NEW URBAN GEOLOGY INFORMATION USING GEOTECHNICAL TESTS DATA FOR THE IMPROVEMENT OF MICROZONATION STUDIES IN BUCHAREST CITY AREA

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S.F. Balan (1), B.F. Apostol (1), C.O. Cioflan (1), J.R.R. Ritter (2)

(1) National Institute for Earth Physics, Bucharest-Magurele, Romania, sbalan@infp.ro

(2) Karlsruhe Institute of Technology, Germany

INTRODUCTION

Bucharest, the capital of Romania, with almost 2.8 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 (Dilley et al., 2005). Four major earthquakes with moment-magnitudes between 6.9 and 7.7 hit Bucharest in the last 65 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 earthquakes are generated within a small epicentral area the Vrancea region - about 150 km north of Bucharest. Thick unconsolidated sedimentary layers in the area of Bucharest amplify the arriving seismic shear-waves causing severe destruction. Thus, disaster prevention and mitigation of earthquake effects is an issue of highest priority for Bucharest and its population.

Ten boreholes were drilled in the city and were started the dynamic tests at the soils and rocks of the drilling cores.

THE BOREHOLE SITES

The boreholes with a depth of 50 m in the metropolitan area of Bucharest were drilled in order to obtain the necessary data for a new and modern map with site effects related to earthquake wave amplification. The boreholes are placed near URS stations (Urban Seismology project 2003/2004, Ritter et al., 2005) or K2 stations (a strong-motion recording network) of the National Institute for Earth Physics, Bucharest (NIEP) to allow a direct comparison and calibration of borehole data with actual seismic measurements. Six of the ten boreholes are placed like that, two boreholes are placed in the proximity of K2 stations of NIEP. The positions of the ten proposed boreholes are also chosen in order to fill information gaps in the central part of Bucharest.

The boreholes were drilled by a third party according to the project plan .

Careful selection of the boreholes sites according to the proposed plan and also according to the real situation - in this case being an area of a very populated and rapidly changing city. Two borehole sites were chosen in public places, belonging to the City Hall ("Titan 2" Park and "Tineretului" Park). Other two places are situated at private places - at the Ecologic University, near Dambovita River, and the Astronomic Institute of Romania, near the Carol Park. Thus all four sites are situated inside the central part of Bucharest and fully agree to the aims of the project. All the 10 boreholes designed to be drilled in Bucharest City in the frame of the NATO SFP Project 981882 are presented in Figure 1.

