16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 833

Registration Code: S-E1464032246

NIRD URBAN-INCERC, ROMANIA SEISMIC STRONG MOTION NETWORK: State of the art and needs of development

C. S. Dragomir[(2, 1)], V. Meita[(1)], I. G. Craifaleanu[(3,1)], E. S. Georgescu[(1)]
D. Dobre[(4, 1)]

[(1)] *Senior Researcher, National Institute for Research and Development URBAN-INCERC, Bucharest, Romania, dragomircs@incd.ro; vasile.meita@gmail.com; emilsevergeorgescu@gmail.com*
[(2)] *Associate Professor, University of Agronomic Sciences and Veterinary Medicine, Faculty of Land Reclamation and Environment Engineering, Bucharest, Romania, claudiu.dragomir@fifim.ro*
[(3)] *Associate Professor, Technical University of Civil Engineering Bucharest, Romania,i.craifaleanu@gmail.com*
[(4)] *Lecturer, Technical University of Civil Engineering Bucharest, Romania,dobred@hotmail.com*

Abstract

Romania is a country, member of the European Union, with a unique seismicity in Europe through the presence of Vrancea source, which can produce a direct and indirect impact of national disaster, at a scale of more than 50% of the territory. In a single event with great magnitude very important trans-boundary effects might be produced in Republic of Moldova, Ukraine, and Bulgaria, as it happened in 1940 and 1977. Presently, an urgent necessity is the seismic network function in order to get as much as possible strong-motion data for advanced research and to understand why damages in buildings occurred. The next goal is to have more parametric and spectral data for engineering design, as well as to improve the zoning maps, having more stations at reduced distances. If possible, strong-motion micro-zonation data would explain some specific shaking differences, as a future option for local arrays. The paper presents the necessity, means and requirements of achieving a realistic development and modernization of the national seismic network for constructions, taking into account geological settings, environmental and local soil conditions on regional profiles, attenuation patterns, architectural and structural patterns, and number of seismic stations in specific seismic zones. Some aspects as the purchase, installation, maintening and operating of the network equipment, data transmission, processing and archiving, support research work using these data, dissemination etc. could present better the financial reality of this national network.

Keywords: seismic stations, digital accelerometer, acquisition and processing data

1. Introduction

The Vrancea intermediate source is the most important seismic zone from Romania, taking into account the energy, the extent of the macro seismic effects and that it can produce a direct and indirect impact of national disaster level on the scale of more than 50% of the territory. Thus, there is a need to be prepared for the moment when one of the strong events would strike. Knowing the dynamic structural characteristics and monitoring their evolution during the service life of the building can pro-vide useful information on its state, representing also a basic reference for post-earthquake assessment.

In Fig.1, earthquakes distribution in Romania as crustal earthquakes and sub-crustal earthquakes and the zoning map in PGA, from Romanian Seismic Design Code P100-1/2013, for earthquakes with average recurrence interval 100 years, are shown [1, 2].

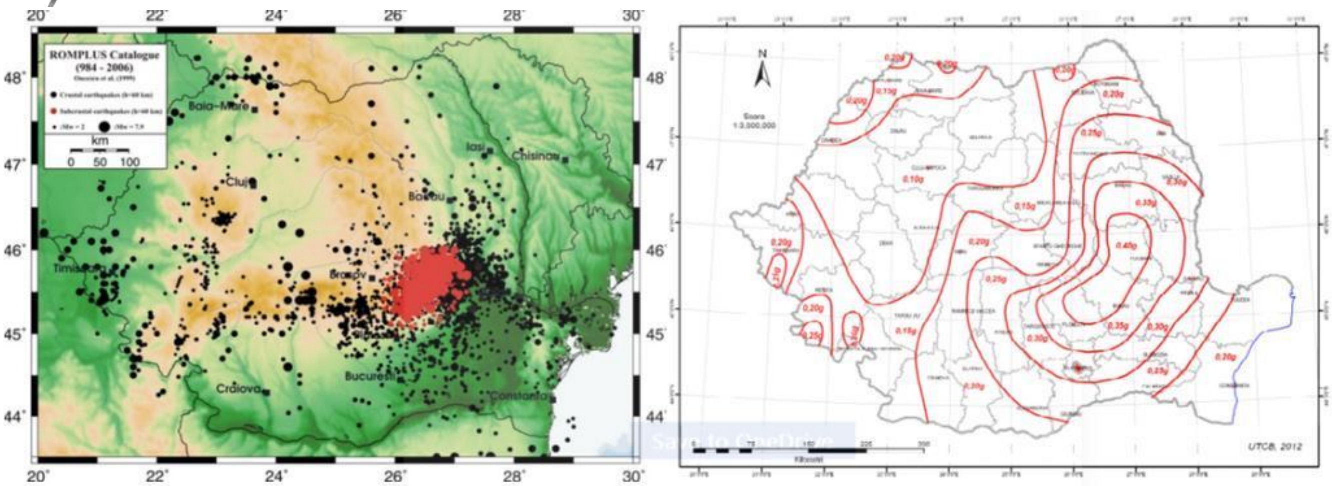


Fig. 1 - Earthquakes distribution in Romania, left. Zoning Map in PGA Code P100-1/2013, for earthquakes with average recurrence interval 225 years, right

During strong earthquakes, many usual buildings can be loaded beyond the elastic range, which could lead to a significant change of their dynamic characteristics, as consequence of structural damage and of the alteration of physical-mechanical characteristics. Typically, structural damage involves the decrease of building stiffness and the increase of natural periods. The measurement of structural vibration periods in different situations, i.e. after building construction completion, during normal service, after earthquakes occurrence, following retrofitting or other modifications affecting the building, allows a straightforward assessment of the damage degree.

