Romanian Reports in Physics, Vol. 65, No. 1, P. 285–298, 2013

IN SITU BOREHOLE MEASUREMENTS AND LABORATORY MEASUREMENTS AS PRIMARY TOOLS FOR THE ASSESSMENT OF THE SEISMIC SITE EFFECTS

A. BALA[1], C. ARION[2], A. ALDEA[2]

[1] National Institute for Earth Physics, Bucharest - Magurele, Romania, E-mail: bala@infp.ro
[2] Technical University for Civil Engineering, Bucharest, Romania.

Received March 6, 2012

Abstract. Within the NATO Science for Peace Project 981882 *"Site-effect analyses for the earthquake-endangered metropolis Bucharest, Romania"* we obtain a unique, homogeneous dataset of seismic, soil-mechanic and elasto-dynamic parameters. Ten 50 m deep boreholes are drilled in the metropolitan area of Bucharest in order to obtain cores for dynamic tests and vertical seismic profiles for an updated microzonation map related to earthquake wave amplification. The boreholes are placed near former or existing seismic station sites to allow a direct comparison and calibration of the borehole data with actual seismological measurements. A database is assembled which contains P- and S-wave velocity, density, geotechnical parameters measured at rock samples and geological characteristics for each sedimentary layer. All the $V_{S\text{-}30}$ computed values belong to type C of soil after this classification (Romanian Code for the seismic design for buildings – P100-1/2006). Approximately 250 samples were gathered from the 10 drill sites. These samples were mostly not disturbed (samples as they were recovered from the tube of the drilling rig) and partly disturbed (those which had no proper consistency). Results obtained by the down-hole method in the 10 boreholes drilled in Bucharest City as well as from laboratory measurements will be used as input data in the program SHAKE2000 in order to obtain the seismic site effects due to the shallow soft layers.

Key words: microzonation, seismic measurements, geotechnical parameters, linear modelling.

1. INTRODUCTION

Bucharest, the capital of Romania, with more than 2 million inhabitants, is considered, after Istanbul, the second-most earthquake-endangered metropolis in Europe. It is identified as a natural disaster hotspot by a recent global study of the World Bank and the Columbia University [1]. Four major earthquakes with moment magnitudes between 6.9 and 7.7 hit Bucharest in the last 72 years. The most recent destructive earthquake of 4 March 1977, with a moment magnitude of 7.4, caused about 1.500 casualties in the capital alone. All disastrous intermediate depth earthquakes are generated within a small epicentral area – the Vrancea seismogenic region – about 150 km north-east of Bucharest (Fig. 1). Thick unconsolidated sedimentary layers below Bucharest amplify the arriving seismic waves causing severe destruction. Thus, disaster prevention and mitigation of earthquake effects is an issue of highest priority in Romania.

2. NATO SCIENCE FOR PEACE PROJECT 981882

The zoning of the metropolitan area of Bucharest for seismic amplification pattern (microzonation) has been pursued with great effort since the 1977 disastrous event. Geophysical groups at the National Institute for Earth Physics (NIEP) and civil engineers at the Technical University for Civil Engineering (UTCB) worked on this problem, as well as foreign institutions like the Universität Karlsruhe (KIT), the University of Trieste and the Japanese International Cooperation Agency (JICA). Their work resulted in an improved seismic database obtained from modern seismic observation networks as well as several borehole analyses. Based on these observations recent microzonation studies were performed in Bucharest area by e.g. [2, 3, 4, 5, 6].

However, all of these separate studies could cover only fraction of the microzonation problem, because either of the methods employed or being based on general average data instead of in situ measurements.

A distinct feature of some studies consisted in assuming the Quaternary geological layering in Bucharest and some average seismic properties cited from literature like [6]. Other studies were based on seismological data alone like [2]; [7] and used spectral amplification factors and a probabilistic method to determine ground motion site effects.

More consistent microzonation studies were done by [4] and [8] based on a more restrictive deterministic approach in order to determine the ground motion site effects in Bucharest.

A common drawback of all these studies is missing geophysical and geotechnical information from well-distributed boreholes in the Bucharest City area.

There are only a few sites which were investigated coincidently with geophysical and geotechnical techniques, in order to relate the local geology with seismic wave propagation properties in Bucharest City (especially amplitude-amplification properties). Therefore, the main purpose of the NATO SfP Project 981882 was to obtain a unique, homogeneous dataset of soil-mechanic and elasto-dynamic parameters of the subsurface of Bucharest from ten new boreholes to model the so-called seismic site responses. Here we present the *in situ* seismic measurements in all the boreholes, as well as the laboratory results for samples from selected sites.

