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Prospective Studies for the Implementation of a Remote Access Earthquake Damage Detection System for High-Rise Buildings in Romania

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Abstract. The rapid increase of the number newly-erected high-rise buildings in Romania during the last two decades brought up the importance of the continuous monitoring of their state. For seismic actions, a post-event modification of the dynamic characteristics of a building can provide a rapid indicator about its potential damage. The paper presents the methods, procedures and steps by which a system providing online remote access to data resulting from building vibration monitoring could be implemented and used for buildings in Romania. The system would allow rapid identification of building damage, based on the processing of recorded data. Identified issues, as well as potential bottlenecks are presented, together with the proposed solutions. The system is planned to be implemented by using the infrastructure available at NIRD URBAN-INCERC, Romania. The paper also presents a case study concerning the structural health monitoring of a multi-story reinforced concrete building, carried out by the project team.

1. Introduction

The rapid increase of the number newly-erected high-rise buildings in Romania during the last two decades brought up the importance of the continuous monitoring of their state. This is essential not only from the point of view of the comfort and serviceability requirements, but also for safety reasons. In the first case, the changing of monitored parameter values could trigger automatic or human intervention for restoring normal values (e.g. for HVAC and security systems). In the second case, if occupant's safety could be affected (as infires or earthquakes), the monitoring system could trigger the evacuation alarm.

The investigation of buildings is in accordance with two important Romanian Codes [1], [2], Romanian Normative concerning construction's behaviour in time- P130/1999 and the Seismic design code P100-2013. In P100-1/2013, states (in Annex A) the following seismic instrumentation provisions [1]:

- in areas where seismic acceleration value is ag>=0,24g, having IMR>= 100years, buildings over 50m with a height of 16 floors or more, or having a developed area of over 7500m^2, will be monitored by a digital acquisition system and with minimum 4 triaxial sensors for acceleration;

- this minimal instrumentation will be located as follows:1 sensor in free field adjacent of building, 1 sensor on the basement floor and 2 sensors on top floor; equipments will be placed so that the access at all devices is possible at any time;
- the instrumentation, maintenance and operation is funded bythe owner of the building and are performed by authorized organizations;
- records obtained during strong earthquakes should be available to competent authorities and institutions specialized in 24h after earthquake.

Criteria for selecting buildings proposed to be investigated/monitored are numerous: seismic zoning of the territory; data on structural system and types of existing structural systems, depending on the material pre and post-1940; the effect of vibration other than from the seismic vibration; location-site; seismic stations and sensors, sensors position/location in a building; correlations between data obtained directly on the ground, the analytical and from the instrumented buildings; the allocated budget; should be applied taking into account the possibility of obtaining the agreement of the institutions owning, their owners etc.[3]

2. A remote access earthquake damage detection system for high-rise buildings in Romania

For seismic actions, a post-event modification of the dynamic characteristics of a building can provide a rapid indicator about its potential damage. If such information from several buildings is gathered and made available to decision factors through a data transmission system, this can substantially increase the efficiency of their post-earthquake reaction, directing interventions towards the most affected buildings and also helping identify associate effects, as road blocks due to fallen building debris. Long-term building monitoring can provide as well important data on structural degradation accumulation, such as that caused by material property modification due to aging, climatic actions etc.

The methods, procedures and steps by which a system providing online remote access to data resulting from building vibration monitoring could be implemented and used for buildings in Romania. The system would allow rapid identification of building damage, based on the processing of recorded data. The system is planned to be implemented by using the infrastructure available at NIRD URBAN-INCERC, Romania. This includes several digital accelerometers, installed both on instrumented buildings and in free field conditions, totalling 56 stations, of which 10 in Bucharest and the other distributed all across the country. A dense instrumentation, with equipment of high performance, is a prerequisite of making accurate observations on the effects of earthquakes and to establish the design parameters and / or of rehabilitation of the built environment [4]. In Romania, the National Seismic Network of URBAN-INCERC has a strategic importance in terms of safety of public buildings and the initiated investigations and the results are the basis of a proposal on an extensive program of instrumental tests in all national seismic areas, with emphasis on those that expect high values of ground acceleration.

