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SPATIAL DATA RESULTING FROM THE AUTOMATION OF THE PERMANENT SEISMIC MONITORING SYSTEM

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Abstract

The stations from the INCD URBAN-INCERC network are distributed throughout the country, including Bucharest, and are located either in free-field conditions, in small buildings, in medium-height buildings or in boreholes. The interactive map representation of the seismic stations and the automatic monitoring of their operation, based on the analysis of received data, are currently carried out with the SeisComP software. The paper exemplifies, as performance benchmarks, some data processing obtained in 2022 within the permanent seismic monitoring system.

Key words*: seismic data, seismic network, spatial analysis, semi-automatic generation of PGA maps.*

INTRODUCTION

In a general context, the main objective of the automation of the permanent seismic monitoring system is to improve the understanding of the structural behaviour of buildings and their damage potential under the dynamic action of earthquakes or of other vibration sources.
The capacity of the seismic network of INCD URBAN-INCERC was developed in this direction and a significant amount of data was obtained through the permanent monitoring of buildings such as that of the General Inspectorate of Emergency Situations, IGSU, the Ministry of Research, Innovation and Digitalization, MCID, the Faculty of Biotechnologies, BTH (USAMVof Bucharest), the University Emergency Hospital, the VENUS and the APATEL buildings, but also through the temporary seismic instrumentation of a number of 14 research and development institutes premises.
This is an important step in the research for increasing public safety, given that the obtained records obtained will provide, in time, important data for the:

- systematic and efficient verification of the performance of the structures and the identification of potential prerequisites for future damage;
- overall vulnerability assessment of instrumented/monitored buildings;
- evaluation of dynamic characteristics as reference data for the future instrumentation of the same buildings, or for informing retrofitting interventions;
- identification of the level of ambient vibrations in some urban areas and of the peculiarities of recorded signals;
- comparison and selection among different operational modal analysis techniques for identifying the structural behaviour from the response analysis in the time and frequency domains under low-amplitude ambient vibrations;
- semi-automatic generation of PGA maps and highlighting of various patterns and trends revealed by the recorded data;
- enriching the existing records database by acquiring real-time data transmitted through the Romanian Special Telecommunications Service network etc.

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BUILDING RESPONSE MONITORING

Some aspects of advanced seismic monitoring are presented in the following. The automatic monitoring of seismic stations operation, the generation of maps with the seismic stations that transmit in real-time and, the advanced spatial analysis of the seismic data and the calculation of various parameters of specific earthquake engineering significance represent some of the main activities conducted in support to and within the broader context of the assessment of seismic risk in case of major earthquakes.

The interactive mapping, based on the analysis of the data received from the stations, is carried out using the SeisComP *scmv* module (gempa.de). Figure 1 shows a map, generated by the SeisComP system, with stations from the INCD URBAN-INCERC seismic network. The stations are distributed throughout the entire territory of the country, including Bucharest, devices/sensors being placed either in free-field conditions, in small buildings, in medium-rise buildings (for seismic monitoring) or in boreholes.

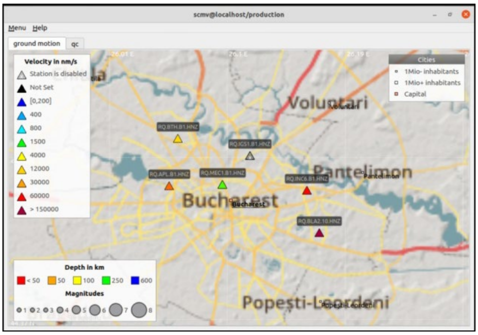

Figure 1.Representation in SeisComP of the seismic stations from the INCD URBAN-INCERC network, with the reference channels (vertical - HNZ) - detail for Bucharest (with also BTH station)

Figure 2 shows the waveforms recorded at some seismic stations of the network during the earthquakes of July 16 and 18, 2022, using the SeisComP scolv module. The waveforms show the automatic identification of the primary ("P") waves and, respectively, the secondary ("S") wave's arrivals. The advanced spatial analysis of seismic data can be performed with the SIGMA program, also developed by gempa.de (Germany), as the SeisComP system. The program performs: interactive or automatic analysis of seismic motions; generates maps of modified Mercalli Intensity (MMI), peak ground acceleration (PGA) and peak ground velocity (PGV); computes earthquake engineering-specific parameters such as, for example, the Arias intensity and duration and allows the selection, mapping and validation of ground motion prediction equations (GMPE). The computed values are stored in a database that can be accessed report generation.

