above appear inter-stratified only over the fields on the left side of the Colentina River, over the Dâmbovița–Colentina Interfluvium and on the right side of the Dâmbovița River. The opinions regarding their origin are quite different, but the eolian conditions and lacustrine forms were accepted.

**Type 3 stratum: Colentina Gravel Complex**, made up gravel and sand (with large variations in grain size) and frequently with water bearing, clayey layers, with a variable phreatic level from 1.5 m to 14.00 m. Thickness locally reaches 20 m. The specific average permeability coefficient of these aquifers is between 50 m to 250 m per day. From a genetic point of view, the crossing structure of gravels indicates very intense torrential conditions. Typical case of complex cone of dejection.

**Type 4 stratum: Intermediate Clay Complex**, made up of alternating brown and grey clays, with intercalation of hydrological fine confined sandy layers. The thickness of this layer reaches a 23 m maximum in the north of the city, but towards south it becomes very thin and disappears. This stratum has disseminated limestone abundantly, limonite, and similitude with clays from the Lacustrine Complex, which led to the conclusion the origin is lacustrine.

**Type 5 stratum: Mostiștea Sand Complex**, a confined water-bearing layer made up of fine grey sands with lenticular intercalation of clay. Its thickness varies from 10 m to 15 m and is continuously extending around Bucharest city. Sometimes the underground water communicates with the upper unconfined layer, such that the water pressure level is approximately the same as the phreatic level.

**Type 6 stratum: Lacustrine Complex**, with thickness of 10–60 m, is made of clays and silty clays, with small lenticular sandy layers, most frequently situated at the top of this complex. The gray colour and also the limestone content show that the conditions are typically for a lacustrine facies.

**Type 7 stratum: Frățești Sands Complex** is the deepest bearing stratum with a thickness of 100 m to 180 m and includes A, B, C Fratești levels. It is made up of sands and gravel, from which industrial and drinking water is usually pumped out (Ciugudean and Stefanescu, 2005).

## 2. DOWNHOLE SEISMIC MEASUREMENTS PERFORMED IN BUCHAREST CITY

Downhole seismic measurements were performed by a combined effort of the National Institute for Earth Physics (NIEP), SC “Prospectiuni” S.A. and SC

METROUL SA in 10 sites (boreholes), which are presented in Table, in the frame of the CERES Project 3-1/2003. The last 2 boreholes in Table 1 were previously measured in the frame of the CERES Project 34/2002 and published by Bala *et al.*, 2005.

The locations of the 10 boreholes, as well as of the last two boreholes (Centura 1 and Centura 2) previously measured and published are presented in Fig. 1.

The boreholes were protected with plastic tubes or steel tubes and seismic measurements are performed down to the bottom of each borehole.

The shot point was fixed at 10–30 m from the borehole, depending on the local conditions in the field. Wave generation was performed by hammer blows on a wooden block. A seismic station type DAQLink-24, with 24 channels (24 bits) was employed, with a sampling rate of 1 ms. The time length of each recording was 1 s. A three component sensor clamped on the borehole wall was used for recording, with a recording offset of 1 m down to 70 m depth and an offset of 2 m below this depth.

P wave onset was read on the vertical component and for the S wave the horizontal components of the sensor were used. Time and frequency criteria were used to correlate the S waves. Separate arrival times *vs.* depth graphs were constructed for P and S waves. Interval seismic velocities  $V_p$  and  $V_s$  are presented in the paper for the 11 boreholes noted with (\*) in Table 1.

