STUDIES OF URBAN SEISMOLOGY IN BUCHAREST

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Etudes de séismologie urbaine en Bucarest. Un projet de forage avec récupération des carottes s'est déroulé à Bucarest, Roumanie. En obtenant les paramètres géotechniques des carottes prélevées des dix sites répandus dans divers emplacements en Bucarest, couvrant des zones où ces paramètres étaient inconnus auparavant, sera très utile pour développer et optimiser la microzonation de la région métropolitaine de Bucarest, pour un design à risques réduits et pour l'amélioration des efforts d'atténuer le risque.

Key words: engineering seismology, boreholes, geotechnical parameters, Bucharest, Romania.

1. INTRODUCTION

Bucharest, the capital of Romania, with about two 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 Columbia University (Dilley *et al.*, 2005). All disastrous earthquakes are generated within a small epicenter area – the Vrancea region – about 150 km north-east of Bucharest. The seismic focal zone in Vrancea is located approximately at 45.7^0N latitude and 26.6^0E longitude. This focal zone is the source of a noteworthy seismic activity, ranging in depth from ~80 km to ~200 km. Four major earthquakes with moment-magnitudes between 6.9 and 7.7 hit Bucharest in the last 65 years (Romanian Earthquake Catalogue, 2005). The most recent destructive earthquake of 4th March 1977, with a moment magnitude of 7.4, caused about 1,500 casualties in the capital alone. 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.

2. DATA RECORDING AND DRILLING PROGRAMME

All the researches and studies in engineering seismology done in the city of Bucharest because they refer only to the city are gathered under the generic name of "urban seismology". Typically, seismological stations are installed at remote and low-noise sites to achieve a high signal-to-noise ratio for seismic phases. Thus, high quality seismological data from major cities with vigorous human activity are mostly not available. Generally, any triggered strong-motion equipment is used for seismic monitoring. Relatively few data are available to study the characteristics of urban seismic records, which may be further strongly influenced by the effects of the shallow geologic subsurface and the building themselves (Wirgin, Bard, 1996; Boutin, Roussillon, 2004).

A broadband seismic network was installed in the metropolitan area of Bucharest to record the natural and cultural microseismicity as well as earthquake and explosion related seismic waves. These data will allow us to study a wide range of issues, such as the nature of urban noise, the local structure and the structure of distant regions using array techniques. Exploring the horizontal to vertical (H/V) spectra and

spectral ratios with respect to a reference site further allows us to investigate variations of the local amplification factor in the city.

Continuous recordings at 32 sites with broadband sensors, sampling rate 50 Hz, 3 channels (Fig. 1) were performed during a period of ten months. The aim is to measure seismological broadband waveforms in the city area of Bucharest. These data are the basis to verify predicted site amplification effects as well as other research topics. Several seismic recording stations from different institutions are running in the Bucharest area. There are also numerous shallow boreholes from different institutions which were used to map the subsurface lithology. However, there are only 16 boreholes which were partly geotechnical investigated to relate the local geology with seismic wave propagation properties (especially amplitude-amplification properties). Therefore, a NATO Science for Peace project (SfP 981882) was initiated to obtain a unique, homogeneous dataset of soil-mechanic and elasto-dynamic parameters of the subsurface of Bucharest. Within this project 10 new, 50 m deep, boreholes were drilled to recover cores for geotechnical laboratory measurements and to measure *in situ* seismic velocities. These parameters are the input information to model the so-called seismic site responses. In a second step, as aim of further investigations, these modelled site responses will be compared to already available observed site responses (measured seismograms) to derive the relationship between the measured subsurface soil/rock properties and the observed seismic amplitudes. Then, this calibrated relationship can be applied to other available borehole lithologies in the metropolitan area of Bucharest. Thus, in the end this research programme will help to develop an optimised seismic microzonation of the metropolitan area of Bucharest which will be implemented for the future urban planning. In this contribution we report about the geotechnical measurements that are later used for linear and non-linear wave propagation simulations.

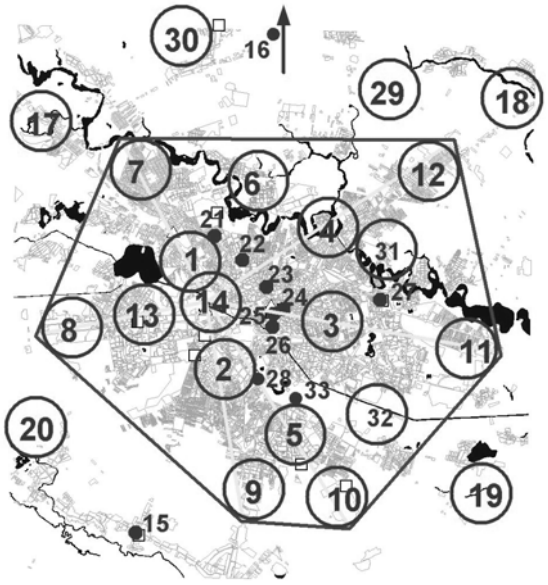

Fig. 1 – URS sites in Bucharest.

