ASSESSMENT OF SEISMIC SITE AMPLIFICATION AND OF SEISMIC BUILDING VULNERABILITY IN THE REPUBLIC OF MACEDONIA, CROATIOA AND SLOVENIA

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ABSTRACT :

A project "Assessment of Seismic Site Amplification and Seismic Building Vulnerability in the Macedonia, Croatia and Slovenia" has been launched (2004) under the auspices of NATO Science for Peace Program (NATO SfP 980857). It is being performed by 3 academic institutions from Croatia, Macedonia and Slovenia (Department of Geophysics, Faculty of Science, University of Zagreb, Croatia; Institute of Earthquake Engineering and Engineering Seismology /IZIIS-Skopje/, University "Ss. Cyril and Methodius", Skopje, Macedonia; Environmental Agency of the Republic of Slovenia - Seismology Office, Ljubljana, Slovenia) and coordinated by the Department of Structures, Soil Mechanics and Engineering Geology, University of Basilicata and the Department of Earth Sciences, University of Siena, both from Italy. The end users of the results are governmental agencies or ministries sectorally responsible for emergency function or planning, i.e.: Ministry of the Environment, Spatial Planning and Energy, Ljubljana, Slovenia, Ministry of Science, Education and Sports, Zagreb, Croatia, Ministry of Environmental Protection, Physical Planning and Construction, Zagreb, Croatia, Sector for Civil Protection, Ministry of Defense, Government of Republic of Macedonia, Skopje, Macedonia, and The City Committee for Urbanism, Communal and Housing Affairs, Traffic and Environmental Protection, City of Skopje, Skopje, Macedonia.

The SfP 980857 project, based on microtremor and ambient vibration measurements of free-field locations and buildings, in itself promotes a new integrated method and technology for "fast" seismic microzonation and estimation of seismic vulnerability of buildings with wide application possibilities in particular for identification of locations with potential resonant characteristics and thus, the increased seismic risk for buildings.

The paper, in all details, presents objectives and scope of NATO SfP 980857 Project as well as some general results and findings achieved during its 3 years of implementation.

KEYWORDS: microtremor, ambient vibration, amplification, vulnerability, microzonation.

1. INTRODUCTION

Recent examples from worldwide earthquakes showed that the resonance between soil and building may substantially enhance earthquake damage, and even buildings designed as seismic resistant, in certain cases, are suffering more damage than expected when resonance occurred. There is general agreement that soil-building resonance might be a cause of damage enhancement, as well as suggestions that peculiar damage patterns (e.g. the collapse of a single building in a set of identical ones) is and/or might be the consequence of it.

To better quantify the occurrence of resonance taking into account the time-varying, non-linear behavior of soil and building subjected to strong ground motion a project "Assessment of Seismic Site Amplification and Seismic Building Vulnerability in the Macedonia, Croatia and Slovenia" has been launched (2004) under the auspices of NATO Science for Peace Program (NATO SfP 980857).

It is being performed by consortium of 3 academic institutions from Croatia, Macedonia and Slovenia (Department of Geophysics, Faculty of Science, University of Zagreb, Croatia; Institute of Earthquake Engineering and Engineering Seismology /IZIIS-Skopje/, University "Ss. Cyril and Methodius", Skopje, Macedonia; Environmental Agency of the Republic of Slovenia - Seismology Office, Ljubljana, Slovenia) coordinated by the Department of Structures, Soil Mechanics and Engineering Geology, University of Basilicata and the Department of Earth Sciences, University of Siena, both from Italy. The end users of the results are governmental agencies or ministries sectorally responsible for emergency function or planning, i.e.: Ministry of the Environment, Spatial Planning and Energy, Ljubljana, Slovenia, Ministry of Science, Education and Sports, Zagreb, Croatia, Ministry of Environmental Protection, Physical Planning and Construction, Zagreb, Croatia, Sector for Civil Protection, Ministry of Defense, Government of Republic of Macedonia, Skopje, Macedonia, and The City Committee for Urbanism, Communal and Housing Affairs, Traffic and Environmental Protection, City of Skopje, Skopje, Macedonia.

The Project commenced in March 2005 and terminated in March 2008.