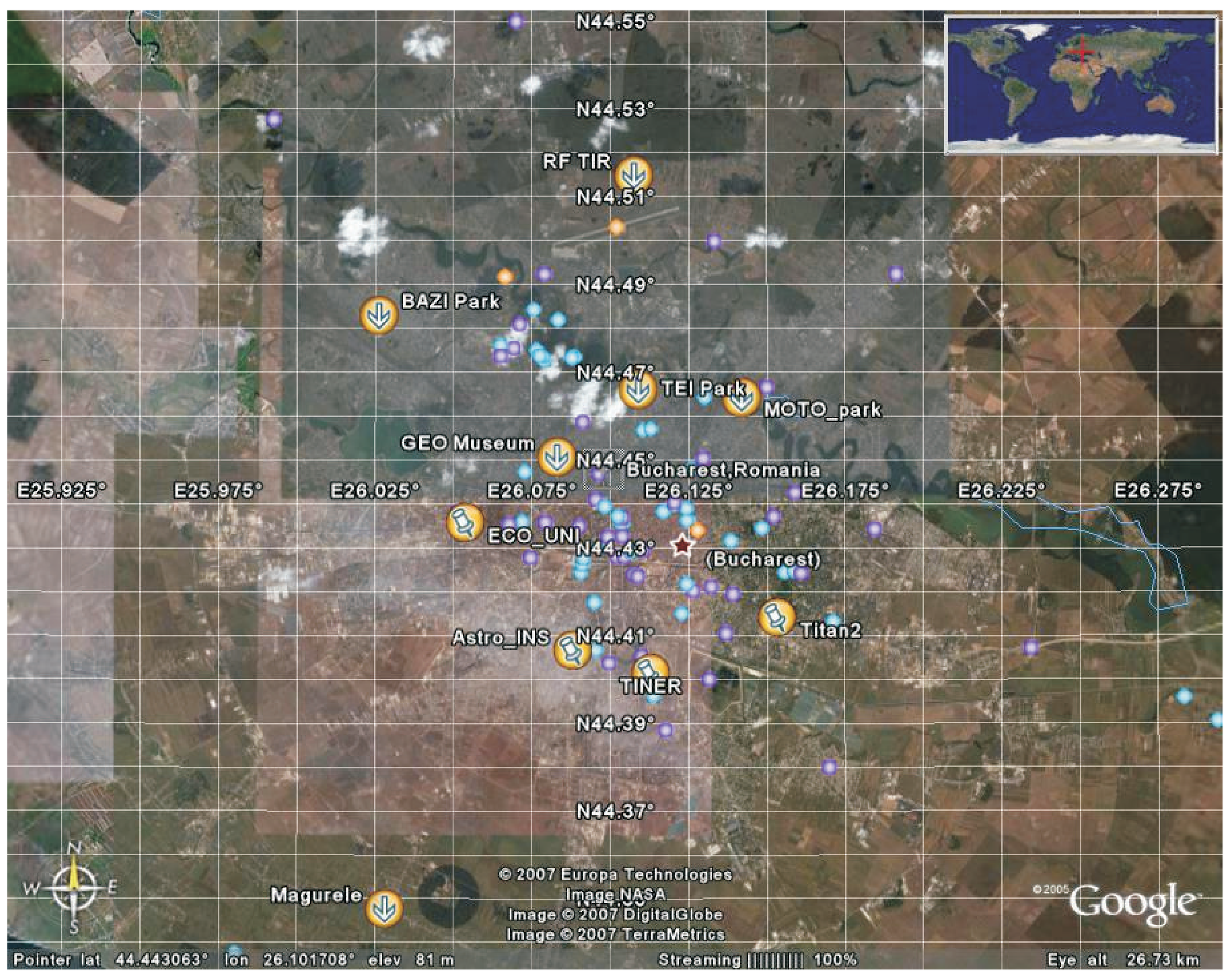

Fig. 1: Map of the Bucharest City area with location of the 10 boreholes.

Operation	Number	Objective
Drilling	4 boreholes	Drilling and Probing Operations
Resonant column tests	28	Dynamical parameters for linear and non-linear modeling
Triaxial tests (dynamical, undrained); edometric tests, maximum and minimum compactness	6	Dynamical and mechanic parameters
Granulometry	30	Standard geotechnical experiment
Maximum and minimum compactness	6	Standard geotechnical experiment
Determination of e_min and e_max	4	Standard geotechnical experiment
Determination of liquid and plastic limit	4	Standard geotechnical experiment

Table 1: Geotechnical operations for 4 sites.

A number of 250 **soil and rock samples** were gathered from the 10 drill sites by the department of Engineering Seismology. These samples were carefully selected without disturbances (sampling as it was recovered from the tube of the drilling machine) and partly disturbed (soil samples which had no proper consistency). See Figure 2.

Fig 2: Recovered drill samples in field box. Directly after the recover from the borehole the samples were wrapped carefully in plastic foil to avoid dehydration and send to the laboratory for Geotechnical testing.

Laboratory tests with samples from the drillings

Dynamic triaxial tests for the determination of the deformability properties of the geomaterial from the boreholes was done in accordance international specifications, e.g. with the Romanian standard P125 84 "The Determination of Shear Resistance of Soils under Cyclic Dynamic Load through Cyclic Compression Tests", but also the restrictive Japanese norm: "Standards of Japanese Geotechnical Society for Laboratory Shear Tests JGS 0542-2000 Method for Cyclic Triaxial Test to Determine Deformation Properties of Geomaterials".

The triaxial apparatus used is the model : DTC 367 (Seiken Inc. Japan), see Fig. 3.

Test procedure

A sample is first consolidated and than an initial stress is applied. The axial load is build up with a pneumatic actuator and the shear cycles are applied to the sample with a very small amplitude. The points obtained at the end of each cycle of loading are represented graphically in the stressstrain diagram.