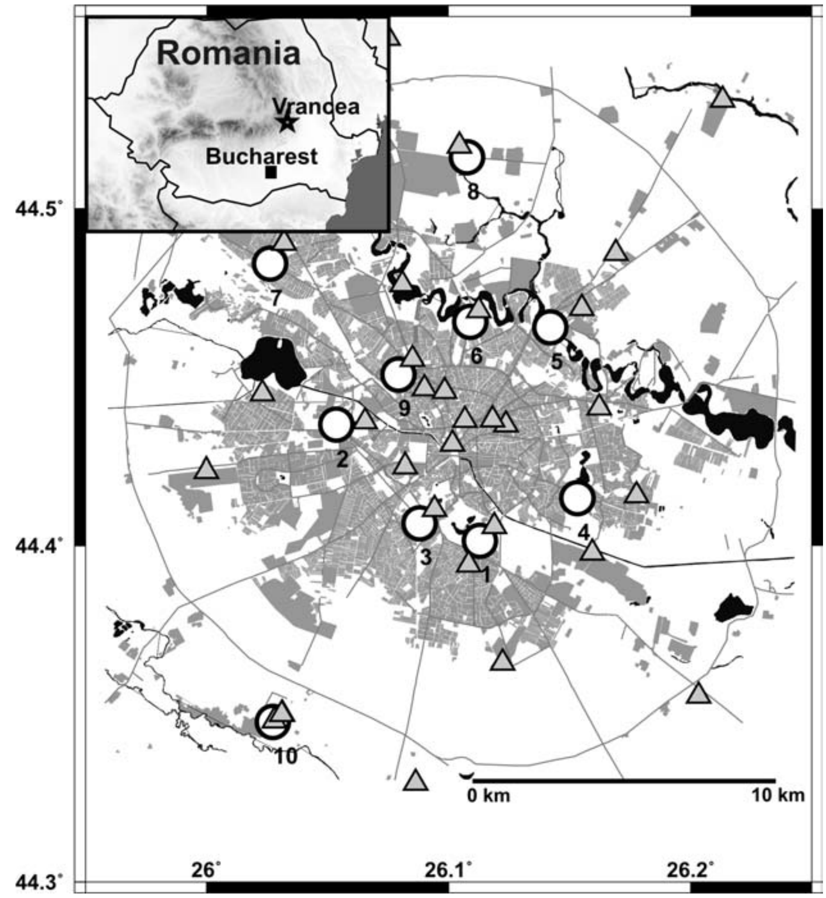


Fig. 1 – Map with area under investigation. The metropolitan region of Bucharest, Romania, is mainly inside the characteristic ring road with a diameter of about 20 km. Residential and industrial areas are indicated in grey; lakes, channels and rivers in black. The ten borehole sites are shown as circles and numbers (after [14]).

3. PHYSICAL PARAMETERS OF QUATERNARY SEDIMENTARY LAYERS IN BUCHAREST

3.1. *IN SITU* SEISMIC MEASUREMENTS IN BUCHAREST AREA

Previous down-hole seismic measurements were performed by a combined effort of National Institute for Earth Physics (NIEP), SC “Prospectiuni” S.A. and SC METROUL S.A. in 12 sites (boreholes) from Bucharest City in the frame of the CERES Project 34/2002 and CERES Project 3-1/2003. Detailed information about the measurements and seismic velocity values obtained were presented by [9] and [10].

Following the Romanian-German collaboration on seismic effects of the Vrancea earthquake over Bucharest, based on Cooperative Research Center 461, the necessity of in-depth studies regarding shear wave velocities for different soil layers appeared. This necessity occurs mainly because the existing information was not representative for the whole city area. To close this gap, characteristic shear wave velocities were first determined by [11] 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 [12].

The National Center for Seismic Risk Reduction (NCSRR, Bucharest) instrumented in 2003 seven sites in the northern half of Bucharest City [13] in cooperation with the Japan International Cooperation Agency (JICA). NCSRR performed downhole measurements at all sites that were instrumented, the deepest investigation going down to 140 m depth.

A comprehensive study of the *in situ* measurements of seismic velocities performed in Bucharest in the last decade was done in [15]. A critical comparison between different measurement methods used and the sharewave seismic velocities obtained demonstrate that the results are very similar for the various depths levels considered [15].

