On-line Data Transmission, as Part of the Seismic Evaluation Process in the Buildings Field

Claudiu Sorin Dragomir$^{1,3}$, Daniela Dobre$^{2,3}$, Iolanda Craifaleanu$^{2,3}$, Emil-Sever Georgescu$^{3}$

$^1$University of Agronomic Sciences and Veterinary Medicine, Faculty of Land Reclamation and Environment Engineering, Bucharest, 59 Marasti Blvd., 011464, Romania
$^2$Technical University of Civil Engineering Bucharest, 122-124 Lacul Tei Blvd., 020396, Romania
$^3$National Institute for Research and Development URBAN-INCERC, Sos. Pantelimon, No. 266, 021652, Bucharest, Romania

claudiu.dragomir@incd.ro

Abstract. The thorough analytical modelling of seismic actions, of the structural system and of the foundation soil is essential for a proper dynamic analysis of a building. However, the validation of the used models should be made, whenever possible, with reference to results obtained from experimental investigations, building instrumentation and monitoring of vibrations generated by various seismic or non-seismic sources. In Romania, the permanent seismic instrumentation/monitoring of buildings is part of a special follow-up activity, performed in accordance with the P130/1999 code for the time monitoring of building behaviour and with the seismic design code, P100-2013. By using the state-of-the-art modern equipment (GeoSIG and Kinematics digital accelerographs) in the seismic network of the National Institute for Research and Development URBAN-INCERC, the instrumented buildings can be monitored remotely, with recorded data being sent to authorities or to research institutes in the field by a real-time data transmission system. The obtained records are processed, computing the Fourier amplitude spectra and the response spectra, and the modal parameters of buildings are determined. The paper presents some of the most important results of the institute in the field of building monitoring, focusing on the situation of some significant instrumented buildings located in different parts of the country. In addition, maps with data received from seismic stations after the occurrence of two recent Vrancea (Romania) earthquakes, showing the spatial distribution of ground accelerations, are presented, together with a comparative analysis, performed with reference to previous studies in the literature.

1. Introduction

The modelling of seismic actions (peak ground acceleration, wave propagation), of building structures (vertical and plan irregularities, member stiffness, structural walls layout, foundation type and conditions) and of soil (local site conditions) are important for dynamic analysis; however, they must be corroborated with experimental investigation techniques, building instrumentation and monitoring of vibrations generated by various seismic / non-seismic sources.
Building monitoring by seismic instrumentation can contribute directly to the identification and determination of the temporal variation of modal characteristics, damping coefficients etc. It also plays an important role in verifying the maximum drift, the torsional response (especially for asymmetric structures), in identifying needs for future building repair and strengthening, as the effectiveness of previous intervention measures etc.

The current trend in building instrumentation and monitoring is the setup of a wireless sensor network, capable of providing the necessary information for the analysis and assessment of building response and post-earthquake damage. In addition to getting the collected data in real time, this creates also the possibility of getting alerts through alarms, email or SMS, for certain categories of users, about potential risks to the instrumented buildings.

2. Building instrumentation and monitoring of vibrations generated by various seismic / non-seismic sources

A dense instrumentation with high performance equipment is a prerequisite for making accurate observations on the effects of earthquakes on buildings and for the future establishment of design and / or rehabilitation parameters. In Romania, the public building instrumentation activities performed by the team of the National Seismic Network of URBAN-INCERC contribute significantly to providing information about the safety of these buildings. The initiated investigations and their results form the basis of a proposal for an extensive program of building instrumentation in all seismic areas of the country, with emphasis on those of high seismicity.

On the other hand, concerning the monitoring of vibrations generated by non-seismic sources, for floor layouts with large openings, buildings located near active industrial areas etc., the recording of the low amplitude oscillations of buildings is a second type of activity performed by the staff of the National Seismic Network.

The recording / measuring of the above-mentioned oscillations is made by using state-of-the-art equipment (various types of digital instruments: tri-axial accelerometers, 12-channel seismic stations etc.).

3. Real-time data transmission system within the National Seismic Network for Buildings of "URBAN-INCERC"

The monitoring of the evolution of dynamic characteristics by vibration instrumentation, as a requirement of structural safety assessment, has evolved over time, at URBAN-INCERC, into the deployment of a sensor network, used for building vibration recording and connected to a central server, allowing for real-time data transmission, recording and management. This network is deployed in parallel with the network of accelerometers located in small buildings or in similar to free-field conditions.

At present, the National Strong Motion Network of URBAN-INCERC (RNSC) consists of 55 accelerometers, located in 45 localities in Romania (Figure 1).

Recently, a plan for real-time transmission of the recorded seismic data was developed in collaboration with the Romanian Special Telecommunication Service. Accordingly, starting with November 15, 2015, 32 seismic stations, of which 4 in Bucharest and 28 distributed throughout the country, are connected to real-time data transmission. This is provided both for stations located in free field-type conditions and for monitored buildings.
4. Some recent examples of instrumented buildings (2016-2017)

In [1], [2], [3], the need for ambient vibration measurements, originating from seismic / non-seismic sources, is reiterated. Three case studies are presented below.

