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EARTH PHYSICS

SHEAR-WAVE VELOCITIES OF THE QUATERNARY LAYERS, DETERMINED BY MULTI-OFFSET VERTICAL SEISMIC PROFILING (MOVSP) IN BUCHAREST, ROMANIA

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Abstract. The Collaborative Research Center 461 (CRC-461):"Strong Earthquakes: a Challenge for Geosciences and Civil Engineering", was initiated by the University of Karlsruhe, Germany in 1995. From the beginning of the research works, the necessity to know the soil parameters of the Quaternary layers in Bucharest was felt. For linear ground response analyses, first of all shear-wave velocities (v_s) of the geologic layers must be known. Until 2002 shear-wave velocities of the Quaternary layers were known in Bucharest only in a single borehole of 70 m depth at INCERC (Lungu *et al.*, 1999). In May 2002 a measuring campaign of shear-wave velocities by Multi-Offset Vertical Seismic Profiling (MOVSP), in eight boreholes was financed by the CRC-461. The depth of the boreholes ranges from 30 m until 200 m. After a short description of the applied MOVSP measuring technique, averaged v_s-values for the main Quaternary layers are presented. This method enables v_s-measurements only from depths of 20 m downward. Using for the upper layers elder v_s-values deduced from measurements prior to 2002, a complete v_s-model, is presented. Mean densities for the Quaternary layers, deduced mainly from geophysical borehole logging (ATLAS-G.I.P. S.A.), complete the model of static soil properties.

Key words: shear wave velocity, vertical seismic profiling, soil parameter, groundwater level.

1. INTRODUCTION

Seismic site effects generally are connected to local variations of the near-surface geology. This opinion becomes more evident at places where the source-to-site geometry remains practically invariable. In conditions of thick soft soil deposits with lateral and vertical heterogeneities, more pronounced site effects can be expected. In the case of Bucharest, the capital of Romania, the source geometry

of the intermediate-depth Vrancea earthquakes in respect to the city area remains almost the same, the hypocentral distances being about 150 km. Compared with the diameter of Bucharest of about 15 km, influences like source directivity and travel path effects are assumed to be constant over the entire city area. Thus, the observed site effects inside this area can be attributed to the variation of local soil and hydrogeologic near-surface conditions.

The shallowest hard rock in the Moesian platform underling the Bucharest city can be considered as the surface of the Cretaceous layer, a limestone eroded relief with p-wave seismic velocity of 4-5 km/s and s-wave velocity of about 3 km/s or more (after Raileanu *et al.* [7]; Raileanu *et al.* [10]). Under the Bucharest this hard rock basement descents from about 700–800 m in south to 1200 m in north (see Dumitrescu & Sandulescu [8]).

The shallow geologic underground of Bucharest, represented by Quaternary sediments, is characterized by an alternation of soft cohesive and non-cohesive soil layers down to a depth of about 300 m. Within the Quaternary, three main porous aquifer systems with specific seasonal variations and long-time trends of the groundwater level are influencing in addition this complex geologic structure, by variable saturations within the non-cohesive soil layers. These Quaternary soil layers are grouped after lithologic and hydrogeologic criteria in 7 main layers. Their horizontal and vertical distribution is relatively well known through a lot of geotechnical exploration drillings, mainly provided from the subway planning company in Bucharest, METROUL S.A. Based on about 500 drillings, mainly until 30 m, but also 70 m, 200 m and even 2300 m depth, a geologic underground model for Bucharest was deduced (after Kienzle, [4]). Using a Geographic Information System (GIS), an ACCES database and interpolation techniques, practically at each point of the city area of Bucharest the geologic depth-profile till at least 30 m depth may be known. In order to use this existing geologic underground model for the evaluation of the dynamic soil behaviour and further for seismic hazard, vulnerability and risk analyses, it is necessary to attribute to each of the soil layers a corresponding shear-wave velocity (v_s). For this reason the so-called Multi-Offset VSP-method (MOVSP), as a special version of the classical VSP-method was chosen, and applied in eight existing or special executed boreholes distributed, as possible, all over the city.

2. GEOLOGIC AND HYDROGEOLOGIC CONDITIONS IN BUCHAREST

Due to the mentioned high seismic risk potential of Bucharest and due to the necessity to explain the occurrence of local site effects, it is necessary to know in detail the geologic and hydrogeologic background of this area. For an earthquake-endangered region, the city area of Bucharest presents quite special geological conditions.

Under the Bucharest the hard rock of Cretaceous limestone descents from about 700–800 m in the south to 1200 m in the north (see Tectonic map of Romania, [8]). Three main porous aquifer systems within the Quaternary layers represent the hydrogeologic conditions. Laterally heterogeneities and vertical thickness variations of the soft soil deposits complicate the geologic structure.

2.1. QUATERNARY DEPOSITS

Based on the geological, geotechnical and lithological description of the Quaternary deposits in the area of Bucharest (Liteanu [5], Lungu *et al.* [6], Ciugudean & Martinof [3].) a classification of 7 main layers (beginning from the surface to depth) is accepted (Fig. 1) having following names and following general characteristics:

Layer 1: *Anthropogenic backfill and soil*, with a thickness varying between 3–10 m.

Layer 2: The *Upper clayey-sandy complex*, represent Holocene deposits of Loess, sandy clays and sands. The thickness of this complex varies between 2–5 m in the "Dambovita-Colentina inter-fluvial domain", 10-16 m in the northern and southern Plaines (Baneasa-Pantelimon and Cotroceni-Vacaresti) and 3-6 m in the river meadows.

Layer 3: The *Colentina gravel complex* bearing the *Colentina-aquifer*, is a layer containing gravels and sands with varying grain size distribution. The thickness is variable, between 1–20 m, lacking in the western part of Bucharest.

Layer 4: The *Intermediate clay layer* containing up to 80% hard consolidated clay and calcareous concretions with intercalated thin sand and silt lenses. The thickness of this layer varies between 0–25 m.