In the northern part of Bucharest (Otopeni area)  $V_p$  velocities are increasing from 500 m/s to 2250 m/s and  $V_s$  from 200 m/s to 611 m/s. Some inversions of the

Table 1

The 12 locations for down-hole seismic velocity measurements in Bucharest

No.	Borehole	Depth [m]	Geographic coordinates	
			Latitude (N)	Longitude (E)
1	Bazilescu_172	172	44.490	26.040
2	Foradex_81*	81	44.470	26.060
3	Grivita_110*	110	44.460	26.080
4	Iorga_170*	170	44.451	26.083
5	Policolor_100*	100	44.410	26.200
6	Buciumeni_150*	150	44.539	25.952
7	Otopeni_200*	200	44.550	26.100
8	Politehnica_200*	200	44.446	26.090
9	IMGB_156*	155	44.355	26.203
10	Magurele_112*	112	44.348	26.028
11	Centura 1*	80	44.405	26.212
12	Centura 2*	60	44.410	26.219

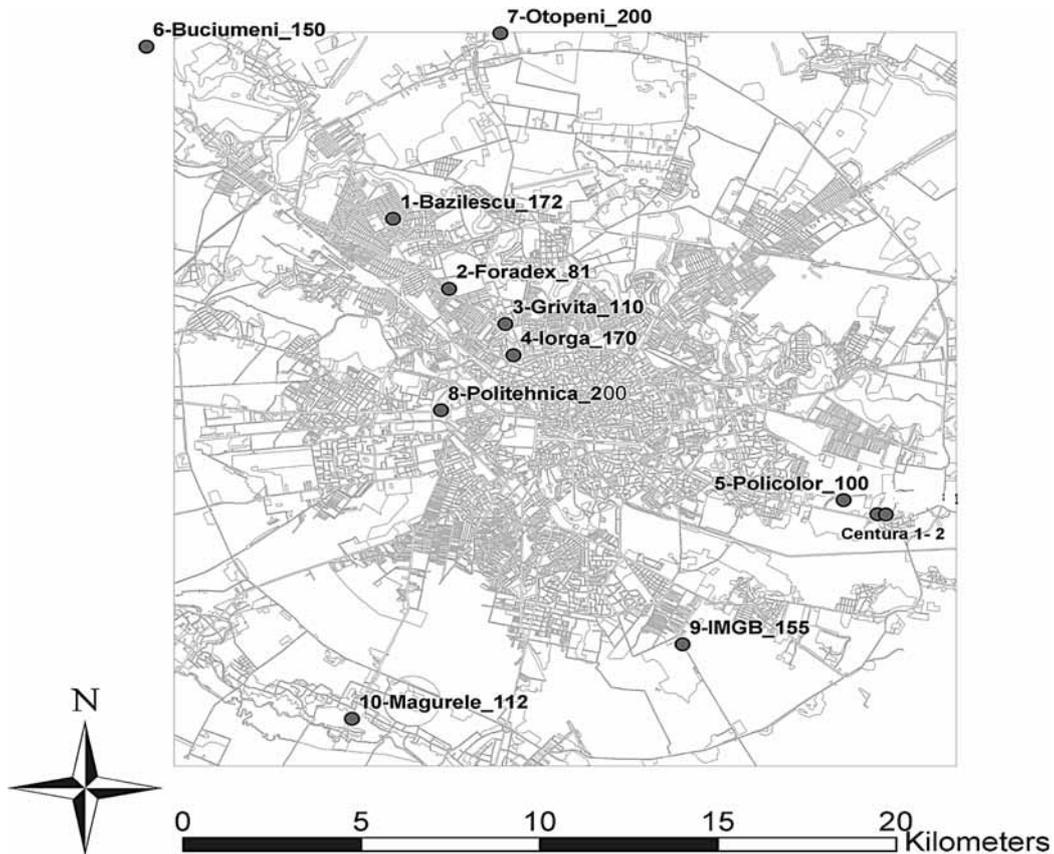


Fig. 1 – Position of the boreholes from Table 1, in which down-hole seismic measurements were performed. The circular contour delimits the Bucharest City area with a diameter of roughly 20 km.

velocity values in depth are present. In the southern part of Bucharest (Magurele and IMGB locations)  $V_p = 960 \text{ m/s} - 2300 \text{ m/s}$  and  $V_s = 260 - 588 \text{ m/s}$ . Frequent velocity inversions are present for both  $V_p$  and  $V_s$ , especially in IMGB borehole. An unusual high  $V_s$  velocity of  $833 \text{ m/s}$  is recorded in IMGB borehole at  $150 - 156 \text{ m}$  depth. In the central part of Bucharest (Politehnica and Policolor boreholes)  $V_p$  is increasing gradually from  $833 \text{ m/s}$  to  $2800 \text{ m/s}$  (at  $60 \text{ m}$  depth). Frequent velocity inversions are encountered for greater depths.  $V_s$  velocities are increasing from  $227 \text{ m/s}$  to  $612 \text{ m/s}$ , with some inversions in the shallow part.