3. Methods within online remote access to data resulting from building vibration monitoring

The applied method leads to the determination of the modalities to acquire data from ambient / seismic vibrations, in real time or from temporary instrumentation, the evaluation of the quality / consistency of these data, the data processing and correlation analyzes, the data archiving and securing methods, as well as the servers, complex visualization of the obtained results, their interpretation and decision making (following the application of the algorithms to determine the damage degree of a structural system). Within it, with software applications, Strong Motion Analyst and GeoDAS (produced by Kinemetrics (USA) and GeoSIG (Switzerland)), the real-time data on a dedicated server are collected, processed and graphically represented [5]. Computing the Fourier amplitude spectra and the response spectra, the modal parameters/predominant frequencies of buildings are determined (from a horizontal/vertical scheme for sensors setting), as well as from the theoretical approach formulae. The variation of accelerations/velocities on vertical direction are also obtained.

4. Case study for a multi-story reinforced concrete building

The Office tower building, from Bucharest, is situated on the Dambovita riverside and its height H= 61 m, figure 1a. A structural system with basement, ground floor, 15 levels and a technical floor, built in December 2008, which is one of the monitored buildings, figure 1b, figure 1c. In this case, the admissible values are distributed in a relatively large band of values and refer to an allowable level of vibration (17 ... 20 vibrars), the maximum instantaneous oscillation velocity of the soil (3 ... 25.4 mm/s), the maximum instantaneous oscillation velocity of the structure (8 ... 25.4 mm/s at ground level).

Figure 1. a) Office tower building

Figure 1.b) The GRANITE station installed with 3 sensors (at the top level, level 4 and basement) and a GMS18 GeoSIG station at the groundfloor (which it will be removed further – figure 1.c)

Figure 1.c) GMS18 GeoSIG station at the ground floor (left side) has been replaced with a triaxial sensor connected directly at the Granite multichannel station

In the studied building were made micro-earthquakes and microvibrations/ambient recordings, these being calibration readings, or zero readings in the history of the recordings that will follow (at significant earthquakes). Thus:

– for the Vrancea seismic event of March 18, 2016, M = 3.9, considering that the two equipments had trigger thresholds set at the acceleration value of 5cm/s2, no records were made at this magnitude event. However, from manual recordings for ambient vibrations, in the same period, the following maximum values were recorded, Table 1, and the response spectra in accelerations at ground floor is presented, figure 2a and figure 2b.

Table 1. The maximum instantaneous values of accelerations, velocities and displacements recorded with GMS 18 (ground floor) and GRANITE (terrace)

Level	PGA (cm/s^2)	PGV (cm/s)	PGD (cm)
Ground floor – GMS18	0.20	0.01	0.002
Terrace- Granite	3.7	0.16	0.045

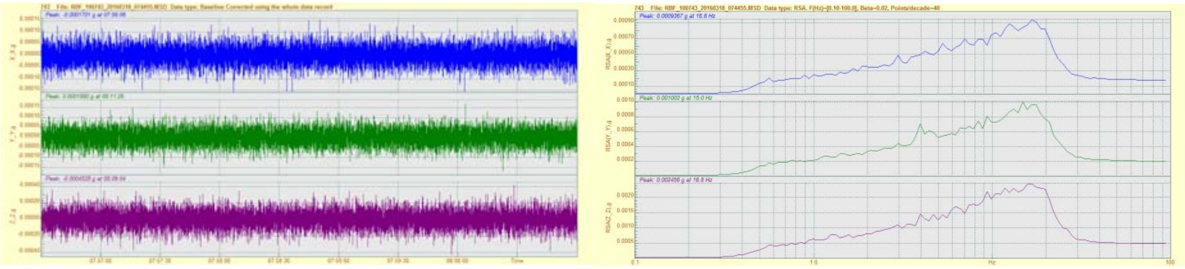

Figure 2.a) Acceleration histories and AccelerationResponse Spectrum for X, Y and Z directions (Ground Floor) – Ground floor GMS18