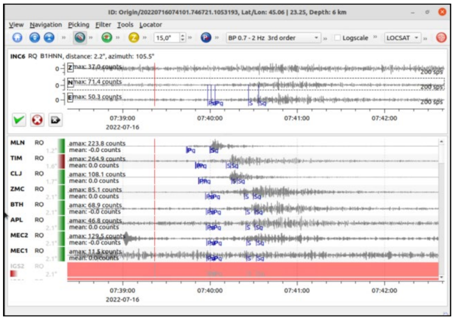

Figure 2. Waveforms recorded at the stations of the INCD URBAN INCERC network during the seismic event of 16.07.2022. Representation generated by using the *scolv* module of SeisComP

The waveforms in Figure 2, displayed for the earthquake on 07/16/2022 (M_L=4.1), show various times of arrival of P- and S-waves for stations in Bucharest, including those recorded at the Faculty of Biotechnologies (USAMV of Bucharest) seismic station, code BTH.

In Figure 3, a map is displayed for another earthquake, that of November 3, 2022 (M_L = 5.4), with the recorded peak accelerations of the soil (as resulting from the countrywide seismic monitoring).

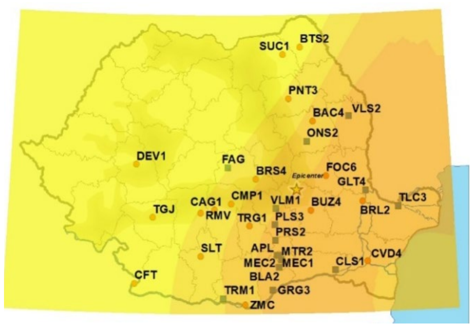

Figure 3. PGA map for the earthquake of 11/03/2022

RESULTS AND DISCUSSIONS

Processing of data recorded by seismic stations. For each of the recordings, the desired components can be selected and the response spectrum, phase spectrum and power spectrum can be computed and displayed, using different options related to axes, corrections etc. Wave forms recorded at the seismic stations can be also represented using the *scolv* module of SeisComP.

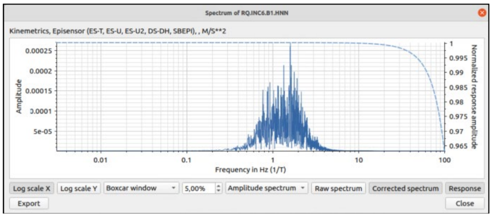

Figure 4. Response spectrum of the earthquake recording from 16.07.2022, INC6 station (INCERC Bucharest branch), N-S component. Representation made with the *scolv* module of SeisComP

Spatial analysis and advanced processing of seismic data. In the following figures (5 to 8), the application of the SIGMA program for the Vrancea subcrustal earthquake of 17/18.07.2022is presented for illustration.

Figure 5. Waveforms (corrected accelerations) recorded in the pilot stations of the seismic network of INCD URBAN-INCERC during the earthquake of 17/18.07.2022

The recorded amplitudes have important applications in earthquake early warning, which can be performed directly at station level, thus gaining time in case of the exceedance of the preset levels (Marmureanu et al., 2021; Tiganescu et al., 2022).