The  $V_p$  and  $V_s$  seismic velocities from the first 10 boreholes in Table 1 are in the same range as seismic velocities presented by Bala *et al.*, 2005 for 2 boreholes in the eastern margin of Bucharest City – Centura 1 and Centura 2 in Fig. 1.

In Fig. 2 the relation  $V_s/V_p$  is presented for 5 of the boreholes in which down-hole seismic measurements are performed in Bucharest area. The interval seismic velocities have some dispersion, but they generally covered the same area.

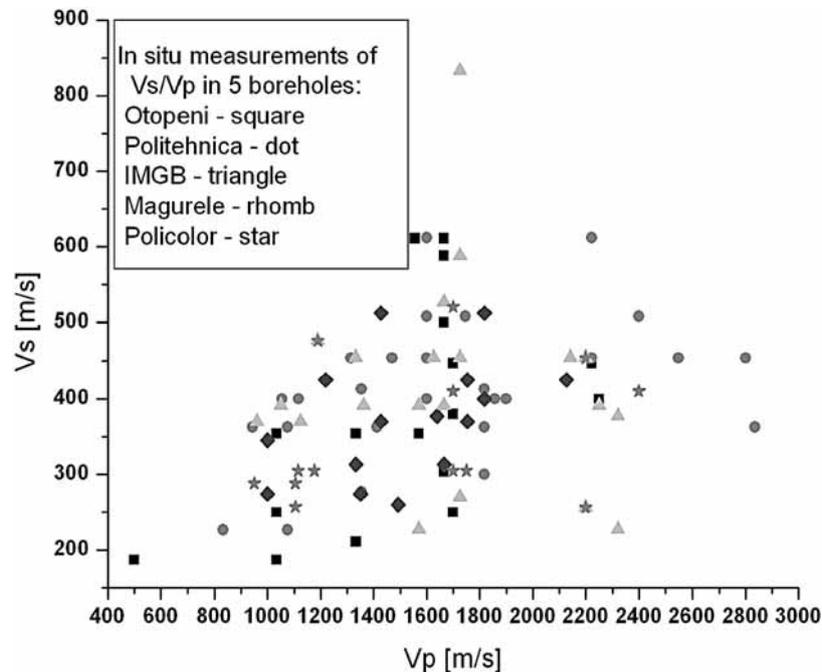


Fig. 2 – Vs to Vp relation in the 5 boreholes in Bucharest area: Otopeni, Politehnica, IMGB, Magurele, Policolor.

## 2.1. PROCESSING OF THE SEISMIC SIGNAL AND PROCEDURES TO ENHANCE THE SIGNAL/NOISE RATIO

All the seismograms resulted from the summation process were gathered in the depth order in a single wave table. The time picking for the P and S waves was done on filtered seismograms, on a minimum or a maximum phase.

Tube waves were put into evidence on some seismograms with a seismic velocity greater than that of P waves.

Time pickings for the P wave were less affected by seismic noise (natural or man-made), but time pickings for the S waves were affected by the interference with later arrivals of the P wave, by primary and/or multiple reflections, diffractions. Due to the fact that S waves have a lower frequency band, a low-pass filtering with cut-off frequency of 40 Hz considerably improved the signal/noise ratio for these type of waves.

Corrections were applied for the time picking due to the fact that the offset distance between borehole – source point was 20–30 m. These corrections were computed by multiplying the picked times with the cosine of the angle between the borehole direction (vertical) and the source point-recording point direction.