3.2. SEISMIC MEASUREMENTS PERFORMED IN THE FRAME OF THE NATO SfP PROJECT 981882

The latest results in the shear wave velocity measurements in 10 boreholes in Bucharest were obtained in the frame of the **NATO SfP Project 981882** in the years 2006–2007 and they were reported by [14] and by [15] (Fig. 1). The mean seismic velocities computed for the 10 particular sites given in Table 1 are representative values for the 6 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 1

Mean weighted sharewave seismic velocities for the first 6 (of 7 types) of Quaternary layers in 10 boreholes in Bucharest City from Fig. 1. For a description of the geologic layers [10, 14, 16]

	Geologic stratum type	**1**	**2**	**3**	**4**	**5**	**6**		
Site no. in Fig. 1		**Mean weighted seismic velocities [m/s]**							
		Vs	Vs	Vs	Vs	Vs	Vs	V_{S-30}	V_{S-50}
1.	**Tineret Park**	140	220	299	--	398	---	**263**	**304**
2.	**Ecology Univ.**	120	220	241	354	390	401	**286**	**326**

Table 1 (continued)

3.	**Astronomy Institute**	120	260	330	350	390	433	**283**	**320**
4.	**Titan2 Park**	160	250	250	350	381	450	**299**	**341**
5.	**Motodrom Park**	200	200	320	393	410	410	**288**	**327**
6.	**Student Park**	210	210	342	370	375	400	**295**	**319**
7.	**Bazilescu park**	160	160	317	390	408	---	**294**	**334**
8.	**Romanian Shooting Fed.**	210	330	350	400	400	---	**327**	**347**
9.	**Geologic Museum**	180	310	322	376	380	---	**320**	**328**
10.	**NIEP site Magurele**	250	350	350	320	337	410	**326**	**338**
	All sites	**169**	**252**	**320**	**367**	**386**	**417**		

Mean weighted values for V_p and V_s are computed for each site (borehole) according to the following formula:

$$\overline{V_S} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{V_{Si}}}, \qquad (1)$$

where h_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. As they are described in Romanian Code for the seismic design for buildings - P100-1/2006 [17] and EUROCODE 8 [18].

The seismic velocities determined in the present study in Table 1 are in the same range as those presented by [11], measured in other 6 locations in Bucharest (Table 2). Especially in the geologic layers 3, 4 and 5 we can find very close values of the mean weighted velocity.

In a recent paper [19] shear-wave velocity values for 2 sites in Bucharest City are presented: Tineret Park (site A) and Bazilescu Park (site B). The seismic measurements are made by refraction profiles intersecting each other in the central part up to a distance of 300 m from the seismic source.

The following values were obtained for Bazilescu Park in the first 3 layers: layer 1: 140–175 m/s; layer 2: 275–280 m/s; layer 3: 31–350 m/s. These velocity values, which are presented in Table 2, column 6 and 7, are consistent with those presented in the present study.

As for Tineretului Park (site A in [19] the seismic velocity V_s values are: layer 1: 175–200 m/s; layer 2: 230 m/s; layer 3: 300–345 m/s. Again these values are consistent with those computed in the present study for this particular site.

All these papers are presenting values of the average values of shear-wave velocity measured *in situ* and reported in 4 papers, using three different methods, in boreholes and at surface and the results obtained for Bucharest City are very close (Table 2). They are placed in a narrow range of mean shearwave velocities, which are significantly lower than the values cited by [6], especially for the geological layers 5–7.

Table 2

Comparison of *in situ* seismic measurements made in Bucharest in recent years by different authors

Main geologic layer no.	Depth of the upper limit of the geologic layer [m]	Density [g/cm3]	Averaged Vs [m/s] in 7 boreholes (6 sites) After Hannich et al., 2005 [11]	Averaged values of the mean weighted seismic velocity Vs in 11 boreholes [m/s] After Bala et al., 2006 [9]	Mean weighted seismic velocity Vs in 10 boreholes [m/s]	Seismic velocity Vs measured at surface [m/s]	
After Ciugudean and Stefanescu, 2006					After Bala et al., 2010 [15]	After Von Steht et al., 2008 [19]	
						Bazilescu Park	Tineret Park
1. Backfill	0	1.10	135	167	169	140-175	175-195
2. Upper Clay Layer	0.5 - 5	1.75	305	244	252	275-280	230
3. Colentina Aquifer (sand+gravel)	5 - 12	1.99	335	274	320	315-350	300-345
4. Intermediate Clay Layer	10 - 20	2.07	378	327	367	--	360
5. Mostistea Aquifer	15 -35	2.00	400	340	386	---	---
6. Lacustrine Layer	35 -50	2.14	442	397	417	---	---
7. Fratesti aquifer A	100 - 180	2.05	500	545	---	---	---

4. GEOTECHNICAL LABORATORY ANALYSIS AND MEASUREMENTS OF CORE SAMPLES

The Dynamic Deformation Characteristics of the soil are used in order to calculate seismic response of ground, earth structures and structure-ground response. They are also used to express phenomena that make soil to fail under seismic loading.