According to the proposed plan of the project, ten new boreholes with a depth of 50 m were drilled in the metropolitan area of Bucharest in order to obtain the necessary data for a new and modern map with site effects related to earthquake wave amplification. The boreholes (Fig. 2) 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. The positions of the ten boreholes were also chosen in order to fill geophysical and geotechnical information gaps in the metropolitan part of Bucharest.

Four boreholes were drilled in Spring, 2006. These boreholes are in the following locations: Titan 2 Park, Tineretului Park, Ecologic University (near Dâmbovița River) and the Astronomic Institute of Romania (near the Carol Park). In 2007 another six boreholes were drilled at the following sites: Motodrom Park, Tei Park, Bazilescu Park, Romanian Sport Shooting Federation, Geological Museum (Victory Place – central Bucharest) and the last one in southern part of the city, at the National Institute of Earth Physics (NIEP), in Măgurele.

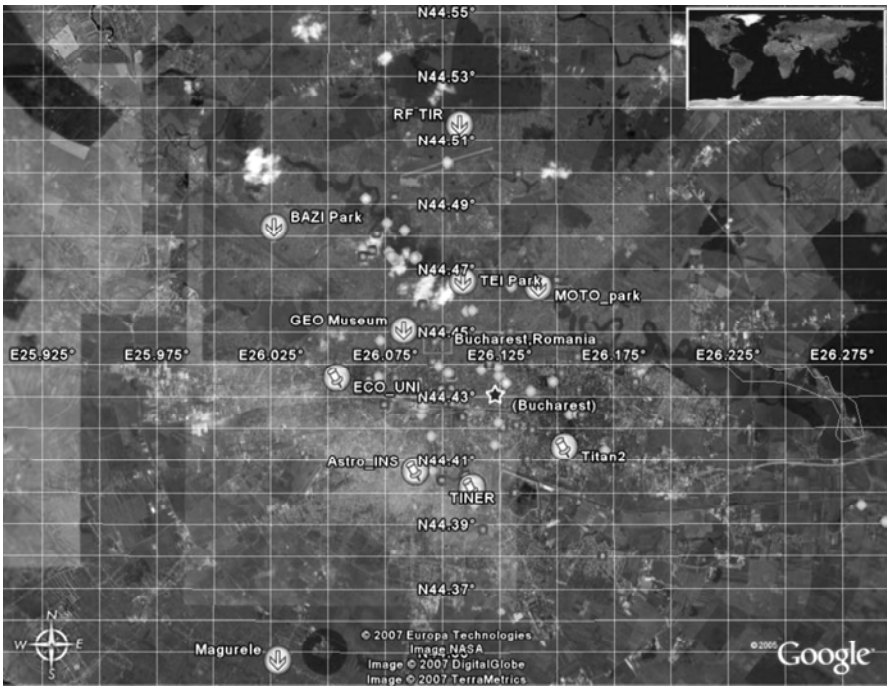

Fig. 2 – Map of the Bucharest city area with location of the 10 boreholes.

3. GEOTECHNICAL AND SEISMOLOGICAL INVESTIGATIONS

A total number of 250 soil and rock samples were gathered from the 10 drill sites at different depths by the department of Engineering Seismology (NIEP). These samples were carefully selected mainly without disturbances (sampling as it was recovered from the tube of the drilling machine) and partly disturbed (soil samples which had no proper consistency). With the data from these samples we created a data base, which contains the following parameters: drill location, GPS drill coordinates, date of recover, depth of the samples, a short geological and mechanical characterisation of each sample.

A large number of soil tests were done on the samples as: resonant column tests, triaxial tests (dynamical, undrained), CU triaxial test, edometric tests, angle of response, granulometry, maximum and minimum compactness, determination of e_{min} and e_{max} determination of liquid and plastic limit. All these experiments bring new geotechnical data about these sites.

In Table 1 all the geotechnical experiments performed with the samples from the ten sites are summarised.

Seismological investigations were performed using all the seismic events recorded during the URS experiment with magnitudes M_W between 3.5 and 4.5. The spectral ratios are computed for each seismic station. In Fig. 3 are exemplified these spectral ratio for four URS station, denoted by the name of the station, for the seismic events and noise. The spectral ratio curve is period-dependent. The dashed lines are

the root mean square (rms) of the H/V ratio. The average shear wave velocity for the layers above Frăteşti has values between 340 m/s (in the South-East) and 390 m/s in the north-western part of the city. Due to this velocity structure dangerous amplifications in the long period range could be expected in this city area in case of strong Vrancea earthquakes.