### 3. PHYSICAL PARAMETERS OF QUATERNARY SEDIMENTARY LAYERS IN BUCHAREST CITY

The 7 Quaternary types of layers encountered in Bucharest City area were identified on each lithologic column of the 12 boreholes. Weighted mean values for  $V_p$  and  $V_s$  are computed for each of the 12 boreholes according to the following formula:

$$\bar{v}_s = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{v_{si}}} \quad (1)$$

where  $d_i$  and  $v_{si}$  denote the thickness (in meters) and the shear-wave velocity (in m/s) of the  $i$ -th layer, in a total of  $n$  layers, existing in the same type of stratum (Romanian Code for the seismic design for buildings – P100-1/2006 and EUROCODE 8).

All these mean weighted seismic velocity values are presented in Table 2. In the last row, mean weighted velocity values are computed using the particular values in the 11 sites. The site Bazilescu was excluded from Table 2 because of unusual low velocities recorded in all the layers, for which a satisfactory explanation was not yet found.

However in a recent paper [Hannich *et al.*, 2006] seismic measurements using SCPTU techniques are presented for the same site (BAZI) and low  $V_s$  values are presented of about 250 m/s at 26 m depth, with a large drop (150 m/s) between 7–11 m depth. This confirmation of low velocity of the shear waves in the same site will lead us to reconsider our own measurements in Bazilescu site.

Shear wave seismic velocities are poorly recorded or not at all in stratum types 1 and 2, due to the fact that they could be measured only in a few layers from Otopeni, Policolor and Centura 1–2 sites.

In stratum type 3 the velocities cover a fairly wide range 227–393 m/s, being represented by one or two layers in each borehole.

Stratum types 4 and 5 have a quite large range of  $V_s$  velocities, between 278–400 m/s, depending of the recording site. The mean weighted velocities in these two layers are still very close: 327 m/s and 340 m/s.

In stratum type 6 the seismic velocities ( $V_s$ ) are around 400 m/s: 349–444 m/s.  $V_s$  seismic velocities in stratum type 7 are in the range 508–528 m/s with an unusual large velocity of 628 m/s in borehole IMGB. It should be noted that all these values are obtained by “in situ” measurements in Bucharest City area.

The mean seismic velocities computed for the 11 particular sites in Table 2 are representative values for the 7 types of Quaternary sedimentary layers in Bucharest City and in this way they can be correlated with averaged  $V_s$  values obtained by direct measurements and cited by other sources.

Table 2

Mean weighted seismic velocities for the 7 main types of Quaternary layers determined in 11 sites from Bucharest City

Stratum type	1		2		3		4		5		6		7	
	Vp	Vs	Vp	Vs	Vp	Vs	Vp	Vs	Vp	Vs	Vp	Vs	Vp	Vs
Mean weighted seismic velocity values [m/s]														
Borehole site														
Otopeni	500	187	1034	187	1034	250	1034	354	1333	354	1740	403	1666	523
Politehnica	–	–	833	227	1076	227	1211	335	1797	353	1731	444	1746	508
IMGB	–	–	960	370	1203	393	1541	362	1541	362	1716	400	1725	628
Magurele	–	–	–	–	1492	260	1000	309	1413	325	1725	415	1818	512
Policolor	298	153	975	288	1140	284	1544	305	1544	305	1828	383	–	–
Buciumeni	–	–	400	181	541	243	1555	278	1977	321	1727	369	–	–
Iorga	–	–	–	–	594	240	2600	292	2600	280	1953	384	1815	528
Foradex	–	–	600	270	1500	270	2200	305	1519	356	1906	349	–	--
Grivita	–	–	–	–	–	–	875	400	1100	354	1535	398	–	--
Centura 1	298	153	460	249	1465	337	2129	326	1677	289	1670	439	–	–
Centura 2	300	150	600	230	1450	230	1880	333	1754	391	–	–	–	–
Mean weighted seismic velocity values Vp, Vs [m/s]	370	167	687	244	1044	270	1488	327	1563	340	1753	398	1740	544