Despite the fact that 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 (Fig. 2). Therefore nonlinearity of dynamic deformation characteristics, the G- γ, E- γ and h- γ curves, are significant in seismic response analysis. All the moduli E, v, G, h depends on strain range but the dependency of v is considered rather small.

The evaluation of shear modulus of soils at very small levels of strains was a main concern of researchers. To obtain a 10^{-4}–10^{-5} axial strain we must use a very small deviator stress. This modulus is called maximum shear modulus, initial shear modulus, or low amplitude shear modulus and is noted by $G_{\max}$ or G_0.

The relationships obtained in DDC (dynamic deformation characteristics tests) are generally recognized to express the shear deformation characteristics of soil. A complication is that the value of the shear modulus for natural soils depends very much on the magnitude of the shear strains. Its value may vary between fairly wide limits, and its influence on the results is very large. For very small strains the shear modulus may be a factor 10 or even 100 larger than it is for large strains.

The most widely used of the cyclic loading laboratory tests is the cyclic triaxial test. The difference between static and dynamic loading conditions is in the term of time of loading and is expressed in terms of speed of loading or rate of straining (speed effect or rate effect). The “time of loading” is defined as ¼ of the period at which the load is reciprocated. If load application last more than 0.1 seconds then we have “static problems” and if load application have a shorter time of application we have “dynamic problems” [20].

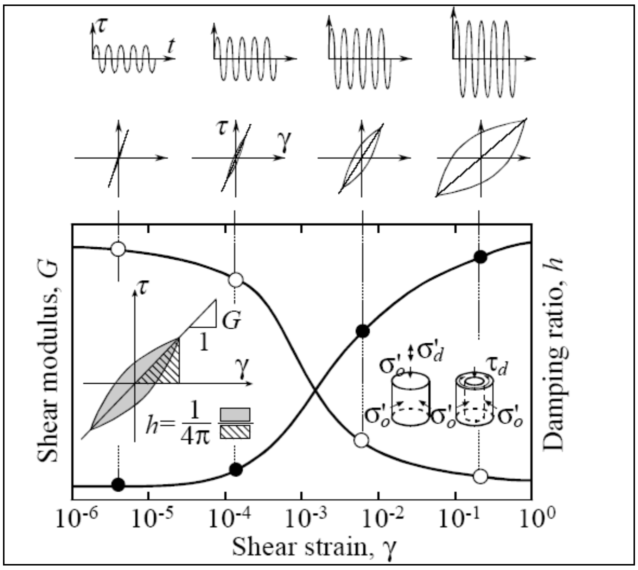


Fig. 2 – The data processing in dynamic deformation characteristics test (triaxial test).

The test results showed that the shear modulus values obtained at the 2nd and 10th cycles differ at most by 10% when the shear strain is larger than 10^{-4}. The same percentage was observed for damping characteristics. The shear modulus did not start do drop until the shear strain amplitude grew to a 5×10^{-5} in the case of clay soils and this is in contrast with the cohessionless soils in which the modulus reduction start to occur from a smaller strain of about 10^{-5}.

In a cyclic test the load is applied to a column of soil over a number of cycles slowly enough that inertial effects do not occur. The response at one amplitude of load is observed, and the test is repeated at a higher load. Cyclic load is usually applied as cyclic axial load by mechanical, hydraulic or pneumatic actuator.

The *cyclic undrained triaxial test* method allows the determination of elastic modulus E (daN/cm^2), damping D for different levels of shear strain (in the low strain-level) and the *"undrained compressive strength of soil"* (the strength of soil determined as the maximum stress difference applicable to the soil specimen when no pore water is allowed to go into or come out of the specimen).

The *cyclic undrained triaxial test* is defined as a test to apply a symmetrical cyclic axial force having fixed amplitude to a saturated and isotropically consolidated specimen using a fixed frequency. This test method covers the determination of the relationships between the single amplitude of cyclic deviator stress or the cyclic stress ratio, which is applied under undrained condition with cyclic triaxial apparatus, and the number of cycles required to cause a specified value of double amplitude of axial strain or to cause a specified value of excess pore water pressure ratio [21].