Layer 5: The *Mostistea sandbank*, bearing the *Mostistea-aquifer*, is a sand layer with sands of medium to fine grain size. The thickness varies in the area of Bucharest between 1–25 m.

Layer 6: The *Lacustrine complex*, composed by a variation of limy marled clay and fine sands, the grain size <0,005 mm consisting about 86%. The upper face of the complex lies at 20-50 m depth, but the thickness varies from about 60 m in the southern part of Bucharest to about 130 m in the North. The variable thickness is due to the underlying *Fratesti complex* which descents northward.

Layer 7: The *Fratesti complex* or *Lower gravel complex*, bearing the "Fratesti aquifer", lies discordant on Pliocene Levantine clay layers. This complex comprehends three thick (10–40 m each) sandy gravel layers (named A, B and C), separated by two marl or clay layers (each of 5–40 m thickness). This thick complex (total thickness 100–180 m), continuous present in the whole area of

Bucharest, dips northward, its upper surface lying at about 75 m depth in the southern part of Bucharest and at about 190 m depth in the North.

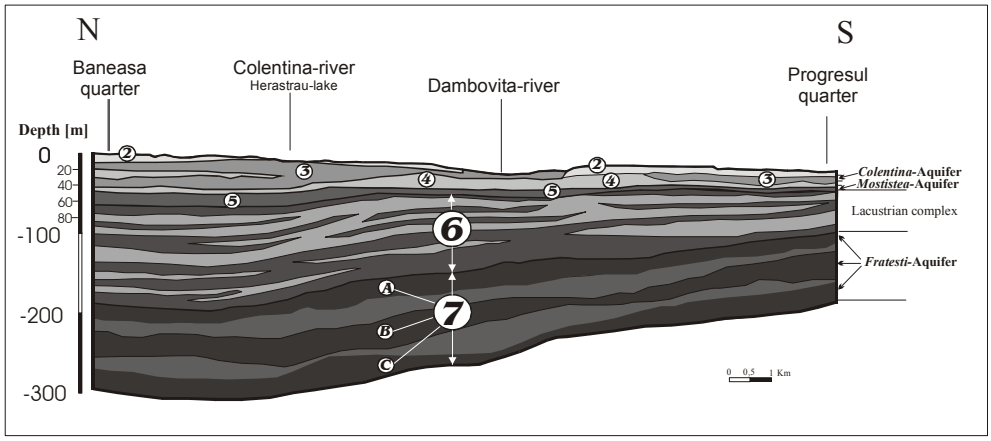

Fig. 1 – The 7 Quaternary layers and the 3 main aquifers in Bucharest (based on Sandi *et al.* [11]).

2.2. HYDROGEOLOGY

Complex hydrogeological conditions are characterizing the underground of Bucharest. Considering only the Quaternary deposits, these contain three main porous aquifer systems, each of them with lateral inhomogeneities and vertical thickness variations.

The upper-most aquifer, the "Colentina-aquifer" is connected to the Colentina gravel complex (Fig. 2). It is a phreatic aquifer in direct hydraulic connection with the alluvial deposits of the two rivers, Colentina and Dambovita. Depending on the geomorphologic units in the area of Bucharest, the phreatic groundwater level presents variable depths: a higher level, between 1 and 5 m depth in the Dambovita and Colentina meadows, between 5 and 10 m in the Dambovita-Colentina inter-fluvial domain and below 10 m in the Cotroceni-Vacaresti and Baneasa-Pantelimon Plains (after Bretotean *et al.* [1]). But important annual and seasonal variations of the phreatic groundwater level, reaching sometimes until 2–4 m, have been observed in the last 25 years (after Bretotean, [2]).

A second aquifer, the "Mostistea-aquifer" is connected to the mentioned Mostistea-sandbank, sands with mostly fine to medium grain size. This aquifer presents great variations of thickness in the area of Bucharest. It is a mainly confined aquifer, but being also at any places in hydraulic contact with the overlying Colentina-aquifer and also especially in the southern part of Bucharest with the surface water system (Fig. 2 and Fig. 3), loosing there his confined character.

The deepest and thickest Quaternary aquifer, the "Fratesti-aquifer" is situated at the base of the Quaternary layers (Fig. 2). It is a regional aquifer system with three distinguished aquifers named A, B and C, each of these 10–40 m thick, being extended continuously in the southern part of Romania, dipping toward the Carpathians and outcropping near the Danube. The most important aquifer of this system is the layer A, being mainly used for drinking water abstraction. The anthropogenic influences due to water abstraction and the seasonal charge influences within this aquifer contribute to complex daily and monthly level oscillations of the groundwater until 2–3 m. In the area of Bucharest, this regional aquifer, especially the layer A, presents a large cone of depression due to a high abstraction rate, reaching a depth difference of about 20 m (Zamfirescu *et al.* [13]).

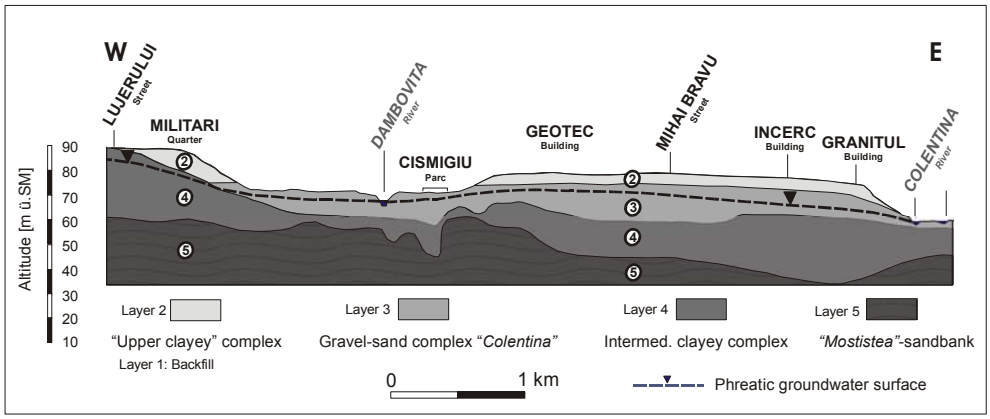

Fig. 2 – Near-surface geology and hydrogeology in Bucharest (based on Lungu *et al.* [6]).