The axial load is measured continuously with a precision of ± 1 % of the double amplitude of the axial load. In the phases of cyclic loading in which (åq)SA is smaller than 0.1%, axial deformation of the sample is measured with gap sensors installed in the triaxial cell. During the experiment the acquisition system monitors all parameters: axial cyclic loading, axial cyclic deformation, water pore pressure.

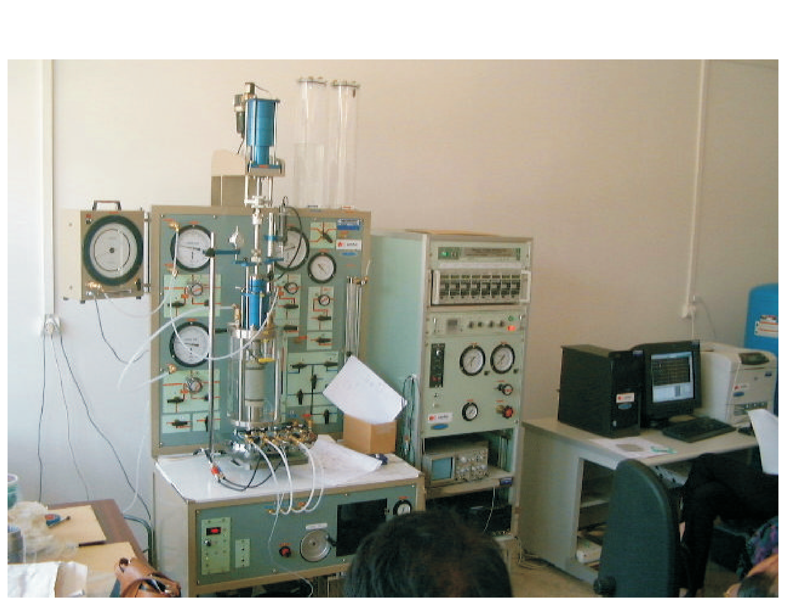

Fig. 3: Triaxial apparatus for borehole sample examinations

GEOTECHNICAL LABORATORY TESTS

Depth (m)	m (g)	m_d (g)	w (%)	w_{medium} (%)	Observations
3.0÷3.5	Without humidity				Sandy clay, red brown
					sandy clay
					16/26/48/6/2/2
					2.7, 10
3.5÷4.0	30.87	23.64	30.58	31	Crey clay, with grey dots, with red insertin
	35.91	27.70	29.64		clay
	31.59	24.21	30.48		34/36/20/6/2/2
	33.34	25.60	30.23		2.72, 28
	147.27	112.65	30.73		Edometric test
4.0÷4.5	30.45	23.28	30.80	31	Brown clay, with brown dots, and red insertion, plastic soft
	31.78	24.36	30.46		clay
	33.03	25.34	30.35		34/44/22/0/0/0
	37.14	28.42	30.68		2.72, 22
	147.26	113.52	29.72		Edometric test
7.0÷8.5	Without humidity				Big sand yellow grey, a little dusty
					dusty sand
					0/14/4/22/58/2
					2.65, -
5.0÷37.0	Without humidity				Gravel in clay mixture, medium size
					dusty sand
					0/12/4/4/4/76
					2.65, -

Legend for Table 2:
Identification of sample in the laboratory
Identificaton of sample after Ternary Diagram
Procent, % Clay/Dust/Fine sand/Medium sand/Big sand/Gravel
Density mineral skeleton
Particle percent with d<2μm

Table 2: Borehole location Parcul Tineretului

Laboratory Test Results

For the triaxial tests were used samples from cohesive soils (undisturbed samples) and from uncohesive soils (disturbed soils) as given in the following Table 3.