Seismic velocities in Table 3 (column 4) are obtained by Hannich *et al.* 2005 using Multi-Offset Vertical Seismic Profiling (MOVSP) technique applied in 7 boreholes (6 sites) in Bucharest for the sedimentary layers 4–7. The Multi-Offset VSP measurements in Bucharest / Romania were carried out by the *Deutsche Montan Technologie GmbH (DMT)* in May 2002 (Orlowski *et al.*, 2003). To enhance and complete the results obtained through the applied MOVSP-techniques in Bucharest, especially for the near-surface layers (Layers 1–3 in Table 3 – gray area), additional  $V_S$ -values, previously determined by different measuring techniques (by seismic downhole measurements in some boreholes and laboratory tests like the resonant column method, the triaxial cyclic method were used.

These available  $V_S$  data were obtained mainly by GEOTEC (Department of Geophysics and Engineering Seismology), INCERC (National Institute for Building Research) and UTCB (Technical University of Civil Engineering) in Bucharest. Careful analyses of these additional available  $V_S$  data permitted to integrate them in the results obtained by the MOVSP techniques (Hannich *et al.*, 2005).

Depth of the main geologic layers and averaged density of the sedimentary layers in Table 3 are averaged values from many borehole measurements in Bucharest area (Ciugudean and Stefanescu, 2005).

Table 3

Seismic share-wave velocity ( $V_s$ ) / density model of the Quaternary sedimentary layers in Bucharest City area. Completed after Ciugudean and Stefanescu, 2005; Hannich *et al.*, 2005

Geologic layer no.	Depth of the upper limit of the geologic layer [m]	Averaged density [g/cm <sup>3</sup> ]	Averaged $V_s$ [m/s]	Mean weighted seismic velocity $V_s$ [m/s]
After Ciugudean and Stefanescu, 2005			After Hannich <i>et al.</i> , 2005 for 7 boreholes (6 sites)	From mean weighted velocity in 11 boreholes from Table 2
1. Backfill	0	1.10	135	167
2. Upper Clay Layer	0.50–5.00	1.75	305	244
3. Colentina Aquifer (sand+gravel)	5.00–12.00	1.99	335	270
4. Intermediate Clay Layer	10.00–20.00	2.07	378	327
5. Mostistea Aquifer (fine to medium sand)	15.00–35.00	2.00	400	340
6. Lacustrine Layer	35.00–50.00	2.14	442	398
7. Fratesti aquifer A (sand+gravel)	100.00–180.00	2.05	500	544

The mean weighted values of share wave velocity are presented in Table 3/ column 5. Seismic velocities in stratum 1 (**167 m/s**) is higher than that presented by Hannich *et al.* 2005 after some other measurements.

For stratum types 2 and 3 it seems that average seismic velocities (**244 m/s and 270 m/s**) obtained in the present paper from measurements in 11 sites are lower than those cited by Hannich *et al.* 2005 (305 m/s and 335 m/s).

The values given in Table 3 after Hannich *et al.*, 2005 for average  $V_s$  seismic velocities in the stratum types 4, 5 and 6 are higher (with 10–15 %), while that for type 7 is lower than that obtained in the present study.

One of the possible cause of these differences might be the measurement methodology, which was different from a straightforward method of downhole measurement. In this way the mean velocity values determined by Hannich *et al.* 2005 in geologic layers 4, 5 and 6 are greater than those determined in Table 2.

### 3.1. MEAN WEIGHTED SEISMIC VELOCITY $V_{S-30}$

Seismic velocities in Table 4 are obtained by several authors by seismic measurements in boreholes. They were gathered in order to compute the mean weighted seismic velocity for the first 30 m depth ( $V_{S-30}$ ), for each case according to formula (1). A first map of  $V_{S-30}$  is presented in Fig. 3.