- Block of flats, Bucharest. Section E, built in 1968, has a structural system with basement, ground floor, 10 stories and a technical floor, with vertical regularity. The plan dimensions are 24.10 x 12.65 m and the total height is H=30.36 m (Figure 2).

Figure 1. Seismic stations and instrumented buildings in the URBAN-INCERC network

Figure 2. Block of flats-type building, Balta Alba Bucharest. Fourier spectra at the top level, from ambient vibrations/generated by non-seismic sources (frequencies: fx= 1.73 Hz and fy= 2.05 Hz)
A diagram of the vertical variation of accelerations on building height is shown in Figure 3.

**Figure 3.** Order of magnitude \([\text{m/s}^2]\) and variation of accelerations recorded using the vertical instrumentation scheme

- Block of flats, city of Galati. Built in 1961, it has a structural system with 2 basements, ground floor, 10 stories and a technical floor, with vertical regularity. The plan dimensions are 28.5 x 18.10 m; the total height is \(H=30.50\) m (Figure 4), variation of accelerations recorded using the vertical instrumentation scheme is shown on Figure 5.

**Figure 4.** Block of flats, Tiglina, Galati. Fourier spectra at the top level, from ambient vibrations / generated by non-seismic sources (frequencies: \(f_x=1.88\) Hz and \(f_y=1.83\) Hz)

**Figure 5.** Order of magnitude \([\text{m/s}^2]\) and variation of accelerations recorded using the vertical instrumentation scheme
Office tower building, Bucharest, is situated on the Dambovita riverside. It has total height $H = 61$ m. The structure, built in December 2008, has basement, ground floor, 15 stories and a technical floor, Figure 6-up.

**Figure 6.** Office tower building in Bucharest (up). Fourier spectra at the top level, recorded during the $M=4.7$ Vrancea earthquake of May 19, 2017 (frequencies: $f_x=1.5$ Hz and $f_y=1.3$ Hz)

**Figure 7.** Maps with distribution of recorded peak ground accelerations for the two 2016 earthquakes (adapted from URBAN-INCERC earthquake reports)
5. On-line data transmission, an essential precondition for near real-time mapping of seismic accelerations. Recent examples

During the recent $M_L=5.3$ earthquakes of September 24, 2016, and December 27, 2016, the seismic network of URBAN-INCERC has provided several ground motion records. Maps with the spatial distribution of acceleration values were generated. These are presented comparatively in Figure 6.

The maps of peak ground accelerations for 2016 earthquakes confirm certain patterns observed also in past earthquakes, such as the NE-SW general directivity and the PGA amplification at large distances from the epicentre area, by comparison with the values recorded in the vicinity of the Vrancea area. It can be noticed that the maximum values (PGA = 0.7…0.9 m/s²) were recorded at the Iasi seismic station and in its vicinity, for the Vrancea earthquake of 24.09.2016 (Figure 7, left). A rather similar PGA distribution pattern can be observed, even though with different values, for the 27.12.2016 Vrancea earthquake (Figure 7, right).

6. Conclusions

Some of the most important results obtained recently at URBAN-INCERC in the field of building monitoring and the situation of some significant instrumented buildings located in different parts of the country were presented. Maps are presented as well, with data received by the real-time transmission system from the URBAN-INCERC seismic stations across the country during two recent $M>5$ Vrancea (Romania) earthquakes, showing the spatial distribution of ground accelerations during these events. Within the research programme “Integrated researches for resilience, efficiency and comfort of built environment – CRESC, PN 16-10.01.01 Programme”, the expansion of the seismic network is an ongoing process. The number of continuously monitored buildings, as well as that of installed seismic stations, is planned to further increase in the near future.

Acknowledgements

This paper is based on results obtained in the research programme “Integrated researches for resilience, efficiency and comfort of built environment” – CRESC, PN 16-10.01.01.

References

[1] C. Michel, P. Guéguen, P. Y. Bard, “Dynamic parameters of structures extracted from ambient vibration measurements: an aid for the seismic vulnerability assessment of existing buildings in moderate seismic hazard regions”, https://hal.archives-ouvertes.fr/file/index/.../CMichel.et.al-SDEE2006-pre-print.doc, 2006.

[2] C. S. Dragomir, D. Dobre, E. S. Georgescu, “Seismic instrumentation as a demand of building safety”, 3rd International Conference CICOP.NET, 21st Century Heritage without Borders - Sustainability and Heritage in a World of Change, Proceedings of the 3th Conference Importance of place, Mostar International Conference Confederation, Italy – Bosnia and Herzegovina–Serbia, 2015.

[3] D. Lungu, A. Aldea, S. Demetriu, I. G. Craifaleanu, Acta Geod. Geoph. Hung (2004) 39: 233. doi:10.1556/AGeod.39.2004.2-3.8.

[4] Romanian Norm concerning construction's behavior in time, P130/1999 (in Romanian: Normativ privind comportarea in timp a constructiilor).

[5] Romanian Earthquake Design Code – Part I, Design Provisions for Buildings, P100-1/2013 (in Romanian: Cod de proiectare seismica).