3. VSP- AND MOVSP-MEASUREMENTS

3.1. BASIC PRINCIPLES

"Vertical seismic profiling" (VSP) is a geophysical borehole method based on the measuring of received, artificial produced, seismic signals at geophones installed in a borehole. Thus, the dynamic properties of the subsoil are explored by measuring the propagation time of the received seismic waves. The coupling between the receivers and the borehole casing can be realized mechanically (geophones) or hydraulically (hydrophones). The seismic signals are produced at the surface near the borehole by a seismic source, which can be a vibrator, by blasting or a falling weight. At the Multi-Offset VSP method, called also Walkaway-VSP method, seismic signals at several source-locations along profiles around the borehole are produced [after Orlowski *et al.* [9]. Figure 3 shows

schematically the measuring principle of MOVSP-measurements. The source-locations on the surface and the recording-locations (geophones) in the borehole can be observed. Wave travel paths of waves coming direct from a source to a receiver (down-waves) as well as of waves reflected at a geological limit (up-waves) are schematically represented.

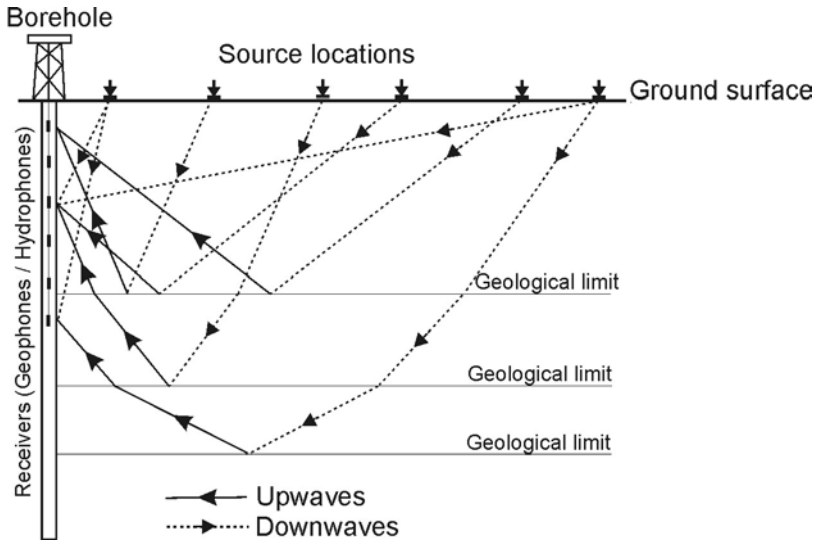

Fig. 3 – Schematic measuring arrangement (sources and receivers) and possible wave travel paths at a Multi-Offset Vertical Seismic Profiling (after Orlowski, *et al.* [9]).

Through a proper preparation of the recorded data, the separation of down- and up-waves, the application of the CDP-transformation (Common Depth Point), the evaluation of an optimal velocity-depth-function, the determination of averaged velocities, transformed then in velocities for depth-intervals, are realized. Finally through migration techniques used in the reflection seismology, the zero-offset-section is transformed in a vertical section of the geologic underground.

3.2. MOVSP FIELD MEASUREMENTS IN BUCHAREST

For the application of the above-mentioned Multi-Offset VSP method (MOVSP) in Bucharest, adequate boreholes had to be available. These boreholes must have the casing of plastic (not of steel) and must be filled with water, because the chosen receivers were hydrophones. Eight suitable boreholes, partly existing partly new performed, were chosen (Fig. 4). Five of them were existing boreholes and three were new ones. Table 1 contains the name, final depth and coordinates of the boreholes used for the MOVSP measurements.

Table 1

Name, depth and location of the boreholes used for MOVSP measurements

Crt.Nr.	NAME	FINAL DEPTH	UTM coord. E-W	UTM coord. N-S
1	INCERC1–100 m	100	433291	4921215
2	INCERC2–200 m	200	433112	4921158
3	EREN-60 m	60	425900	4924825
4	METROUL–80 m	80	437207	4917164
5	OPERA–58 m	58	426870	4920780
6	UTCB-70 m	70	430356	4923639
7	UTCB-30 m	30	430382	4923670
8	Piata Victoriei–150 m	150	426937	4922556

To obtain accurate and detailed results, following additional premises had to be met during the measurements:

- The distances between the source positions on the terrain surface and between the geophones within the borehole must be chosen as small as possible.
- A good coupling between the source and the soil as well as between receivers and the underground must be realized.
- The geometry of the source profile on the surface in relation to the borehole must form a right angle to existing geologic fractures.

Two kinds of chains of hydrophones were used separately, with different distances between hydrophones: one with 0.5 m (chain A) and another with 2 m (chain B). Chain A comprises 48 hydrophones, whereas chain B comprises 69 hydrophones. As seismic source-generator a mini-vibrator (MHV3) with 70 kN peak force was used, generating signals with frequencies of 16–500 Hz. For each borehole it was tried to place two transverse profiles with source positions at distances of about 10 m depending on the local terrain conditions. In Fig. 5 the source-positions along two profiles for the INCERC1-100 m borehole, as example, are shown.

A specialized company from Essen, Germany carried out in May 2002 the Multi-Offset VSP measurements in Bucharest.

3.3. DATA PREPROCESSING AND PROCESSING

The preprocessing of the recorded raw field data consists in a lot of preparations as sampling of the data, the first-break picking, formatting in proper internal formats, a spectral adjustment, the determination of the interval velocity function and diverse filtering operations. Objective of the preprocessing of the data was to increase the data quality, to eliminate the casing-waves and the down-waves and to capture finally only the p-up-waves. Due to the use of hydrophones, direct s-waves do not occur; s-waves could be received only at the casing-wall, converted

from direct arriving p-waves. In Figs. 6, 7 and 8, examples of preprocessing operations and wave separation are presented.