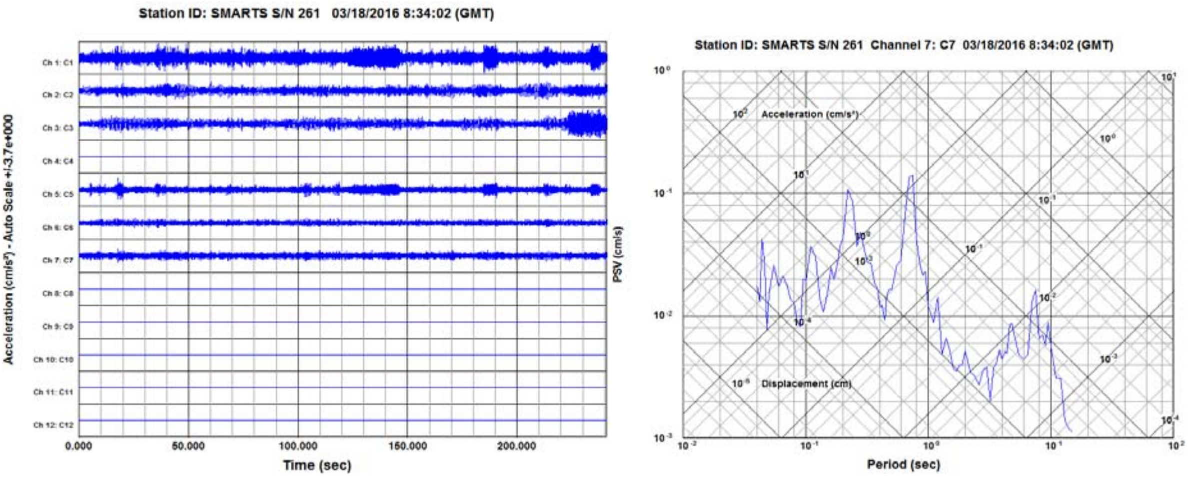

Figure 2.b) Acceleration histories and Acceleration Response Spectrum for X, Y and Z directions - Granite with two sensors on the terrace and the level 4

– for the Vrancea seismic event of 24.09.2016, M = 5.3, records were made at this magnitude event, Table 2, and the response spectra in accelerations at ground floor is presented, figure 3.

Table 2. The maximum instantaneous values of accelerations, velocities and displacements recorded with GMS 18 (ground floor) and GRANITE (terrace)

Level	PGA (cm/s^2)	PGV (cm/s)	PGD (cm)
Ground floor – GMS18	3.66	0.11	0.003

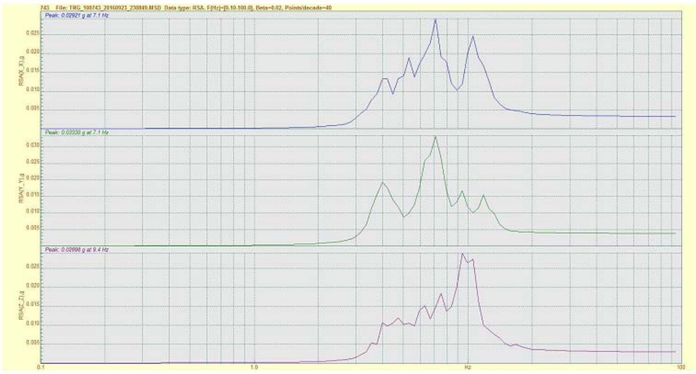

Figure 3. Acceleration Response Spectrum for X, Y and Z directions

– for the Vrancea seismic event of 28.12.2016, M = 5.3, records were made at this magnitude event, Table 3, and the response spectra in accelerations at groundfloor and a tripartite representation of acceleration, velocity and displacement spectra are presented, figure 4.

Table 3. The maximum instantaneous values of accelerations, velocities and displacements recorded with GMS 18 (ground floor) and GRANITE (terrace)

Level	PGA (cm/s^2)	PGV (cm/s)	PGD (cm)
Ground floor – GMS18	5.31	0.13	0.004
Terrace-Granite	33.90	2.61	0.263

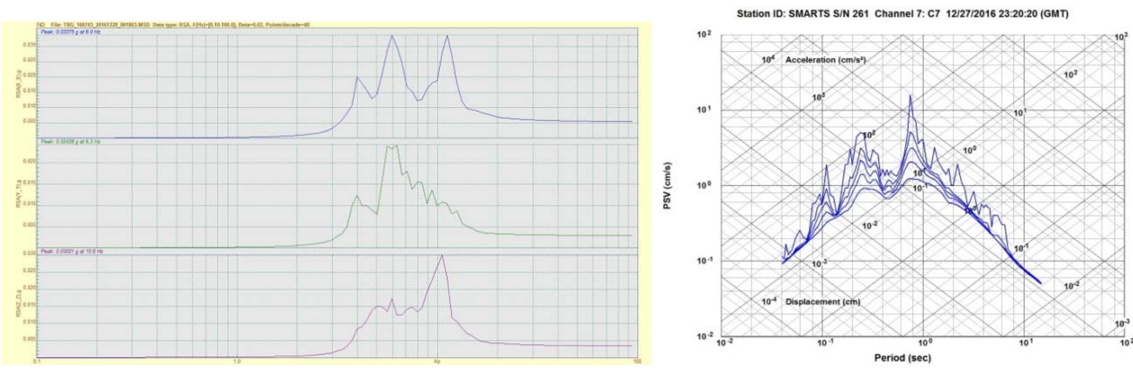

Figure 4. Acceleration Response Spectrum for X, Y and Z directions. Tripartite representation of acceleration, velocity and displacement spectra (channel 7)