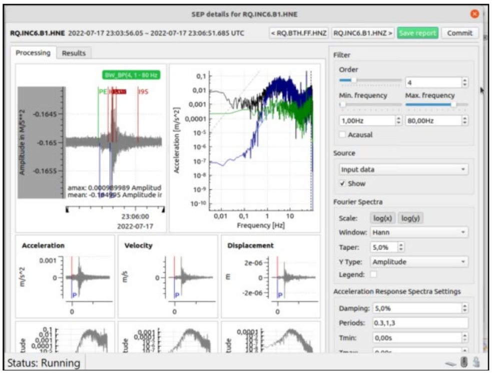

Figure 6. Detailed processing carried out with the SIGMA program for a pilot station of the seismic network of INCD URBAN-INCERC, for the earthquake of 17/18.07.2022

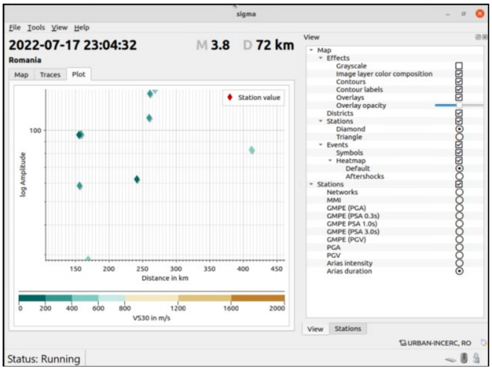

Figure 7. Chart of amplitudes as a function of epicentral distance

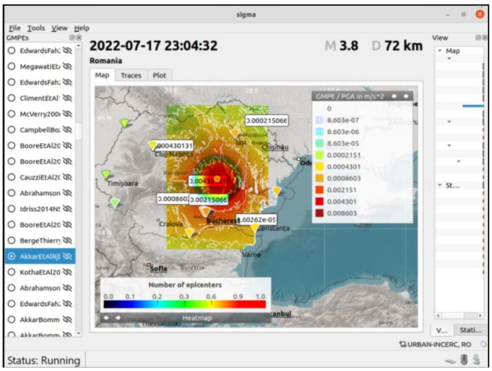

Figure 8. Testing of Ground Motion Prediction Equations (GMPEs) with SIGMA

The role of seismic instrumentation. Up to 2022, 14 research and development institutes have been instrumented by INCD URBAN-INCERC, apart from another set of permanently monitored buildings. The obtained results contribute to the development of the existing database and to the analysis of the differences between the structural dynamic properties determined by measurements and the results from the application of the simplified formula from the Romania seismic design code P100-1/2013 (Figures 9, 10, 11).

Also, as the dynamic properties evaluated by seismic instrumentation (under low-intensity excitations) will likely not coincide with the dynamic properties recorded under severe earthquakes, arrange of frequently recorded accelerations, is considered (Dragomir et al., 2017; 2018; 2020).

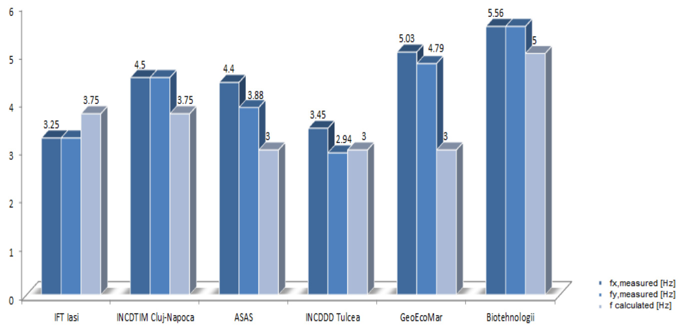

Figure 9. Average level of frequencies recorded from ambient vibrations and computed according to the P100-1/2013 code, for 3-story buildings (including the BTH_USAMV station)