Borehole location	Depth of the samples (m)	Nature of soils	Diametre of the sample (cm)	Height of the sample (cm)	Weight of the sample in natural mode (g)	Weight of the sample in dry mode (g)	Volume of the sample (cm^3)	Density of the sample in natural mode (g/cm^3)	Density of the sample in dry mode (g/cm^3)	Humidity (%)
Institutul Astronomic	28.50	Grey compact fat clay	4.98	10.00	402.63	348.71	194.68 3	2.068	1.791	15.46
Parcul Titan	39.00	Grey sandy clay with iron oxides	4.99	10.00	398.65	355.39	195.46 6	2.039	1.818	12.17
Universitatea Ecologica	30.00	Grey compact fat clay with high plasticity and lenses of fine grey sand	5.00	10.00	417.40	358.64	196.25 0	2.127	1.827	16.38
Institutul Astronomic	43.00	White-grey fat, compact clay with irony spots	5.02	10.00	413.19	356.93	197.82 3	2.089	1.804	15.76
Parcul Tineretului	37.00	Fine medium gry sand	5.06	9.90	-	318.38	198.97 8	-	1.600	-
Universitatea Ecologica	48.00	Fine grey clay sand with intercalations of small gravel	5.00	9.96	-	321.01	195.46 5	-	1.642	-

Table 3

Geotechnical Laboratory Test Results

Sample	1.1	1.2	3.1	3.2	4.1
$\%<2\mu m$	28	22	31	29	4
w	31	31	19	19	7
wp	22	20	17	17	15
wL	62	51	45	47	25
Ip	40	31	28	30	10
Ic	0.78	0.65	0.93	0.93	1.80
I_A	1.43	1.41	0.90	1.03	2.50

Legend for the Table 4 :

w_L	Flow limit
wp	Kneading limit
Ip	Plasticity index
I_C	Consistency index
I_A	Activity index
1.	borehole: Parcul Tineretului
1.1.	P2 3.5÷4.0m
1.2.	P3 4.0÷4.5m
2.	borehole: Parcul Titan

Table 4: Plastic limit determination.

Sample	1.1	1.2	2.1	3.1	3.2	3.3	4.1
$M_{0.5-1}$=	4545	3333	9091	25000	10000	16667	1515
M_{1-2}=	5263	3774	11111	25000	12500	18182	2632
M_{2-3} =	5556	5882	11111	15385	15385	16667	4255
ε_2 =	4.10	5.40	2.10	0.75	2.10	1.15	9.90
a_v=	3.347E-04	3.136E-04	1.409E-04	1.046E-04	1.036E-04	1.013E-04	3.549E-04
γ =	19.1	19.1	19.9	19.9	20.3	19.6	19.0
n=	46	46	36	38	37	41	34
e=	0.86	0.84	0.57	0.61	0.59	0.69	0.51
S_r=	0.98	0.97	0.76	0.80	0.87	0.87	0.37

Legend for the Table 5 :

$M_{0.5÷1}$	Edometric modulus in the range of pressure of : 50÷100kPa, in kPa
$M_{1÷2}$	Edometric modulus in the range of pressure 100÷200kPa, in kPa
$M_{2÷3}$	Edometric modulus in the range of pressure 200÷300kPa, in kPa
	Specific deformation for the pressure stage of 200kPa, in %
a_v	Volumic compresibility coeficient , in kPa^{-1}
n	Porosity, in %
e	Pore index, adimensional
S_r	Saturation range, in %

1. borehole: Parcul Tineretului
1.1. P2 3.5÷4.0m
1.2. P3 4.0÷4.5m
2. borehole : Parcul Titan
2.1. P14 12.5÷13.0
3. borehole: Institutul Astronomic
3.1. P4 3.0÷3.50m
3.2. P5 5.0÷5.5m
3.3. P42 47.0÷48.0m
4. borehole: Universitatea Ecologicaă
4.1 P5 4.5÷7.5m

Table 5: Tests of compression - settling

After a through examination of the database 56 samples were chosen from representative geological layers for tests in the resonant column. One sample was chosen from a soil layer. The Drnevich resonant column is used for the experimental determination of the dynamic soil response at harmonic oscillations, through soliciting a cylindrical sample with harmonic stationary vibrations, torsional and/or longitudinal in resonance mode. In our case the torsional mode is applied.

A picture of the used Drnevich instrument at NIEP is displayed in Fig. 4. The soil and rock samples which are tested in the resonant columns are cylindrical of the following dimensions: diameter 3.57 (7.11) cm and height of 8 (14.2) cm. The lower base of the sample is fixed, and upon the top of the sample an electromagnetic vibration unit is placed. This assembly (sample vibrator) is installed in a plastic translucid high resistance cell, in which hydrostatic pressure with air, oil or water is produced. The value of this pressure is chosen to be equivalent with the in situ sample pressure.