– for the Vrancea seismic event 8.02.2017, M=5.0, records were made at this magnitude event, Table 4, and the response spectra in accelerations at ground floor and a tripartite representation of acceleration, velocity and displacement spectra are presented, figure 5.

Table 4. The maximum instantaneous values of accelerations, velocities and displacements recorded with GMS 18 (ground floor) and GRANITE (terrace)

Level	PGA (cm/s^2)	PGV (cm/s)	PGD (cm)
Ground floor– GMS18	9.03	0.45	0.03
Terrace- Granite	13.00	0.90	0.07

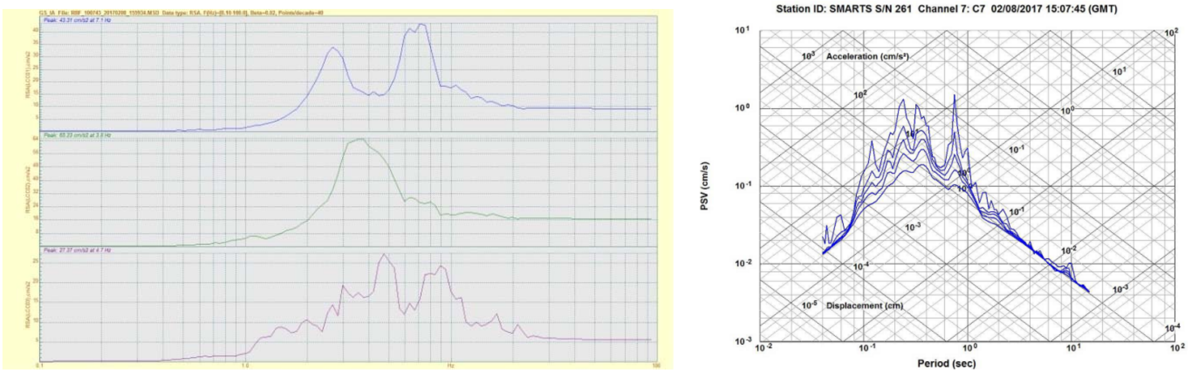

Figure 5. Acceleration Response Spectrum for X, Y and Z directions. Tripartite representation of acceleration, velocity and displacement spectra (channel 7)

Since February 2017, after this earthquake, the GMS18 GeoSIG station installed at the ground floor has been replaced with a triaxial sensor connected directly at the Granite multichannel station. From manual recordings for ambient vibrations, the maximum instantaneous values of the accelerations, velocities and displacements recorded with the three triaxial accelerometers on March 13, 2017, are shown in the following table and the graphical representations are attached, figure 6.

Table 5. The maximum instantaneous values of accelerations, velocities and displacements recorded with GRANITE (terrace)

Level/channel 1	PGA (cm/s^2)	PGV (cm/s)	PGD (cm)
Terrace-Granite	0.17	0.001	0.001
	0.09	0.002	0.001
	0.06	0.001	0.001