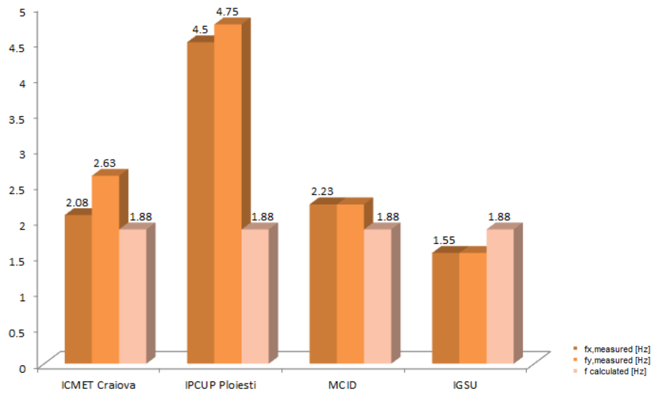

Figure 10. Average level of frequencies recorded from environmental vibrations, compared to those computed according to P100-1/2013, for 7-story buildings

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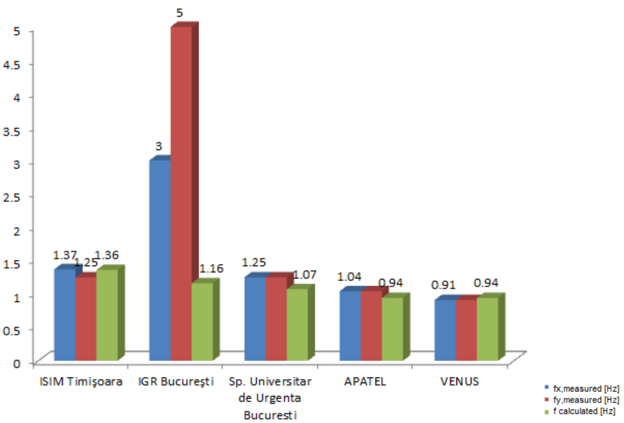

Figure 11. Average level of frequencies recorded from environmental vibrations, compared to those calculated according to P100-1/2013, for 10, 12, 13 and 15-story buildings

CONCLUSIONS

In the context of the applications of the seismic instrumentation/monitoring activity, the possibility of its integration into the new BIM-Building Information Modelling approach, in a multidimensional and multidisciplinary relationship, for a new type of evaluation and mitigation of seismic risk, should also be mentioned, through the following aspects:

– data of interest can be provided on the characteristics of both the structural elements and the non-structural elements of a building, from the BIM model, correlated with the structural instrumentation/ monitoring data;
– the structural health monitoring before and after an earthquake can provide information for a self-diagnosis in BIM;
– structural instrumentation/monitoring to can support the creation of an earthquake emergency management hub within a building management system;
– estimation of structural seismic losses by going through a few successive stages:
– measurement of the structural dynamic response from environmental vibrations and subsequent identification of the characteristics of the structural system only from output data (operational modal analysis);
– experimental and/or analytical structural analysis;
– automatic analysis of seismic losses through implementation in the existing BIM application.

Regarding the semi-automatic generation of PGA maps from seismic actions or other vibrational sources and the rapid assessment of the vulnerability of instrumented buildings, a series of software modules necessary for the automation of the permanent seismic monitoring system, based on the use of the specialized SeisComP software package, were previously prepared, configured and implemented. Thus, the following stages were completed in this process:

– installation and configuration of the program core;
– initial population of the database;
– creation of the inventory of seismic stations;
– definition of the seismic network characteristics;
– import of the characteristics of the seismic recording instruments from the Nominal Response Library database of the Incorporated Research Institutes for Seismology, IRIS;
– definition of data related to the seismic stations (general characteristics of the stations, device locations - geographical coordinates, location within the seismic station, characteristics of the channels);
– generation and import of the XML file with the data on the seismic network into the SeisComP database;

- configuration of online communication, in real time, with the seismic stations in the territory;
- configuration of connections with network stations;
- configuration of local archiving of seismic records;
- graphic representation of data recorded in real-time (waveforms);
- representation of recorded data in real-time, in a special format;
- real-time verification of the quality of the operation of the seismic stations;
- access to files from the SDS archive;
- management of the station metadata file.

Shake maps can be also generated based on the ground motion attenuation equations (laws) selected by the user from a list provided by SIGMA. Attenuation laws can be dependent on PGA, PGV, or on the pseudo-spectral amplitude (PSA) expressed at various period values (0.3s, 1.0s, 3.0s).

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