The resonant column tests are very time consuming: On average one sample to be tested takes 2 days (the first day for mounting the apparatus, than the consolidation period, which varies with the depth (pressure) - a couple of hours to 3 days - , than the test itself as described above, and finally the dismounting of thesample and cleaning the apparatus.

An example of resonant column test on a sample from the site "Parcul Tineretului" can be seen in Fig. 5.

Fig. 4. Drnevich resonant column at the Department of Engineering Seismology, NIEP

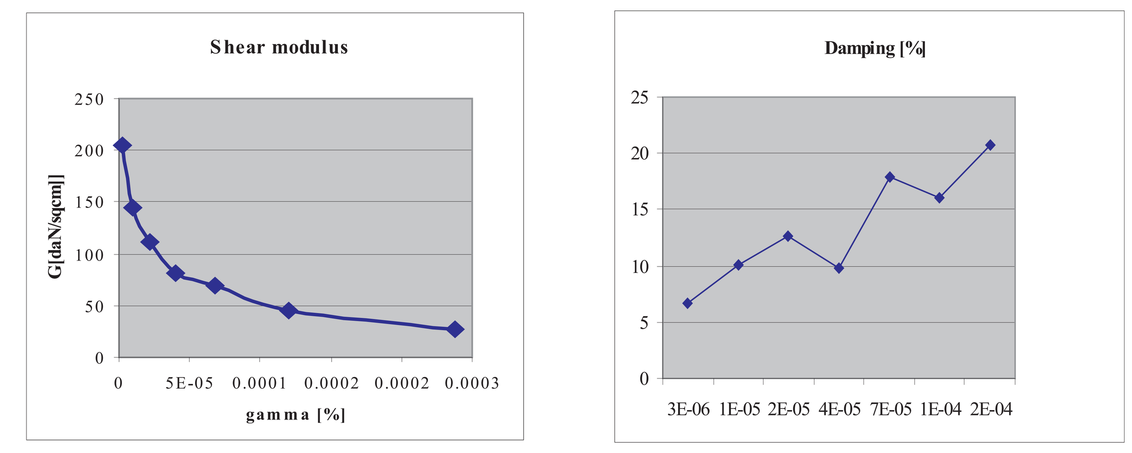

Fig. 5: Shear modulus and damping for sample (sandy-clay) from Parcul Tineretului.

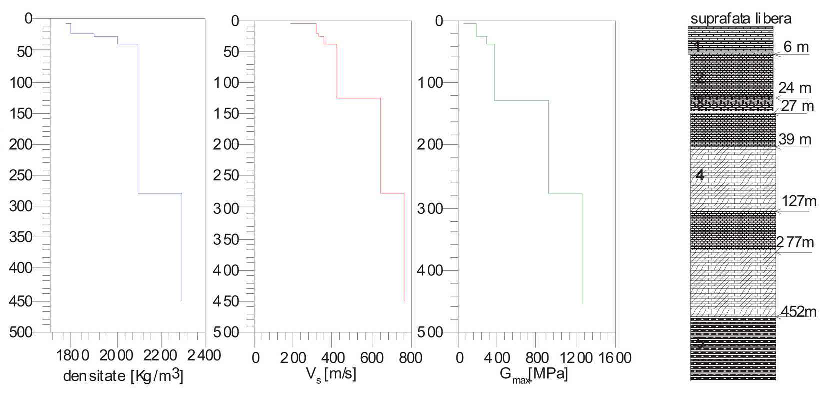

Fig. 6: Characteristics of the local soils

The local structure shown in Fig. 6 is compiled from all the available data on N-E part of Bucharest. For the local soils we considered G=G() şi D=D() curves (Fig. 7), which were experimentally determined in laboratory by Drnevich resonant column tests