2. OBJECTIVES

In the following presented are general and specific objectives set by NATO SfP980857 Project:

General Objectives: To enhance Partner Countries' capability in:

- State-of-the-art signal measurement, recording and acquisition
- State-of-the-art signal processing techniques
- H/V data analysis, synthesis, integration and presentation

Specific Project Objectives:

- Equip partner countries with the state-ot-the-art seismic noise (ambient vibration) measuring instrumentation and processing tools;
- Field measurement of dynamic characteristics of large sets of soil deposits;
- Measurement of dynamic characteristics of large sets of buildings;
- Integration of interpreted measurement data into microzonation maps of studied urban areas;
- Promotion of a new integrated method and technique for "fast" seismic microzoning and seismic vulnerability assessment of buildings with wide application possibilities for identification of locations with potential resonant characteristics and thus, the increased seismic risk for buildings.
- Development of a basis for derivation of quantitative elements for:
    - Disaster preparedness and emergency management planning;
    - Strategy and prioritization for mitigating problems in unfavorable (building-site resonance) zones;
- Project promotion and visibility

3. PROJECT ORGANIZATION

The Project has been organized/performed in 4 phases:

First Phase (3 months): Procurement of equipment, training, development and dissemination of an operational protocol;

Second phase (6 months): Start of the survey; studies of pilot sites in partner countries; checking, by the coordinators, refreshment and improvement of the training level; planning of the field work for the entire campaign; identification of facilities, sites and buildings demanding the highest priority in surveys; compilation of geologic data relevant to the sites to be studied.

Third phase (24 months): Systematic survey in each participating country, at least 15 measurements per day per instrument; collection and analysis of local geological data for each studied site; microtremor measurement campaign on average in a cells of 250x250 meters; selection of representative buildings (3-4) in each cell unit and determination of their frequency characteristics by ambient vibration measurements; quarter yearly exchange of data and results among partners, reporting.

Fourth phase (3 months): Collection and rationalization of results from countries involved; elaboration of general national documents; review and synthesis of national documents; elaboration of reports for national Authorities.

4. ACHIEVEMENTS

General achievements

A set of 20 TROMINO (Micromed, Italy, Fig. 1) digital seismometers has been purchased and delivered to partner countries.

Figure 1
TROMINO (Micromed, Italy), Wireless, Power Independent, Ultra-Compact Digital Seismometer

TROMINO is the new generation of truly portable, wireless (no external cables), power independent, ultra-compact (1.1kg) and ultra-light instrument for high resolution digital seismic noise measurement. It is equipped by 3 orthogonal high resolution electrodynamic sensors (velocimeters) with frequency range 0.1 - 256 Hz.

TROMINO is powered by 2 internal 1.5 V alkaline AA type batteries, lasting beyond 80 hours in continuous recording at 128 Hz sampling rate without GPS, that makes it safe, extremely easy to handle and capable of acquiring high-quality signals even in electromagnetically polluted environments.

It is high resolution analog/digital conversion, 24 bit equivalent, instrument with 2 GB internal memory. Internal GPS (12 channels), GPS synchronization and time marker (precision 1μs) allows TROMINO to be used in array or network configuration.

Procurement of TROMINOs increased substantially the capability of Partner countries for highly mobile, fast and operationally simple microtremor and ambient vibration measurements.

Specific Achievements

Croatia

Free-field microtremor measurements: In total about 790 individual measurement sites, have been performed at number of places all around Croatia, i.e.: Čačvina, Dubrovnik, Hvar, Kosinj, Kukaca, Novalja, Omisalj, Osijek, Ozalj, Palagruza, Ploče, Podubac, Puntijarka, Raša, Sisak, Slunj, Stravča, Strožanac, Šumetlica, Tkalci, Trilj, Ubac, Ugljan, Validići, Vukovar, Zadar, Zaprešić, but dominantly in Ston and Zagreb.

Ambient vibration measurements: have been performed in Ston, Novalja, Ozalj, Zadar, Strožanac, Palagruža, Slunj, Stravča, Trilj, Sisak, but dominantly in Zagreb – 80 RC buildings with height 10 to 100 m.