4.1. LABORATORY MEASUREMENTS ON SAMPLE PROBES COLLECTED DURING THE NATO PROJECT 981882

In July 2003 at CNRRS was installed the triaxial equipment. Seiken Inc. Japan made the equipment and the commissioning [21] and [22]. The equipment fullfills all the requirements of The Japanese Geotechnical Society, 2000. During the last years series of dynamic triaxial tests on the clay and sandy soils were conducted.

The geotechnical laboratory analysis consists in the following parts: geological identification of the sample, identification of the sample after the ternary diagram, percentage of clay – dust → fine sand → medium sand → big sand → gravel, density mineral skeleton, particle percent with diameter $d < 2\mu\text{m}$, plastic limit determination, tests of compression - settling, triaxial (dynamic) test and resonant column tests. In Table 3 cyclic loading tests on Bucharest cohesionless soils samples from 4 sites (drillings) are presented. In Table 4 Cyclic loading tests on Bucharest cohesion soils samples from 8 sites (drillings) collected during the NATO Project 981882.

Table 3

Cyclic loading tests on Bucharest cohesionless soils samples from 4 sites (drillings)
during the NATO Project 981882

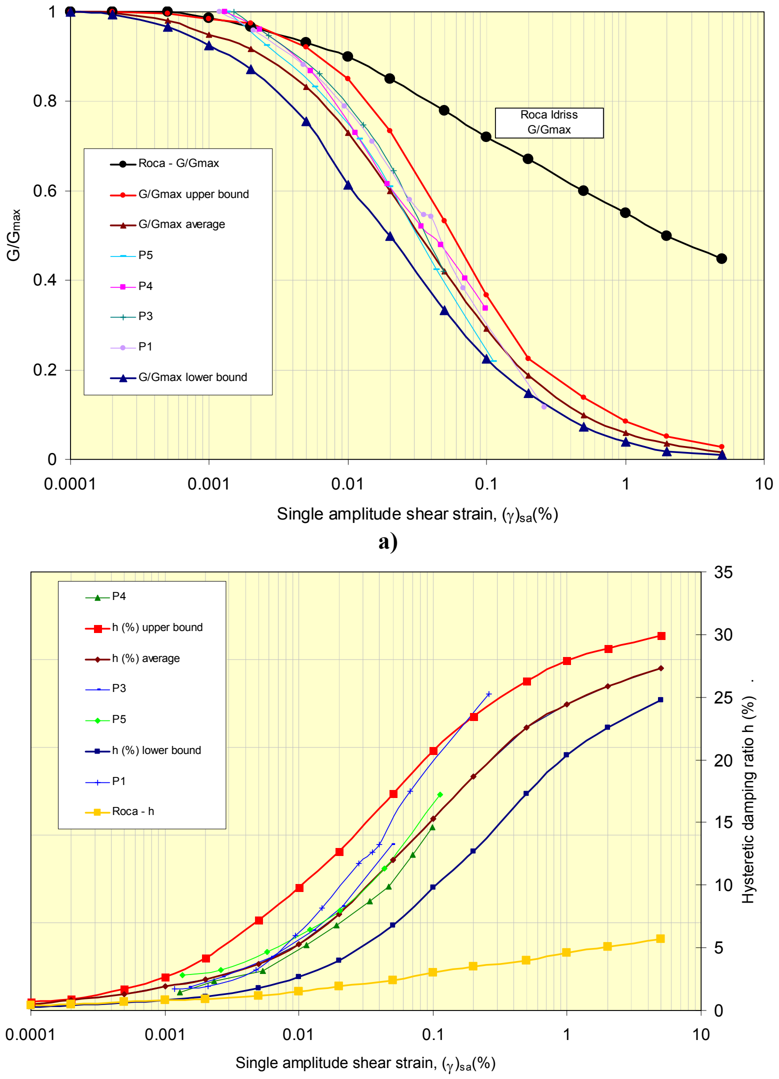
No. of sample	**Site**	**Depth of sample (m)**	**Soil type**	**Sample**		
				Diameter (cm)	**Height (cm)**	**Dry weight (g)**
P1	Bazilescu park	5.50	medium yellow sand	5.07	9.95	294.78
P3	Tineret Park	37.00	fine and medium grey sand	5.06	9.90	318.38
P4	Student Tei Park	39.00	fine and medium grey sand	5.06	9.85	308.76
P5	Ecology Univ.	48.00	fine grey clayed sand	5.00	9.96	321.01

Table 4

Cyclic loading tests on Bucharest cohesion soils samples from 9 sites (drillings)
during the NATO Project 981882