After the preprocessing and the separation of up- and down-waves, the main processing of the data consists in a VSP-CDP transformation (CDP means "common depth point"). In this way, the remaining up-waves, as reflection signals are transformed, like in the surface reflection seismic techniques, in a so-called CDP-section. The position of the CDP-sections for each borehole was defined. An example of the resulting positions of the CDP-section for a borehole is shown in Fig. 5.

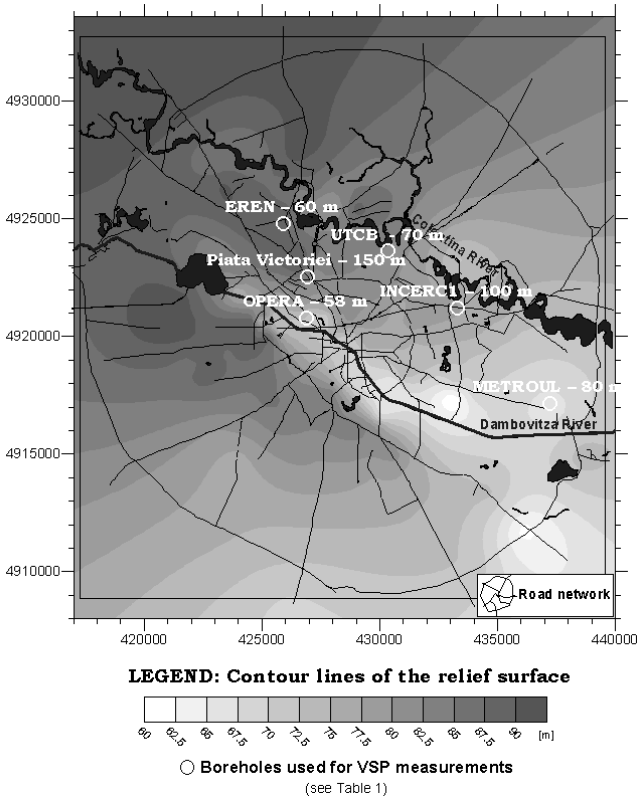

Fig. 4 – The localization of the boreholes used for MOVSP-measurements in Bucharest.

3.4. DETERMINATION OF SHEAR-WAVE VELOCITIES

The main goal of the VSP-measurements was to obtain the generation of shear-waves and their evaluation through the MOVSP technique. As already mentioned, due to the use of hydrophones, direct shear-waves could not be received. The separation of the converted shear-waves from casing-waves was very complicated, due to the fact that their FK-spectrums were nearly superposed. In the

Figs. 6, 7 and 8 steps of this separating process are illustrated. In the absence of direct shear-waves, the evaluation process was reduced to the determination of the p- to s-wave ratio (p/s). Than from the interval velocities of the p-waves, the s-wave velocities were deduced. More details in delineation of the procedure used for determination of p- to s-wave velocity ratio are given by Orlowsky *et al.* [9].

In this way the s-wave velocities for different depth intervals in the 8 designated boreholes in Bucharest were determined. The results of the obtained velocity models are presented as tables with p-wave velocities (v_p) for different depth intervals and the deduced s-wave velocities (v_s) for each borehole. In Table 2 an example of such a velocity model for one of the boreholes, the INCERC1-100 m borehole, is presented. The p-wave velocities (v_p) are having estimated errors of 5%, while s-wave velocities (v_s) have errors of 10%, as a result of the computing process (Orlowsky *et al.* [9]).

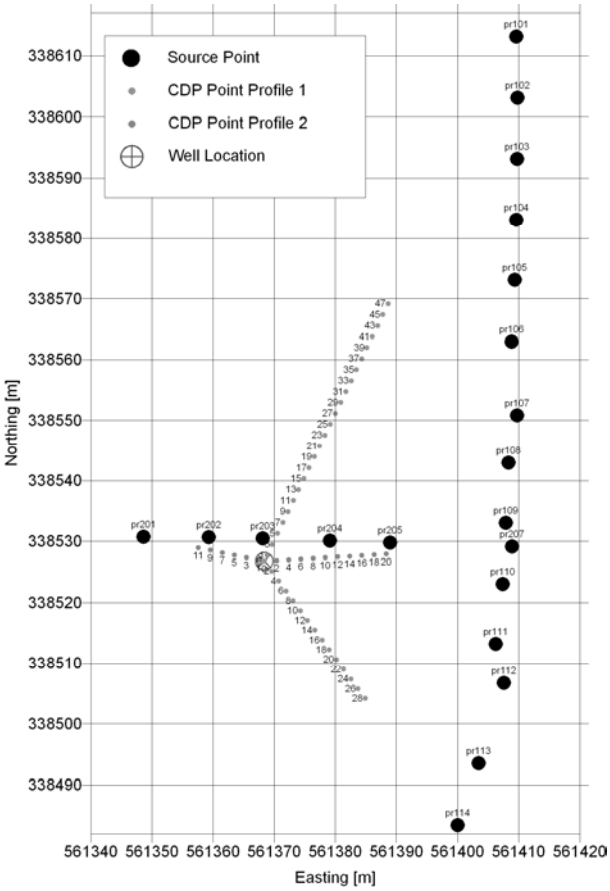

Fig. 5 – The position of the seismic sources (vibrator) along two profiles as well as the position of the resulting CDP-profiles at the INCERC1-100 m borehole (after Orlowski *et al.* [9]).