Software development: Five MATLAB® program packages were prepared – ModelHVSR for interpretation of the free-field measurements, FREDA for analyses of building measurements, TG for calibration of TROMINO instruments relative to a reference seismometer, GTM for comparison of three alternatives the HVSR may be computed, and HVSR-profile for plotting HVSR spatial spectrograms (HVSR profiles).

Promotion and visibility: Creation and maintenance of NATO SfP980875 web -http://nato.gfz.hr/index.html

Macedonia

Free-field microtremor measurements: In total about 327 individual measurement sites, dominantly in Skopje, as well as 70 free-field sites of the Macedonia strong motion network.

Array microtremor and MASW measurements: 4 locations in Skopje.

Ambient vibration measurements: In total 338 buildings (1,530 measurements) of various masonry and RC structural systems and different heights ranging from 3 to 19 storeys.

GPS synchronized ambient vibration measurements: In total 216+10 measurements at several principal facilities of Water-resource system on St-Laurence River, Canada, operated by Hydro-Québec (Beauharnois and the Des Cèdres Power Generating Sites) including Machine Hall (91 measurements), Dam body (41 measurements) and Control Center (39 measurements) at Beauharnois Site, and Transformer station (45 measurements) at Des Cèdres Site. In addition 10 free-field microtremor measurements are taken in the vicinity of listed facilities.

Special measurements: performed to estimate the influence of vibrations caused by work of heavy road construction machinery (100 ton vibro roller) on structural and/or non-structural damage potential to dwelling houses closest to the planned highway route. In total, 73 measurements under regular (without) and extreme (with) deployment of a vibro roller.

Slovenia

Free-field microtremor measurements: In total about 1,415 individual measurement sites, out of which 1032 free-field measurements in 200 m x 200 m grid in Ljubljana, 128 free-field measurements in Bovec basin (NW Slovenia), and 225 free-field measurements in Ilirska Bistrica (S Slovenia)

Ambient vibration measurements: In total 164 buildings, out of which 123 buildings (890 measurements) in Ljubljana (building + free-field measurement in its vicinity) - 46 elementary schools, building of the Faculty of

Civil Engineering, 13 health centers, 32 apartment blocks, 17 houses, 9 commercial buildings and 5 student residence hall; 31 buildings (70 measurements) in Bovec basin; and, 10 buildings (32 measurements) in Ilirska Bistrica.

Array microtremor and MASW measurements: 5 locations in Ljubljana.

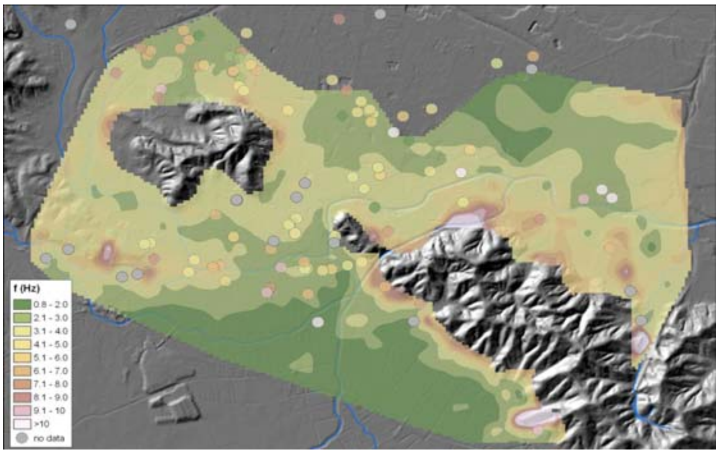

Figure 2
Map of the fundamental ground frequencies of Ljubljana (Slovenia) overlain by frequency characteristics of measured buildings. The same color legend is used for free field and building data.