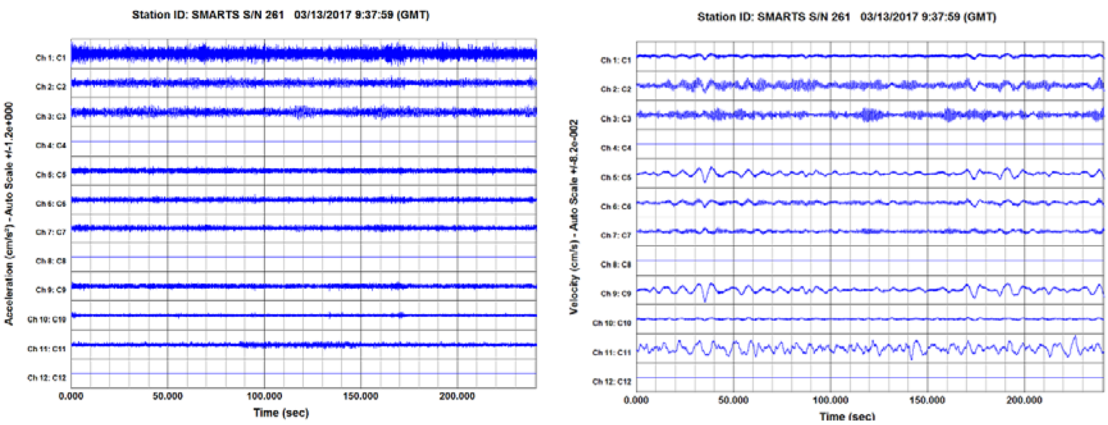

Figure 6. Acceleration and velocities histories time recorded by the three triaxial sensors on the three orthogonal directions X, Y and Z

For the Vrancea seismic event of May 19, 2017, M = 4.7, there was an automatic record at this magnitude event and the Fourier spectra at the top level was obtained, figure 7.

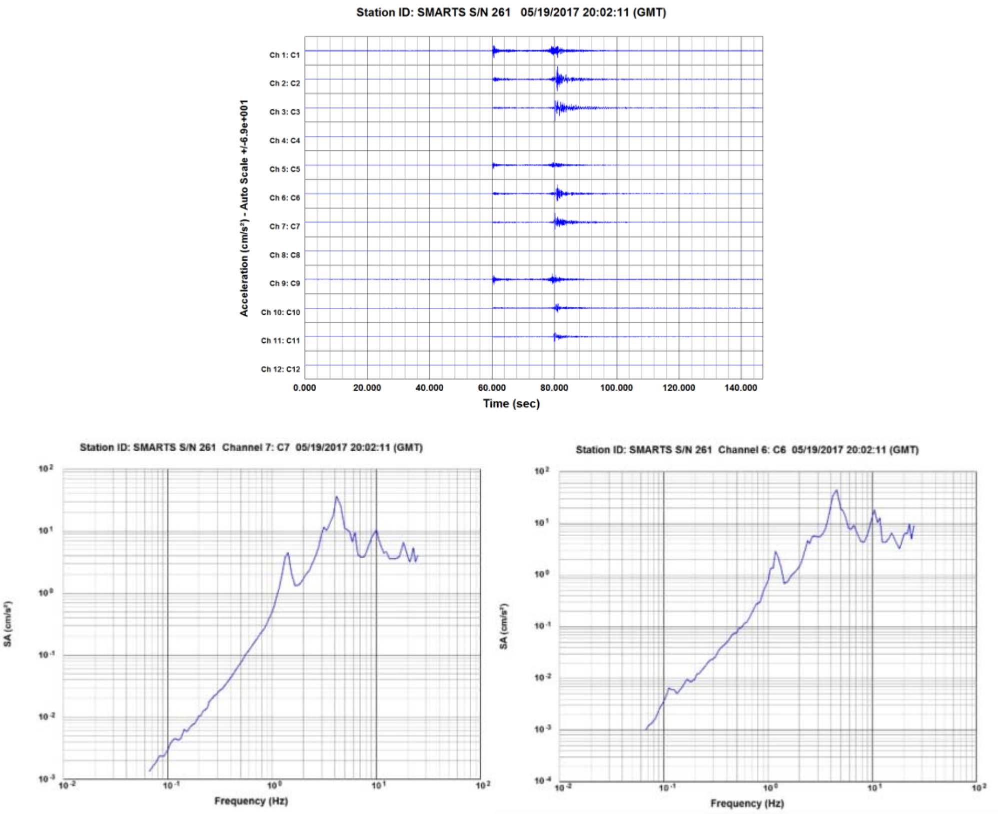

Figure 7. Office tower building in Bucharest. Fourier spectra at the top level (frequencies: fx=1.05 Hz and fy=1.3 Hz)

5. Conclusions

The monitored building, presented as a case study, is an example of concrete application of the concept of structural health monitoring of a building before and after a major seismic event occurs. In the next step of this process, after a seismic event, the damage will be identified based on the vibration records at different levels, their location and severity, the prediction of the remaining period of use of the structure, and the decision to take the necessary measures.

Within Programme "Research for the development of an instrumental detection system for structural damage caused by seismic or non-seismic sources PN 18-35 0101", the expansion of the seismic network for buildings is a continuous process, with the number of permanently monitored buildings rising in 2018 and the number of seismic sensors increased.

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