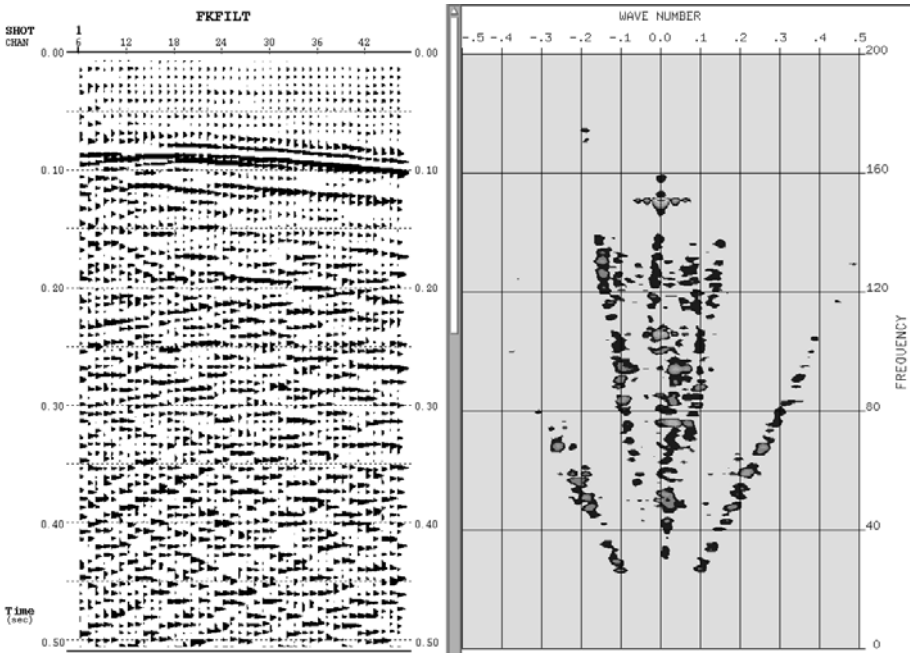

Fig. 6 – Record and spectrum before the FK-filtering process (after Orlowski *et al.* [9]).

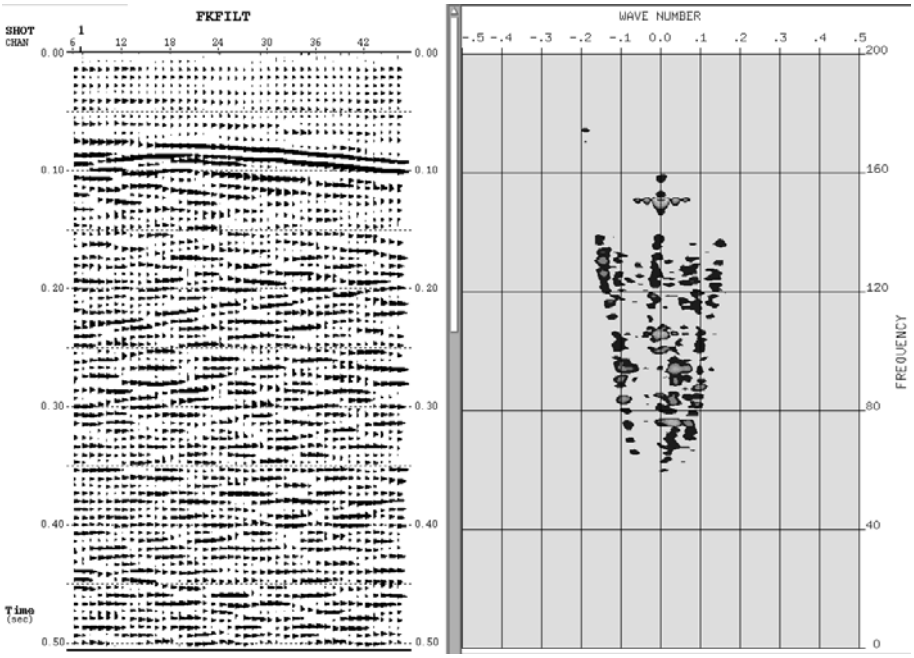

Fig. 7 – Record and spectrum after the elimination of the casing-wave (after Orlowski *et al.* [9]).

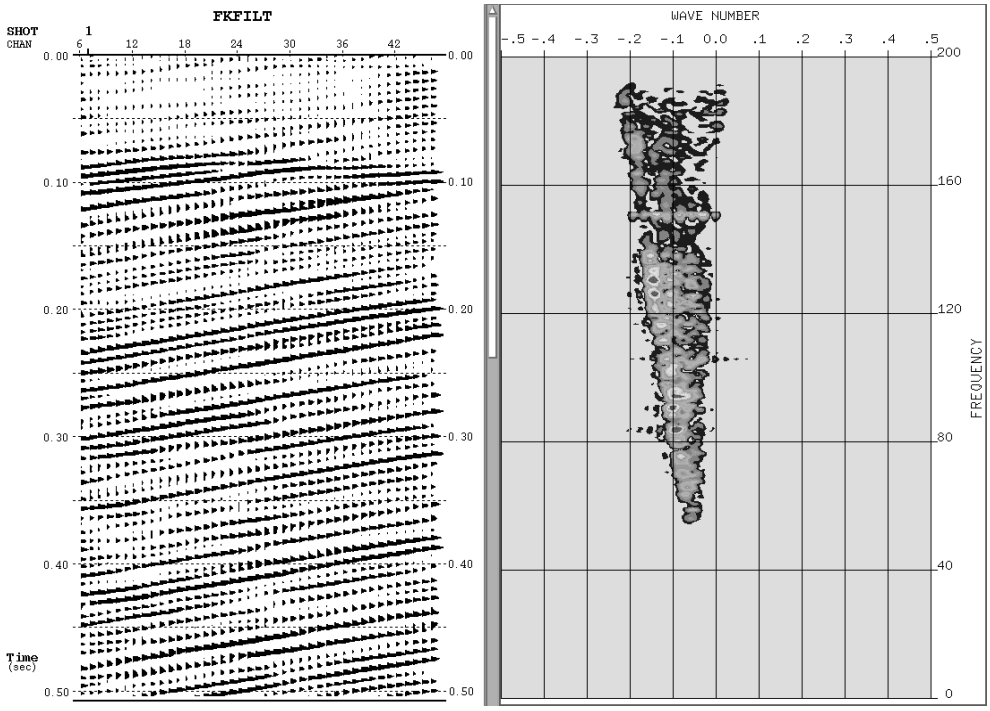

Fig. 8 – Record and spectrum after the elimination of the casing-wave and after the down-wave /up-wave separation (after Orlowski *et al.* [9]).