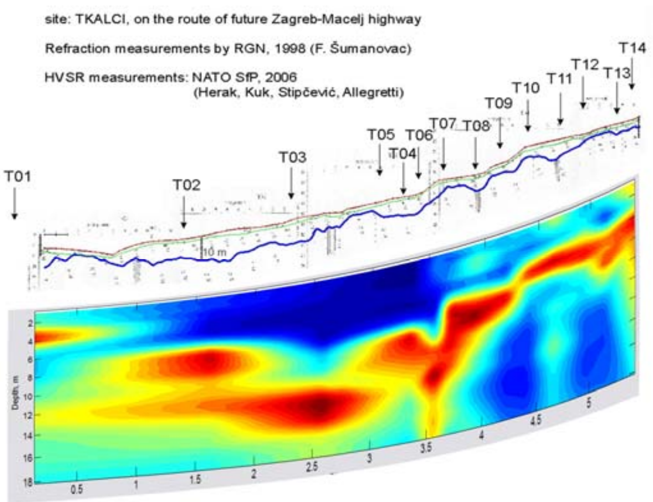

Figure 3
Free-field measurements in Tkalci (NW Croatia) Comparison of 'depth'-distance model obtained from microtremot measurements with the results of the seismic refraction study

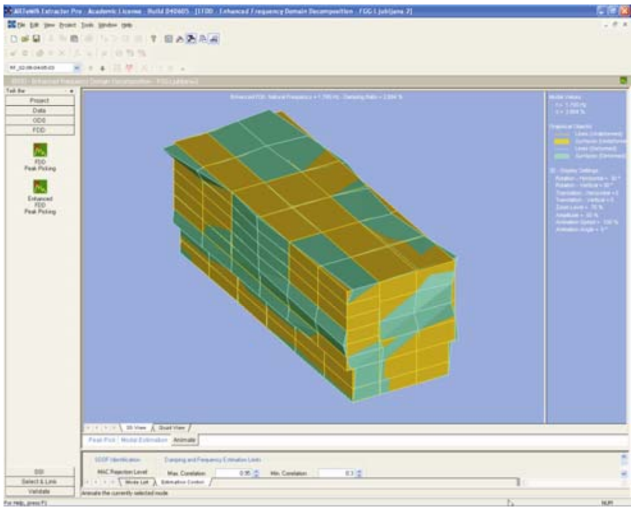

Figure 4
ARTeMIS™ Identification of Structural Dynamic Properties Based on GPS Synchronized Ambient Vibration Measurements / FGG Building, Ljubljana, Slovenia/

5. CONCLUSIONS

Using an up-to-date digital, wireless technology transferred to partner countries (TROMINO seismometer, Micromed, Italy, Fig. 1), undertaken are very dense and detailed microtremor measurements of soil deposit and building frequencies using ambient vibration measurements.

Processing this kind of data may give precise insight on the dynamic behavior of surface deposits and structures in order to identify the more vulnerable buildings and also to point out possible construction defects that may explain the often observed case of single-structure collapse.

Seismic noise, ambient vibration measurements and data processing techniques implemented in the project as well as interpretation of results obtained resulted in:

- Microzonation of predominant frequencies of surface deposits (Fig. 2) in studied areas;
- Proper identification of fundamental building frequencies (Fig. 4);
- Mapping of resonant areas of deposit-building interaction (Fig. 2);
- Identification of stratification patterns of surface deposits (Fig. 3);
- Advanced identification of structural dynamic properties (periods and modes) based on GPS synchronized ambient vibration measurements (Fig. 4) and ARTeMIS™ processing of recorded signals; and,
- Other not mentioned achievements gathered during the course of project implementation.

Besides the expected practical achievements, the project, to a certain extent, helped to answer some open questions in the field of applied seismology and earthquake engineering, such as: correlation of data from low intensity noise with effects of strong to catastrophic earthquakes; validation of the advantages of the 'resonance theory' with respect to other building vulnerability estimates; comparison of 'resonance' method with standard visual screening techniques. Finally, the establishment and wide availability of a large data base of building dynamic characteristics, including location, architectural, structural and material characteristics will allow the use of acquired data for rapid post-earthquake building damage diagnosis and other research needs.

The strong point of the project are: (1) the adequate institutional layout for assuring successful project implementation; (2) the high professional capability in partner countries (Croatia, Macedonia and Slovenia); (3) the transfer of a low-cost, up-to-date technology (instruments, software, know-how); and, (4) the enhancement of partner countries capacity in the field of earthquake damage assessment, prediction and mitigation.

6. ACKNOWLEDGEMENTS

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