No. of the sample	**Site**	**Depth sample (m)**	**Soil type**	**Samples properties**			
				Diameter (cm)	**Height (cm)**	**Natural weight (g)**	**Humidity (%)**
P0	Student Tei Park	4.00	Brown plastic clay	4.927	9.98	393.54	20.09
P1	Motodrom Park	6.50	Silty plastic brown clay	5.033	9.99	392.60	22.85
P2	Romanian Shooting Fed. Baneasa	6.50	Brown plastic clay with calcareous concretions	5.053	10.00	396.78	19.38
P4	Romanian Shooting Fed. Baneasa	13.00	Yellow sandy clay	5.007	9.97	400.13	20.00
P5	Titan2 Park	39.00	Grey sandy clay	4.99	10.00	398.65	12.17
P6	INCDFP Magurele	37.00	Grey clay with calcareous concretions	4.987	9.94	386.01	24.07
P7	Astronomy Inst.	43.00	Brown clay	5.02	10.00	413.19	15.76
P8	Romanian Shooting Fed. Baneasa	41.00	Yellow plastic clay	4.960	9.95	401.29	17.34

In Fig. 3 are represented relations of shear modulus ratio G/G_0 *versus* shear strain (Fig. 3a) and the strain dependent damping ratio (Fig. 3b) for the laboratory samples from Table 3 (uncohesive soils). There were also represented the strain-dependent modulus and damping curves quoted in the literature in the same graph [23] demonstrate the importance of plasticity index I_p of soils. As a result they propose a family of curves which are the averaged relations indicating the effect of plasticity index on the strain-dependent modulus and damping of cohesive soils.

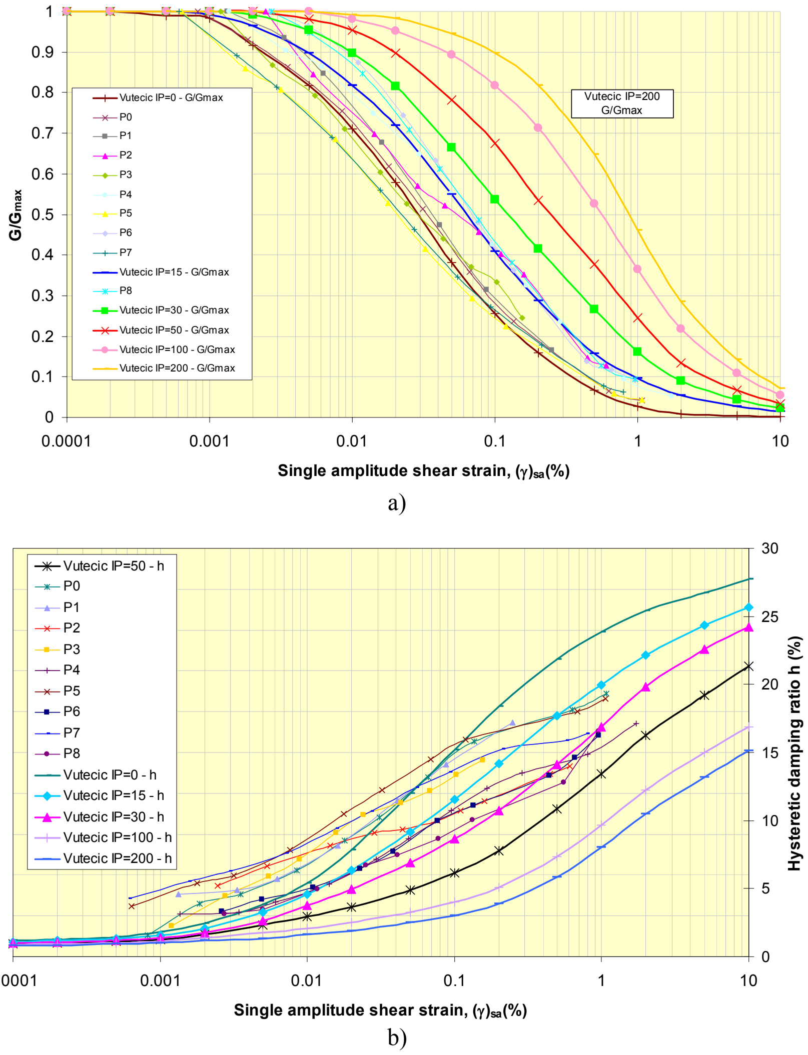


a)

b)

Fig. 3 – Test results for uncohesive soils from Bucharest (P1 - P5 sample cores) and comparison with analytical model curves: a) G/G_{max} curves; b) damping ratio.