4. MEAN SHEAR-WAVE VELOCITIES (v_s) FOR THE MAIN QUATERNARY LAYERS IN BUCHAREST

The final aim of the accomplished VSP-measurements in the eight boreholes at different sites in Bucharest was to obtain representative mean values of the shear wave velocity for the seven main Quaternary layers. The obtained characteristic v_s-values should be used for linear modeling purposes at any locations all over the city area of Bucharest, to deduce transfer functions and/or response spectra for local soil profiles.

In the same way as shown in Table 2 for the INCERC1-100 m borehole, for each of the 8 examined boreholes, shear wave velocities for different depth intervals were determined. These seismically deduced depth intervals do not correspond to the 7 main geologically/lithologically delimited layers. Selecting the obtained v_s-values for different depth intervals, within the depth-range of the corresponding geologic layer, averaged v_s-values for the geologic layers were calculated.

Table 2

Velocity model for the INCERC1-100 m borehole (after Orlowski *et al.* [9])

Borehole INCERC1-100 m		Layer	Depth of layer-bottom [m]	Layer Interval-velocity p-wave v_p [m/s]	Layer Interval-velocity s-wave v_s [m/s]
Max. depth [m]	100	surface layer	18	680	--
Dist. Receiver [m]	2	1	22	1360	350
Water table depth [m]	10	2	28	1550	390
No. sources pr.1	14	3	36	1800	460
No. sources pr.2	6	4	42	1520	390
		5	50	1640	410
		6	56	1830	440
		7	60	1620	400
		8	66	1820	440
		9	70	1700	420
		10	76	1900	490
		11	82	1640	430
		12	94	1850	470
		13	98	1700	480
		14	150	1900	--
		15	250	2200	--

In Table 3 the described procedure is illustrated. It can be seen, that only from the geologic layer no. 4 ("Intermediate clay layer") downward, mean v_s-values could be attributed. For the near-surface layers numbered 1–3, due to technical limitations, shear-wave velocities could not be determined. Using the same procedure, a second example is shown in Table 4 for the Piata Victoriei–150 m borehole. In the same way were deduced mean v_s-values for the geologic layers in all the 8 boreholes. Starting from these mean v_s-values attributed to the 7 soil layers in individual boreholes, averaged v_s-values valid for the whole city area of Bucharest were deduced. In Table 5 the deduced averaged v_s-values, from VSP-measurements (MOVSP-technique), for the geologic layers in Bucharest are presented. The evaluated averaged values were not deduced by simply arithmetic means, but it was a mean value taken into account the thickness of each layer in the geologic model of the borehole.

Table 3

Example of evaluation of mean v_s-values for the geologic layers in the INCERC1-100 m borehole

Layer	Depth of layer-bottom [m]	Layer interval velocity p-wave v_p [m/s]	Layer interval velocity s-wave v_s [m/s]	Geologic layer	Mean v_s [m/s]
	18	680	--	**4**	
1	22	1360	350	bottom-depth: 30,70 m	**370**
2	28	1550	390		
3	36	1800	460	**5**	
4	42	1520	390	bottom-depth : 56,90 m	**425**
5	50	1640	410		
6	56	1830	440		
7	60	1620	400		
8	66	1820	440	**6**	
9	70	1700	420		
10	76	1900	490	bottom-depth: 98,00 m	**447**
11	82	1640	430		
12	94	1850	470		
13	98	1700	480		
14	150	1900	--		---
15	250	2200	--		

Table 4

Example of evaluation of mean v_s-values for the geologic layers in the Piata Victoriei-150 m borehole

Layer	Depth of layer-bottom [m]	Layer interval-velocity p-wave v_p [m/s]	Layer interval-velocity s-wave v_s [m/s]	Geologic layer	Mean v_s [m/s]
surface layer	8	750	--	**3** bottom-depth: 9,00 m	--
1	14	1200	--	**4** bottom-depth: 35,00 m	**370**
2	22	1500	--		
3	28	1750	400		
4	34	1600	340		
5	42	1750	390	**5** bottom-depth: 39,00 m	**390**
6	48	1800	410		
7	58	1700	380		
8	64	1900	420	**6**	
9	70	1750	430		
10	76	1600	390		**416**
11	80	1750	420	bottom-depth: 136,00 m	
12	86	1830	430		
13	90	1770	400		
14	96	1900	400		

Table 4 (continued)

15	104	1750	380		
16	110	1830	440		
17	116	1770	450		
18	128	1850	460		
19	138	1800	500	**7**	
20	150	1850	460	bottom-depth:	**480**
21	200	2000	--	150,00 m	
22	500	2200	--	--	--

Table 5

Averaged v_s-values of the 7 main Quaternary layers in Bucharest, deduced by MOVSP-techniques. For the layers 1 – 3, v_s-measurements are not possible

Quaternar layer Nr.	Averaged v_s [m/s]
1 Backfill	--
2 Upper clay layer	--
3 *Colentina* aquifer	--
4 Intermediate clay layer	378
5 *Mostistea* aquifer	400
6 Lacustrine layer	442
7 *Fratesti* aquifer	500

To enhance and complete the results obtained through the applied MOVSP-techniques in Bucharest, especially for the near-surface Quaternary layers 1–3, additional v_s-values, obtained before 2002 by GEOTEC (Department of Geophysics and Engineering Seismology), INCERC (National Institute for Building Research) and UTC (Technical University of Civil Engineering), were used. These already existing values were obtained by other measuring techniques, mainly by classical seismic down-hole measurements in some boreholes and laboratory tests like resonant column method, or the triaxial cyclic method in Bucharest. After a carefully analyses of these additional v_s-data had permitted to integrate them within the results of the MOVSP techniques, in Table 6, the first 3 values of v_s.