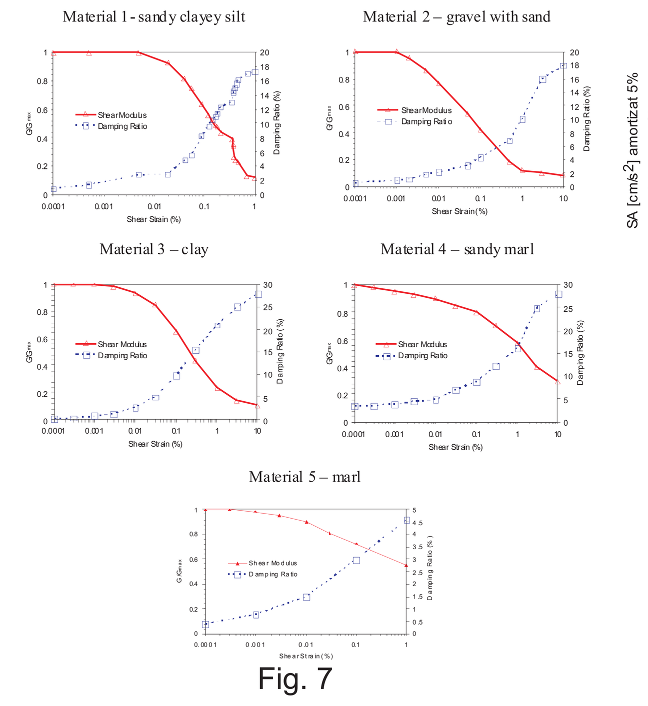

Fig. 7

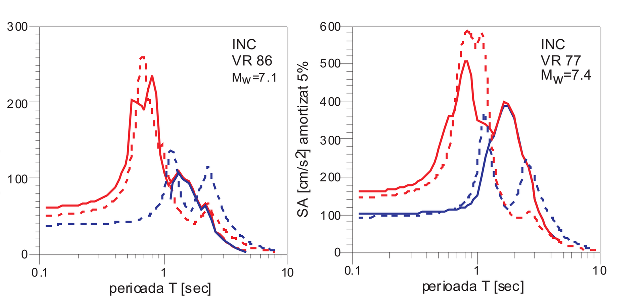

Fig. 8

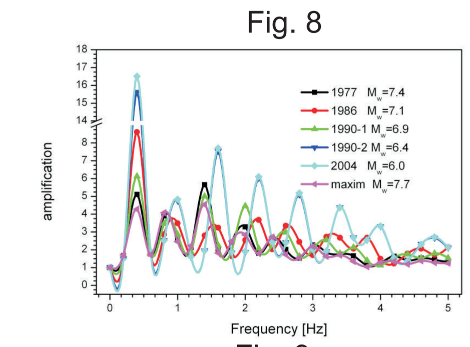

Fig. 9

In Fig. 8 are presented response spectra with 5% damping computed for the seismic station site INC for the strongest recorded events (blue: 0.05-1Hz domain; red: 0.1-2 Hz domain). Continuous line represents transversal recorded spectra and 1 Hz low-pass filtered (blue) and 2 Hz low-pass filtered (red).

The same method was further used to evaluate the seismic response of these local structure for 5 real earthquakes with magnitude between 6 (2004, Oct.27) and 7.4 (1977, March 4) and one hypothetic event," the maximum possible earthquake", with magnitude Mw=7.7. Input motion usually used is represented by strong earthquakes accelerograms previously recorded or synthetically generated. In this approach synthetic accelerograms obtained by modal summation (ref. 1,2) are used.

The local effects described in terms of amplification spectra are represented in Fig. 9. It can be observed that seismic excitation produces strong amplifications in the considered local structure, especially for "small" magnitude earthquakes: Mw=6.0 (2004, Oct. 27), respectively Mw=6.4 (1990,May 31-denoted 1990-2); for strong earthquakes (denoted 1997,1986, maxim), the transfer functions representing the seismic movement amplifications decrease as magnitude increase.

CONCLUSIONS AND RESULTS

The values of the mean weighted seismic velocities computed in the present study are within a narrow range as others obtained by seismic in situ measurements. These tests suggest that near-surface material has the tendency to amplify earthquakes waves. This means that the near-surface layer and its anelastic properties are crucial for understanding the seismic hazard imposed to Bucharest City.

The elastic and dynamic parameters from geotechnical measurements at samples from the near surface layers were added to the already existed database. The data are to be used for further studies on the seismic microzonation of Bucharest City using the equivalent linear approach and will contribute directly to an improvement of the seismic hazard evaluation in the city area and to a better understanding of the links between the geological characteristics of each layer, the geotechnical parameters and development of future ground motion scenarios.

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