In Fig. 4 there are represented relations of shear modulus ratio G/G_0 *versus* shear strain and the strain dependent damping for the laboratory samples from Table 4 (cohesive soils). There were also represented the strain-dependent modulus and damping curves quoted in the literature in the same graph. In this case the curves $G/G_{\max}$ (Fig. 4a) computed for the samples P0 – P8 (Table 4) are on a lower position in comparison with the data cited from [23] being under the curve with IP=15. The Damping ratio curves measured on samples are scattered over a wide range (Fig. 4b).



a)

b)

Fig. 4 – Test results for cohesive soils from Bucharest (P0 - P8 sample cores) and comparison with analytical model curves: a) $G/G_{\max}$ curves; b) damping ratio.

5. CONCLUSIONS

1. The shallow geology of Quaternary layers in Bucharest City is rapidly changing from one point to another in only a few hundreds of meters not only in the thickness of the layers, but also in the geotechnical properties of each layer [15, 16]. The real succession of the 7 principal layers as well as their physical properties can be ascribed only by in situ measurements in boreholes.

2. Seismic velocities in the Table 1 are obtained by direct seismic measurements in the 10 boreholes. They were presented in Table 1 in order to compute the mean weighted seismic velocity for each of the Quaternary complexes present in the underground of Bucharest area. The mean weighted seismic velocity was computed for the first 30 m depth ($V_{S\text{-}30}$) and 50 m depth ($V_{S\text{-}50}$), for each drilling site, according to formula cited in the Romanian Code for the seismic design for buildings - P100 -1/2006 [17] and in EUROCODE 8 [18]. All the $\mathrm{V}_{\mathrm{S}\text{-}30}$ values in Table 1 belong to type C of soil after the classification given in [17]. Even the $V_{S\text{-}50}$ values in the Table 1 fall in the type C of the classification (180 m/s < $\overline{V}_S$ < 360 m/s).

3. The results obtained by CNRRS laboratory in the case of Bucharest clay and sand layers for cyclic loading test shows good correlations with analytical model curves, in the case of the cohesionless samples (Table 3).

However the test results for cohesive soils from Bucharest (Table 4) and comparison with analytical model curves in Fig. 4 demonstrates that lower values should be considered in the future for these types of soils in the process of linear and nonlinear site amplification modeling.

4. Results obtained by the down-hole seismic method in the 10 boreholes drilled in Bucharest City as well as the curves obtained from laboratory measurements on samples collected from the same boreholes are used as input data in the program SHAKE2000 [24] in order to compute the seismic site amplification for Bucharest area.

Acknowledgements. The research work presented in this paper is realized in the frame of the research project PNCDI 31-038/2007, conducted by National Institute for Earth Physics, Bucharest-Magurele, (NIEP), funded by the Romanian Ministry for Education, Research and Innovation, Bucharest, Romania.

Part of the drilling field work and *in situ* velocity measurements were performed during the NATO Project 981882 in the years 2006–2008. The laboratory investigations on the rock samples collected from the drillings were performed in the National Institute for Earth Physics (NIEP), Technical University for Civil Engineering (UTCB) and National Centre for Seismic Risk Reduction (NCSRR).

REFERENCES

1. M. Dilley, R.S. Chen, U. Deichmann, A.L. Lerner-Lam, M. Arnold, J. Agwe, P. Buys, O. Kjekstad, L. Bradfield, B. Lyon, B., Gregory Yerman, *Natural disaster hotspots: A global risk analysis*, Synthesis Report, 2005.