According to this map, the northeastern part of Bucharest is characterized by rather low velocity values, while in the southwest we have medium values. The

Table 4

Mean weighted seismic velocity for the first 30 m depth ( $V_{S-30}$ ) obtained in different sites in Bucharest

Borehole	Lat. X	Long. Y	$V_{S-30}$	References	
Grivita_110	426812	4923378	330.9	Bala <i>et al.</i> , 2006, 2007b	
Politehnica_200	427590.2	4921813.7	297.2		
Policolor_100	436304.0	4917723.5	286.0		
Otopeni_200	428513.1	4933357.0	243.1		
Magurele_112	422527.6	4910985.0	289.8		
Iorga_170	427039.5	4922375.3	245.1		
Foradex_81	425233.7	4924506.5	295.7		
Buciumeni_150	416741.8	4932275.3	255.8		
Bazilescu_172	423669.0	4926746.5	247.3		
Centura 1	437255.2	4917269.9	288		
Centura2	437494.0	4917267.6	260.5		
UTCB Tei	430315.9	4923672.5	300		Lungu and Calarasu, 2005
Victory Square	426962.4	4922598.3	314		
Basarab bridge	426795.8	4921933.6	253		
City Hall	427572.9	4920258.6	360		
Tineretului Park	429355.8	4916850.8	263	Bala <i>et al.</i> , 2007a	
Univ_Ecologica	424690.5	4920717.1	281		
Inst_Astronomic	427386.9	4917452.6	283		
Titan2 Park	432588.8	4918229.9	308		
Motodrom Park	429095.2	4923871	288	Ritter <i>et al.</i> , 2007	
Student Park	429120.1	4924065	295		
Bazilescu Park	422565.1	4926050	294		
Federatia Romana de Tir	429071	4929484	297		
Geologic Museum	426747.4	4922348	320		
AGRO	425899	4924823	311	Hannich <i>et al.</i> , 2006	
BAZI	423080	4926502	267		
INCERC	433298	4921207	311		
INMH	426800	4929086	264		
METRO	437184	4917155	303		
MOGO	421947	4929594	281		
VICT	426908	4922577	290		