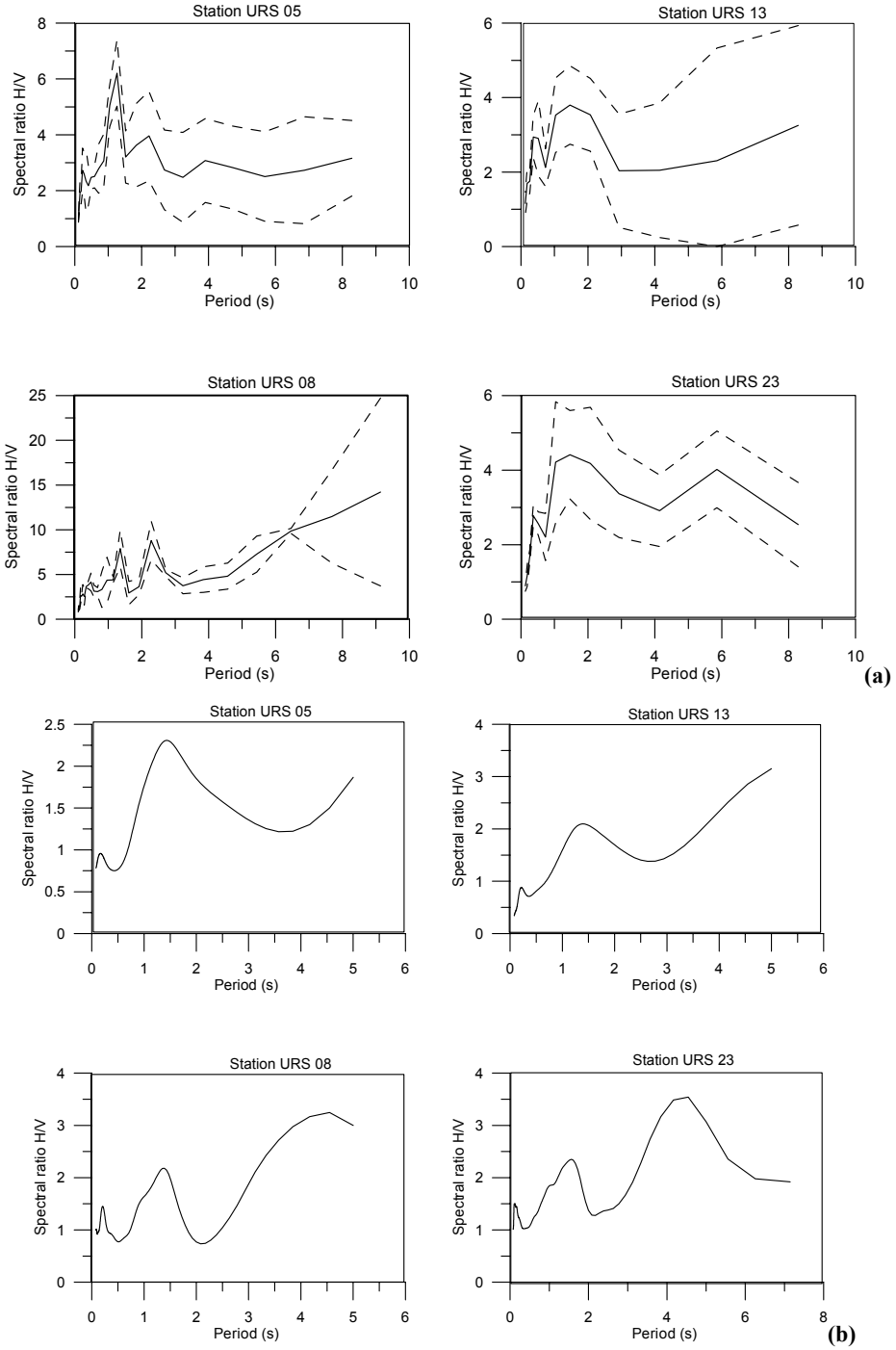

Fig. 3 – The spectral ratios H/V computed for the URS05, URS08, URS13 and URS23 seismic stations: (a) for seismic events and (b) for noise.

Table 1

Geotechnical experiments conducted with the recovered core samples

Operation	No.	Objective
Drilling of 50 m deep boreholes	10	Drilling and Probing Operations
Resonant column tests	58	Dynamical parameters for linear and non-linear modelling of wave propagation
Triaxial tests (dynamical, undrained)	15	Dynamical and mechanic parameters
CU Triaxial test	12	Standard geotechnical experiment
Edometric tests	19	Standard geotechnical experiment
Angle of repose	7	Standard geotechnical experiment
Granulometry	54	Standard geotechnical experiment
Maximum and minimum compactness	6	Standard geotechnical experiment
Determination of e_{min} and e_{max}	12	Standard geotechnical experiment
Determination of liquid and plastic limit	4	Standard geotechnical experiment

4. DISCUSSIONS AND CONCLUSIONS

By obtaining the geotechnical parameters of the core samples for these ten sites situated in different locations in the Bucharest area, we cover zones where these parameters were not known before and this makes it unique and of great importance for the new comprehensive data banks acquired during the project. The geotechnical data vary with the different location of sites in the city, but have the general characteristics of Bucharest geotechnical parameters. This data acquisition is part of a comprehensive project where also geophysical and geological data were gathered.

Through obtaining the geotechnical parameters from the drills, we have tried to bring a contribution to the seismic microzonation of the metropolitan area of Bucharest, for a safer seismic design and for the improvement of risk mitigation efforts. The spectral ratios obtained for the above mentioned locations confirm the correlation of the periods of H/V peaks – from medium seismicity and noise – to fundamental period of the soils from the drills.

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