2. W. Wirth, F. Wenzel., V.Y. Sokolov, K. Bonjer, *A uniform approach to seismic site effect analysis in Bucharest, Romania*, Soil Dynamics and Earthquake Engineer, **23**, 737–758 (2003).
3. A. Aldea, D. Lungu, C. Arion, *GIS mapping of seismic microzonation and site effects in Bucharest based on existing seismic and geophysical evidence*, in: Lungu, D., Wenzel., F., Mouroux, P. & Tojo, I. (eds.), *Earthquake loss estimation and risk reduction*, **1**, 237–249 (2004).
4. C.O. Cioflan, B.F. Apostol, C.L. Moldoveanu, G.F. Panza, G. Marmureanu, *Deterministic approach for the microzonation of Bucharest*, Pure appl. geophys., **161**, 1–16 (2004).
5. A. Kienzle, D. Hannich, W. Wirth, V. Ciugudean, J. Rohn, K. Czurda, *Seismic zonation of Bucharest*, In: Lungu, D., Wenzel., F., Mouroux, P. & Tojo, I. (eds.), *Earthquake loss estimation and risk reduction*, **1**, 251–259 (2004).
6. N. Mandrescu, M. Radulian, Gh. Marmureanu, *Geological, geophysical and seismological criteria for local response evaluation in Bucharest urban area*, Soil Dynamics and Earthquake Engineering, **27**, 367–393 (2007).
7. V.Y. Sokolov, K. -P. Bonjer, F. Wenzel, *Accounting for site effect in probabilistic assessment of seismic hazard for Romania and Bucharest: a case study of deep seismicity in Vrancea zone*, Soil Dynamics and Earthquake Engineering, **24**, 927–947 (2004).
8. C.O. Cioflan, B.F. Apostol, *Modern Evaluation of the Seismic Hazard for Romanian Plain*, Acta Geodaetica et Geophysica Hungarica, **41**, *3–4*, 425–433 (2006).
9. A. Bala, V. Raileanu, I. Zihan, V. Ciugudean, B. Grecu, *Physical and dynamic properties of the shallow sedimentary rocks in the Bucharest Metropolitan Area*, Romanian Reports in Physics, **58**, *2*, 221–250 (2006).
10. 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, pp. 359–366, Bucharest, 2007.
11. D. Hannich , K. -P. Bonjer, H. Hoetzl, D. Lungu, V. Ciugudean, T. Moldoveanu, C. Dinu, D. Orlowsky, *Evaluation of soil parameters through Vertical Seismic Profiling (VSP) in Bucharest*, Romania (in manuscript), 2005.
12. D. Orlowski, C. Witte, B. Loske, *Execution and evaluation of seismic measurements in Bucharest by the Multi-Offset-Vertical-Seismic-Profiling method* (MOVSP) (in German), Internal Report, DMT, Mines & More Division, Essen, 2003.
13. A. Aldea, H. Yamanaka, C. Negulescu, T. Kashima, R. Radoi, H. Kazama, E. Calarasu, *Extensive seismic instrumentation and geophyiscal investigation for site-response studies in Bucarest, Romania*, Proceedings of the Third International Symposium on the Effects of Surface geology on Seismic Motion, Grenoble France, 30 Aug.–1 Sept. 2006, paper 69, 2006.
14. A. Bala, S.F. Balan, J.R.R. Ritter, J. Rohn, G. Huber, D. Hannich, *Site-effect analyses for the earthquake-endangered metropolis Bucharest, Romania*, Edit. Univ. “Alexandru Ioan Cuza”, Iasi, 2010.
15. A. Bala, D. Hannich, J.R.R. Ritter, V. Ciugudean – Toma, *Geological and Geophysical Model of the Quaternary Layers based on in situ measurements in Bucharest, Romania*, Romanian Reports in Physics, **63**, *1*, 250–274 (2011).
16. V. Ciugudean-Toma, I. Stefanescu, *Engineering geology of the Bucharest city area, Romania*, Paper no. 235 submitted to IAEG -2006, Engineering Geology for tomorrow’s cities, 2006.
17. *** Seismic design Code-P100-1/2006**:** *Design Rules for Buildings*, Ministry of Transport, Construction and Tourism, Construction Bulletin , 12-13, INCERC (in Romanian).
18. *** EUROCODE-8: *Design of structures for earthquake resistance*: EN 1998-1 -Part 1: General rules, seismic actions and rules for buildings, CEN, December 2004.
19. M. Von Steht, B. Jaskolla, J.R.R. Ritter, *Near Surface Share wave velocity in Bucharest, Romania*, Natural Hazards and Earth System Sciences, **8**, 1299–1307 (2008).
20. C. Arion, C. Neagu, *Laboratory investigation for estimation of seismic response of the ground*, Proceedings of 1st ECEES First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, 3–8 September 2006, Paper Number: 519, CD-ROM, 2006.

21. C. Arion, C. Neagu, *Laboratory investigation for estimation of seismic response of the ground*, Proc. of ISSRR2007 International Symposium on Seismic Risk Reduction, The JICA Technical Coop. Project in Romania, Bucharest, pp. 121–130 (2007).
22. SEIKEN, Inc., *Technical documentation of triaxial testing apparatus*, Model No. DTC – 367, 2003.
23. M. Vutecic, R. Dobry, Pore pressure build-up and liquefaction at level sandy sites during earthquakes, research report No. CE-86-3 Rensselaer Polytechnic Institute, Troy, NY 12181, 1991.
24. G. A. Ordónez, *A computer Program for the 1-D Analysis of Geotechnical Earthquake Engineering Problem*, SHAKE 2000, 2003.