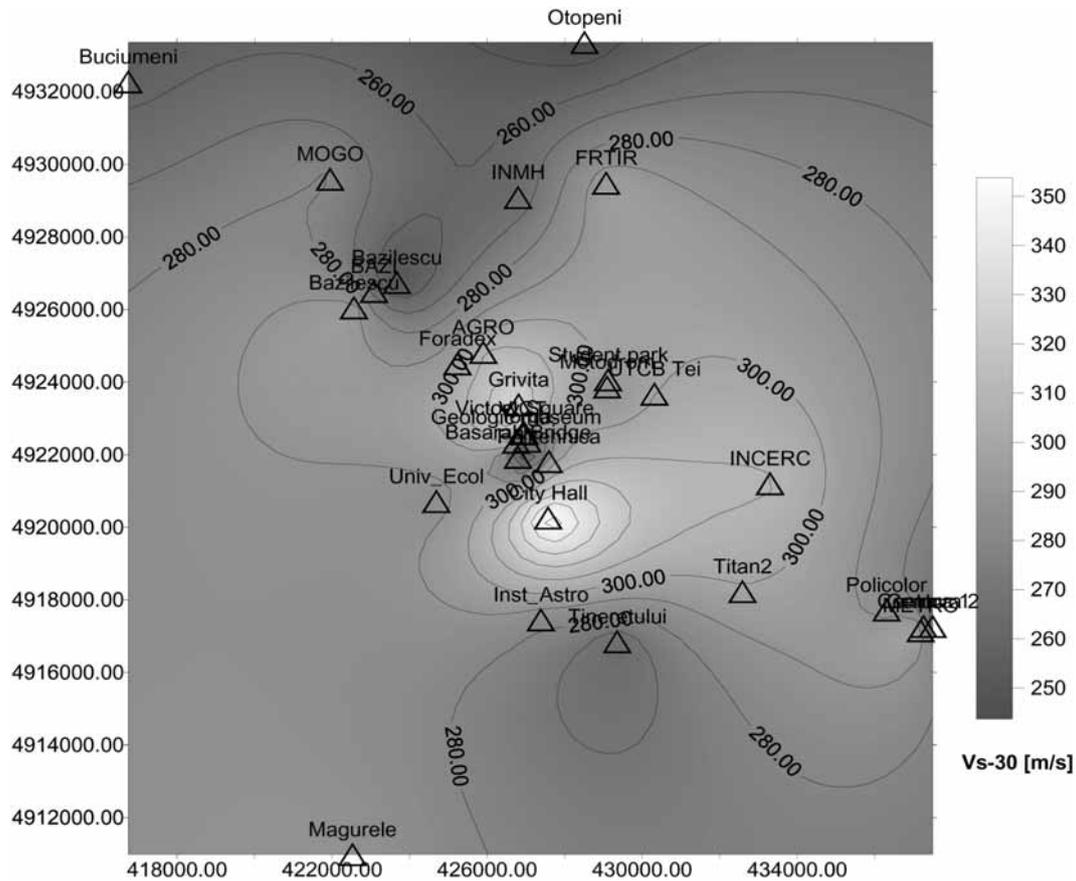


Fig. 3 – Map of the mean weighted seismic velocity ( $V_{s-30}$ ) in Bucharest City from downhole seismic measurements. Coordinates are given in UTM system (meters).

central part is characterized by a complex mixture of low values (Basarab bridge, Iorga\_170) with medium (Politehnica\_200) and high values (City Hall, Grivita).

This image shows that in the central part of Bucharest new measurements are needed in order to have an improved image of this important parameter which influenced the microzonation of the city.

#### 4. CONCLUSIONS OF THE MEASUREMENTS OF PHYSICAL PARAMETERS OF SEDIMENTARY LAYERS IN BUCHAREST CITY

1. The present computed values for seismic velocities are in the same range with others obtained by seismic “in situ” measurements of different types. They are organized in a database, which is a valuable collection of elastic and dynamic

parameters of the sedimentary rocks for further studies on the seismic microzonation of Bucharest City.

2. More precise seismic measurements are needed in order to obtain reliable mean velocity values for stratum types 1, 2 and 3, which are responsible for a great part of the amplification factor during an earthquake. Two different projects having this objective have begun in 2006 (see Ritter, 2006 and Hannich *et al.*, 2006).

3. The mean weighted values of shear-wave velocity are computed from the 11 sites investigated by downhole measurements in Bucharest City (Table 2) and presented in Table 3 for comparison with other results from seismic measurements. Depth of the main geologic layers and average unit weight of the sedimentary layers are also average values from many borehole measurements in Bucharest area (Ciugudean and Stefanescu 2005). Table 3 can be used as valuable input data for further studies of the equivalent linear analysis and nonlinear analysis of the seismic site amplification.

4. As there is still a major gap in the knowledge concerning seismic and geotechnical parameters in the shallow (< 50 m), unconsolidated soil and sediment layers in Bucharest, especially in the geologic layers 1–5, a new international research project was initiated – **NATO SFP Project 981882** and approved: *Site-effect analyses for the earthquake-endangered metropolis Bucharest, Romania*. This project is conducted by *Karlsruhe University*, Germany, and *National Institute for Earth Physics*, Bucharest, Romania and it has as main objective earthquake risk mitigation and better seismic safety of Bucharest (Ritter, 2006).

By conducting seismic measurements in 8 new borehole sites (50 m depth) and geotechnical analysis of the core samples, dynamic parameters of soils and rocks are to be determined. These dynamic parameters will be used as input for linear and non-linear waveform modeling to estimate the seismic amplification at specific sites in Bucharest.

*Acknowledgements.* This work was performed by the joint effort of research partners National Institute of Research and Development for Earth Physics, as scientific responsible of the projects, SC “Prospectiuni” SA and SC “Metroul” SA as partners in the frame of the CERES Contract no. 34/12.11.2002 and Contract no. 3-1/5.11.2003, funded by Romanian Ministry of Education and Research.