Detailed density determinations obtained for the different geologic layers through a complex geophysical borehole logging executed in the INCERC2-200m borehole (Fig. 9) by a specialized company, ATLAS-G.I.P. S.A, where also added to the velocity model. Table 6 contains a complete list of the 7 main Quaternary layers in Bucharest with the corresponding averaged v_s- and density-values. Special geoelectrical loggings has permitted to separate clay and sandy layers and the groundwater saturation of them. A special plot (at the right side of the logging) shows the density (in gr/cm³) of the layers. In this paper, an interpretation of the registered clay and sandy layers, have permitted to identify in the plot the main geologic layers. Further, averaged densities of the main geologic layers were deduced and outlined in the plot (Fig. 10).

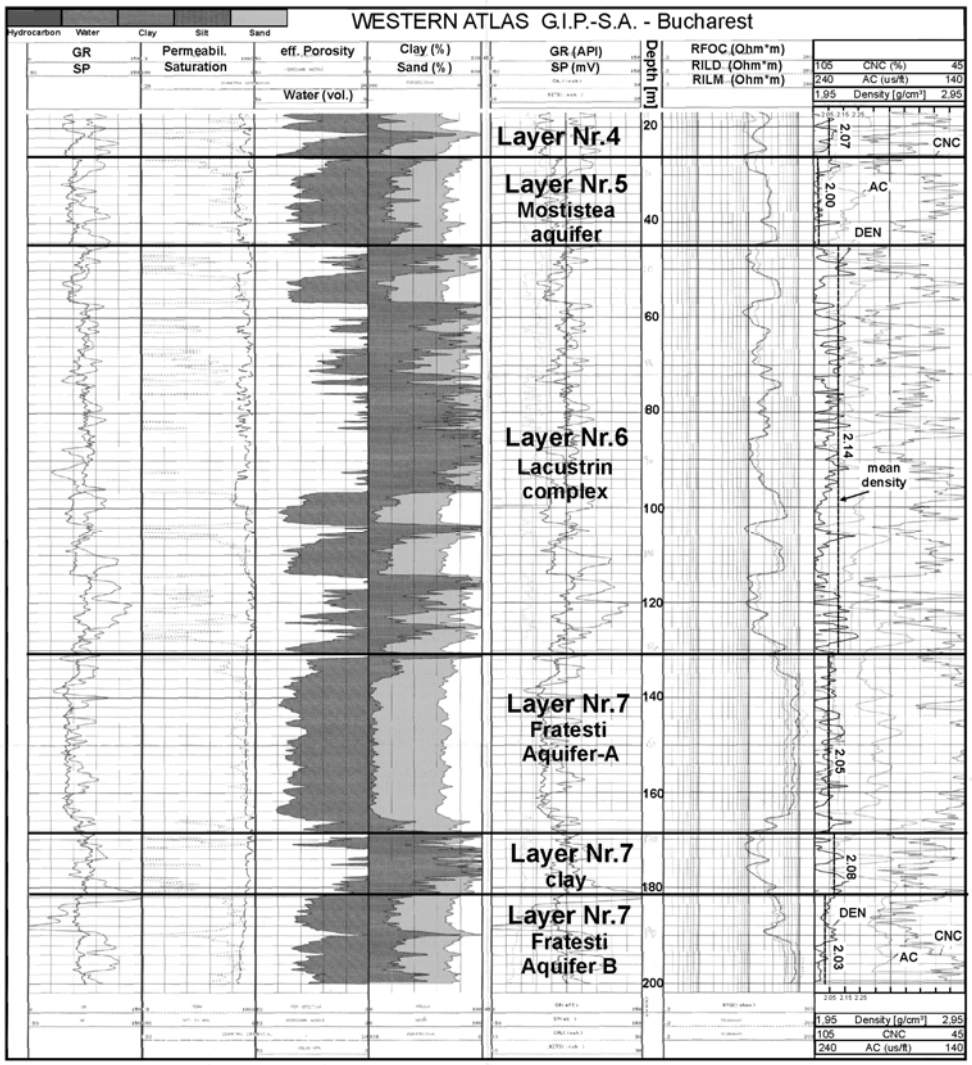

Fig. 9 – Complex geophysical borehole logging data, executed in 1998 in the INCERC2-200 m borehole. The most important results obtained by the interpretation of the measured geophysical loggings show the clay and sand content of the layers, the water saturation and the mean density. From these results the delimitation of the main Quaternary layers was possible. The measurements could be executed only from a depth of about 20 m downwards, that means for the layers 4–7.

