Microzonation of Bucharest, Romania, is a very important task for all scientists involved in seismic risk mitigation. The microzonation map is improving each year because of new data collected from such a vast area as the metropolis of Bucharest. In the framework of the NATO Science for Peace Project 981882 “Site-effect analyses for the earthquake-endangered metropolis Bucharest, Romania” we add new high-quality data from up to 10 boreholes (50 m deep) spread around the city at sites of special interest. It is a complex project, focusing on the measurement of basic geophysical and geotechnical data for a multi-disciplinary program for soil response analyses. In this contribution the geotechnical laboratory tests (resonant column, dynamic triaxial, standard geotechnical tests) for the first 4 boreholes of 2006 campaign are briefly outlined.

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 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 4th 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.

As a major scientific aim we want to develop calibrated seismic response laws which can be used to describe the seismic wave amplification in Bucharest. Several seismological stations from different institutions are running in the Bucharest area to record seismic waves. 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 geotechnically investigated to relate the local geology with seismic wave propagation properties (especially amplitude-amplification properties). Therefore, the main purpose of this project is to obtain a unique, homogeneous dataset of soil-mechanic and elasto-dynamic parameters of the subsurface of Bucharest from up to 10 new boreholes to model the so-called seismic site responses. In a second step these site responses will be compared to observed site responses (measured seismograms) to find a relationship between the measured subsurface 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. In the end, this research programme will help to develop an improved seismic microzonation of the metropolitan area of Bucharest which will be implemented for future urban planning. In 2006 we successfully drilled the first four boreholes in the city and started.
the dynamic tests at the soils and rocks of the drilling cores. Presently this work continues for the remaining boreholes.

![Map of the greater Bucharest area with locations of boreholes and seismic stations. The proposed 8 boreholes (black crosses) are at sites with seismic stations (triangles) and fill gaps between existing boreholes with geotechnical data (filled circles) (modified from proposal to NATO by Balan, Ritter, Bala and Rohn, 2005).](image-url)

Figure 1. Map of the greater Bucharest area with locations of boreholes and seismic stations. The proposed 8 boreholes (black crosses) are at sites with seismic stations (triangles) and fill gaps between existing boreholes with geotechnical data (filled circles) (modified from proposal to NATO by Balan, Ritter, Bala and Rohn, 2005).
THE BOREHOLES AND THEIR SITES

According to the proposed project plan eight new boreholes with a depth of 50 m were to be drilled in the metropolitan area of Bucharest (Fig. 1) in order to obtain the necessary data for a new and modern map with site effects related to earthquake wave amplification. However, due to successful negotiations up to ten boreholes can be realised. The boreholes are placed near URS stations (Urban Seismology project 2003/2004, Ritter et al., 2005; Balan et al., this volume) 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 eight proposed boreholes are also chosen in order to fill information gaps in the central part of Bucharest.

In February and March 2006 careful selection of the 4 boreholes sites was conducted 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. Finally, 2 borehole sites were chosen in public places, belonging to the City Hall (“Titan 2” Park and “Tineretului” Park). The other two places were situated on private land 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. In the 2007 the remaining sites are selected.

GEOTECNICAL LABORATORY TESTS

Altogether 177 soil and rock samples were gathered from the 4 sites by the Department of Engineering Seismology at NIEP in 2006. Most samples were carefully recovered without disturbances (sampling from the tube of the drilling device) and some samples were partly disturbed (soil samples without proper consistency). Additionally, seismic measurements were conducted in the boreholes (Bala et al., this volume).

Table 1. Overview on geotechnical studies with core samples from 4 boreholes in 2006.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Number</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling of boreholes</td>
<td>4</td>
<td>Probing of in situ material</td>
</tr>
<tr>
<td>Conduction of resonant column tests</td>
<td>28</td>
<td>Dynamic parameters for linear and non-linear modelling</td>
</tr>
<tr>
<td>Conduction of triaxial tests (dynamical, undrained)</td>
<td>6</td>
<td>Dynamic and mechanic parameters</td>
</tr>
<tr>
<td>Granulometry</td>
<td>30</td>
<td>Standard geotechnical experiment</td>
</tr>
<tr>
<td>Determination of maximum and minimum compactness</td>
<td>6</td>
<td>Standard geotechnical experiment</td>
</tr>
<tr>
<td>Determination of e_min and e_max</td>
<td>4</td>
<td>Standard geotechnical experiment</td>
</tr>
<tr>
<td>Determination of liquid and plastic limit</td>
<td>4</td>
<td>Standard geotechnical experiment</td>
</tr>
</tbody>
</table>

These rock and soil samples we included in a database which contains the following parameters:
- borehole location,
- GPS coordinates,
- date of recover,
- geological and mechanical characterisation of each sample.
After a thorough examination of the database 28 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 at NIEP 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 resonance modes. In our case the torsional mode is applied. These tests were done in the Laboratory of Engineering Seismology at NIEP. An example of a resonant column test with a sample from the site "Parcul Tineretului" can be seen in Fig. 2. The dynamic laboratory testing data together with the seismic field measurements are used for linear and non-linear modelling of the site response due to Vrancea earthquake waves in Bucharest.

![Shear modulus and damping for sandy clay sample from Parcul Tineretului.](image.png)

Figure 2. Shear modulus and damping for sandy clay sample from Parcul Tineretului.

ACKNOWLEDGEMENTS

The present results were obtained in the framework of the "NATO Science for Peace Project grant SFIP981882". The URS experiment was funded by the Deutsche Forschungsgemeinschaft and the National Institute for Earth Physics, Bucharest - Magurele.

REFERENCES