## REFERENCES

1. A. Aldea, C. Arion, *Microzonarea seismică a condițiilor locale de teren din București*, A doua Conferință Națională de Inginerie Seismică, București, 8–9 noiembrie 2001, vol. 1, 1.72–1.82, editat de INCERC, UTCB, INCDFP, 2001.
2. A. Bala, V. Raileanu, N. Mandrescu, I. Zihan, E. Dananau, *Physical properties of the Quaternary sedimentary rocks in the Eastern Bucharest area*, Rom. Rep. Phys., Vol. 57, No. 1, p. 151–163, 2005.

3. Bala A., Raileanu V., Zihan I., Ciugudean V., Grecu B., *Physical and dynamic properties of the shallow sedimentary rocks in the Bucharest Metropolitan Area*, Rom. Rep. Phys., Vol. 58, no. 2, 221–250, 2006.
4. A. Bala, J. R. R. Ritter, D. Hannich, S. F. Balan, C. Arion, *Local site effects based on in situ measurements in Bucharest City, Romania*, Proceedings of the International symposium on Seismic Risk Reduction, ISSRR-2007, paper 6, 367–374, Bucharest, 2007a.
5. A. Bala, I. Zihan, V. Ciugudean, V. Raileanu, B. Grecu, *Physical and dynamic properties of the Quaternary sedimentary layers in and around Bucharest City*, Proceedings of the International symposium on Seismic Risk Reduction, ISSRR-2007, paper 7, 359–366, Bucharest, 2007b.
6. V. Ciugudean, I. Stefanescu, *Engineering geology of the Bucharest city area, Romania*, paper no. 235 submitted to IAEG -2006, 2005.
7. D. Hannich, K. P. Bonjer, H. Hoetzel, D. Lungu, V. Ciugudean, T. Moldoveanu, C. Dinu, D. Orłowski, *Evaluation of soil parameters through Vertical Seismic Profiling (VSP) in Bucharest, Romania*, paper in manuscript.
8. D. Hannich, G. Huber, D. Ehret, H. Hoetzel, S. Balan, A. Bala, M. Bretotean, V. Ciugudean (2006) SCPTU Techniques Used for shallow geologic/hydrogeologic Site Characterization in Bucharest, Romania, 3rd International Symposium on the Effects of Surface Geology on Seismic Motion, Grenoble, France, 30 Aug. – 1 Sept. 2006, paper 71.
9. E. Liteanu, 1951, *Geology of Bucharest city area*, Technical studies, Series E, Hydrogeology no. 1, Bucharest, (in Romanian).
10. D. Lungu, E. Calarasu, *Some aspects regarding seismic microzonation of the City of Bucharest*, EE-21C, International Conference “Earthquake Engineering in the 21-th Century”, Topic 2: Strong Ground Motion, Engineering Seismology, Earthquake hazard and risk assessment, 1-8, Skopje, Ohrid, Macedonia, 28 Aug. – 1 Sept. 2005.
11. D. Orłowski, C. Witte, B. Loske, Execution and evaluation of seismic measurements in Bucharest by the Multi-Offset-Vertical-Seismic-Profiling method (MOVSP). Internal Report, DMT, Mines & More Division, Essen, 2003. (in German).
12. J. R. R. Ritter, Tiefe Einblicke - NATO finanziert Bohrprojekt im erdbebengefährdeten Bukarest, In UNIKATH, Karlsruhe, Germany, 3, p. 31, 2006.
13. J. R. R. Ritter, S. Balan, A. Bala, J. Rohn, *Annual Technical Report for the NATO Sfp Project 981882 (Oct. 2007)*, Bucharest and Karlsruhe, 2007.
14. Final File report for **CERES Contract no. 34 / 12.11.2002**, “Models of the seismic velocity distributions in the sedimentary layers of the Moesian Platform, with details in the Bucharest City area”, project director dr. Andrei Bala, (in Romanian).
15. File reports III, IV and V **CERES Contract no. 3-1 / 5.11.2003**, “Physical properties of the upper sedimentary rocks in Bucharest Metropolitan area”, project director dr. Andrei Bala.
16. Romanian Code for the seismic design for buildings - P100-1/2006.
17. EUROCODE-8 – prEN1998-1-3 (2001) – Design provisions for earthquake resistance of structures, European Committee for Standardisation.