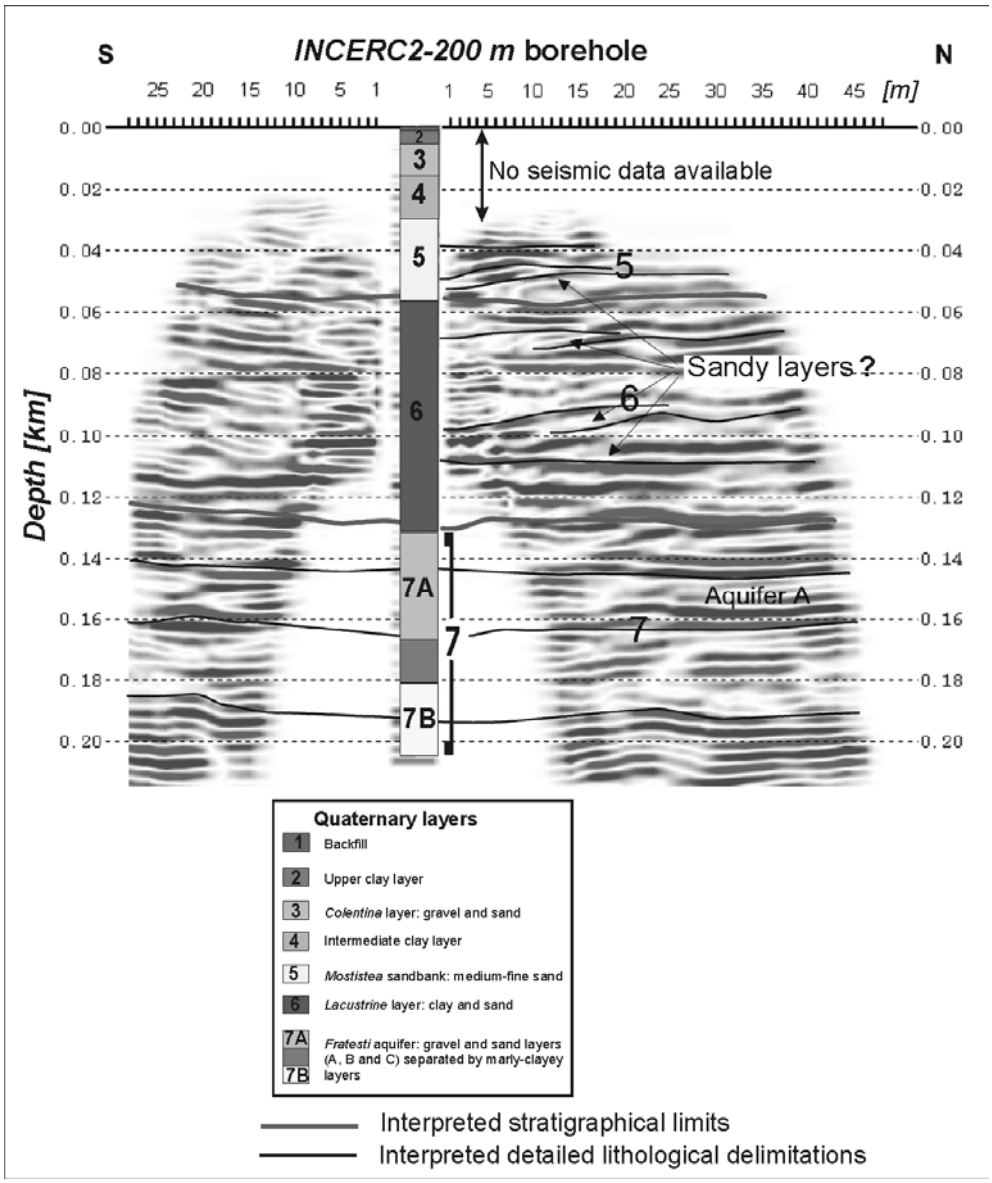

Fig. 10 – Detailed view of the variable density plot for the INCERC2-200 m borehole, obtained by processing and interpretation of the MOVSP-data. Lithological limits interpreted from the variable density plot correspond relatively well with the limits of the seven main Quaternary layers intercepted in the borehole (after Orlowski *et al.* [9]).

Table 6

Complete list with averaged v_s-values and averaged densities for the 7 main Quaternary layers in Bucharest. For the layers 1 – 3, v_s-data from previous authors/methods were used

Geologic layer No.		Depth of the upper limit of the layer [m]	Averaged density [g/cm³]	Averaged v_s [m/s]
1	Backfill	0	1.10	135
2	Upper clay layer	0.50 – 5.00	1.75	305
3	*Colentina* aquifer	5.00 – 12.00	1.99	335
4	Intermediate clay layer	10.00 – 20.00	2.07	378
5	*Mostistea* aquifer	15.00 – 30.00	2.00	400
6	Lacustrine layer	35.00 – 50.00	2.14	442
7	*Fratesti* aquifer A	100.00 – 180.00	2.05	500

5. GEOLOGICAL INTERPRETATION OF THE CDP-SECTIONS AS VARIABLE DENSITY PLOTS OBTAINED BY MOVSP

The resulting CDP-sections for each borehole were represented as variable density-plots. The lithology of each borehole being known, a geologic interpretation of the obtained density-plot was carried out. The interpretation procedure comprehends the attribution of characteristic of reflection-amplitudes to representative geological/stratigrafical limits in the borehole, respectively around the borehole. It is a difficult procedure, because the different geologic layers could not be clear identified at the density plots of the different boreholes. Phase-displacements and –changes in the density plots had not permitted a detailed lithological interpretation and separation of the different sedimentary layers. As characteristic amplitude signals in the density plots are considered weak amplitudes with discontinuous lateral extension characteristics for sandy layers/aquifers. In Fig. 9 the interpreted variable density-plot, obtained for the INCERC2 - 200 m borehole, is presented. Good correlations with the layer 5 (the Mostistea sandbanks respectively the Mostistea aquifer), with the layer 6 (the Lacustrian layer) and the layer 7 (the A-layer of the Fratesti complex) could be obtained. For the near-surface layers 1-4, only pour or not relevant elements could be distinguished in the density plot.

6. CONCLUSIONS

For Bucharest, with a high seismic risk potential and in the same time with a complicated geological and hydrogeological background, it was necessary to know in detail the soil parameters. These are used further for the evaluation of soil response analyses and for seismic hazard, vulnerability and risk analysis at earthquakes. For the evaluation of ground response to earthquakes by linear

modeling calculations, the main soil parameter – the shear-wave velocity v_s of the different geologic layers, together with their density must be well known. Within the CRC-461 it was recognized the necessity to dispose of detailed v_s-values for the Quaternary layers in Bucharest. The measurements of shear-wave velocities initiated in 2002 in eight boreholes in Bucharest, were the first area-wide measuring campaign of this kind.

In the present paper the determination of shear-wave velocities for different depth intervals by Multi-Offset Vertical Seismic Profiling (MOVSP) was described. Further, the deduction of averaged v_s-values for the Quaternary layers in Bucharest is presented. The MOVSP-method could not deliver v_s-values for the upper 20 m of depth due to technical limitations. Finally, completed with previous to 2002 existing shear-wave velocity and density data, a complete velocity/density model for the near surface geologic underground of Bucharest was elaborated. In 2006, within the same CRC-461, v_s-values for the near-surface Quaternary layers 1-3 by Seismic Cone Penetration Tests were deduced. Also several other shear-wave velocity measurements, within Romanian projects and within a NATO-SfP-project were executed. Thus, today a well-documented database with v_s-values is disposable.

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