Monitoring the evolution of dynamic characteristics by vibration instrumentation, as a requirement of structural safety assessment [3, 4, 5, 6], has evolved over time, at URBAN-INCERC, into the deployment of a sensor network, used for vibration recording and connected to a central station, allowing the real-time data transmission, recording and management.

Established in 1967 within the National Institute for Building Research, INCERC, the National Seismic Network for Constructions provided the single record of the destructive earthquake of March 4, 1977 (Mw=7.4). This historical record triggered an essential change of the design spectrum in the Romanian seismic code. The INCERC seismic network contributed with about 75% of the data recorded from the earthquakes of August 30, 1986 (Mw=7.1), May 30 and May 31, 1990 (Mw=6.9 and 6.4, respectively). As stronger earthquakes have been not recorded in the meantime, this data represents up to the present day the basis for seismic hazard and zoning studies in Romania. This network is deployed in parallel with the network of accelerometers located in small buildings (according to ANSS 2001 classification) or similar to free-field conditions. At present, the National Strong Motion Network for Constructions of URBAN-INCERC (in Romanian - RNSC) consists of 55 accelerometers, located in 45 localities in Romania. The present situation of RNSC, as well as some of the landmark buildings instrumented by URBAN-INCERC, is shown in Fig. 1 to 3.

RNSC is considered a strategic infrastructure for public safety; according to the vision of the Romanian government, its mission consists of:

- monitoring situations generated by earthquakes or other dynamic actions on instrumented locations;
- development of advanced processing and specific databases necessary to verify and improve seismic design codes and engineering zoning maps;
- centralization and timely transmission of data and information on the emergency and potential emergency situations or disasters caused by earthquakes or non-seismic sources, using data-base formats compatible with specific intervention systems in Romania;
- permanent acquisition and transmission of information in specific formats (e.g. GIS maps of intensities, local accelerations etc.) for prevention and response actions in case of earthquake, based on recorded data;

- creation, management and storage of databases referred on earthquake emergencies.

The Romanian seismic design code, P100 1/2013, includes, in its Annex A, the following provisions on the instrumentation of buildings:

- "in areas where the value of the design acceleration is ag 0.25g, buildings classified as class I of importance-exposure and buildings with above grade height of over 45 m, classified as class II of importance-exposure, will be seismically instrumented by digital accelerometers placed at the top level and in free field / at the base of the building and, optionally, in specific deep boreholes or in other positions in the building;
- the instrumentation, maintenance and operation are in the responsibility of the owner and records obtained during strong earthquakes should be available to authorities".

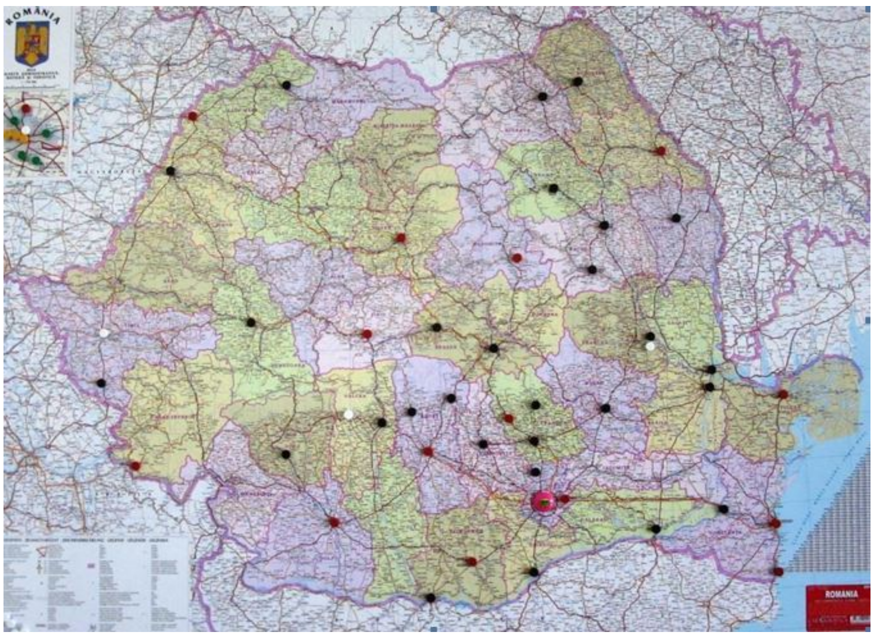


Fig. 2 – Present URBAN-INCERC seismic strong motion network equipments in Romanian territory

At present, the network consists of approximately 55 accelerometers, located in 45 localities in Romania. Of these, 11 accelerometers are located in Bucharest and 44 are deployed all over the country, particularly in the extra-Carpathian area, which is the most exposed to the Vrancea seismic source.

The goals of the network and of the pertaining infrastructure are manifold, aiming not only at ground motion recording, but also, in a larger perspective, at the improvement of the security and resilience of building stock to earthquakes and extreme actions. In this respect, a system for monitoring and displaying recorded ground motion data in real time is envisaged, in conjunction with data provided by SHM devices from instrumented buildings.

Recently, a plan for real-time transmission of the recorded seismic data was developed in collaboration with the Romanian Special Telecommunication Service. Accordingly, starting from November 15th, 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 building structures. The GeoDAS software used for data acquisition and processing is shown in Fig. 3.

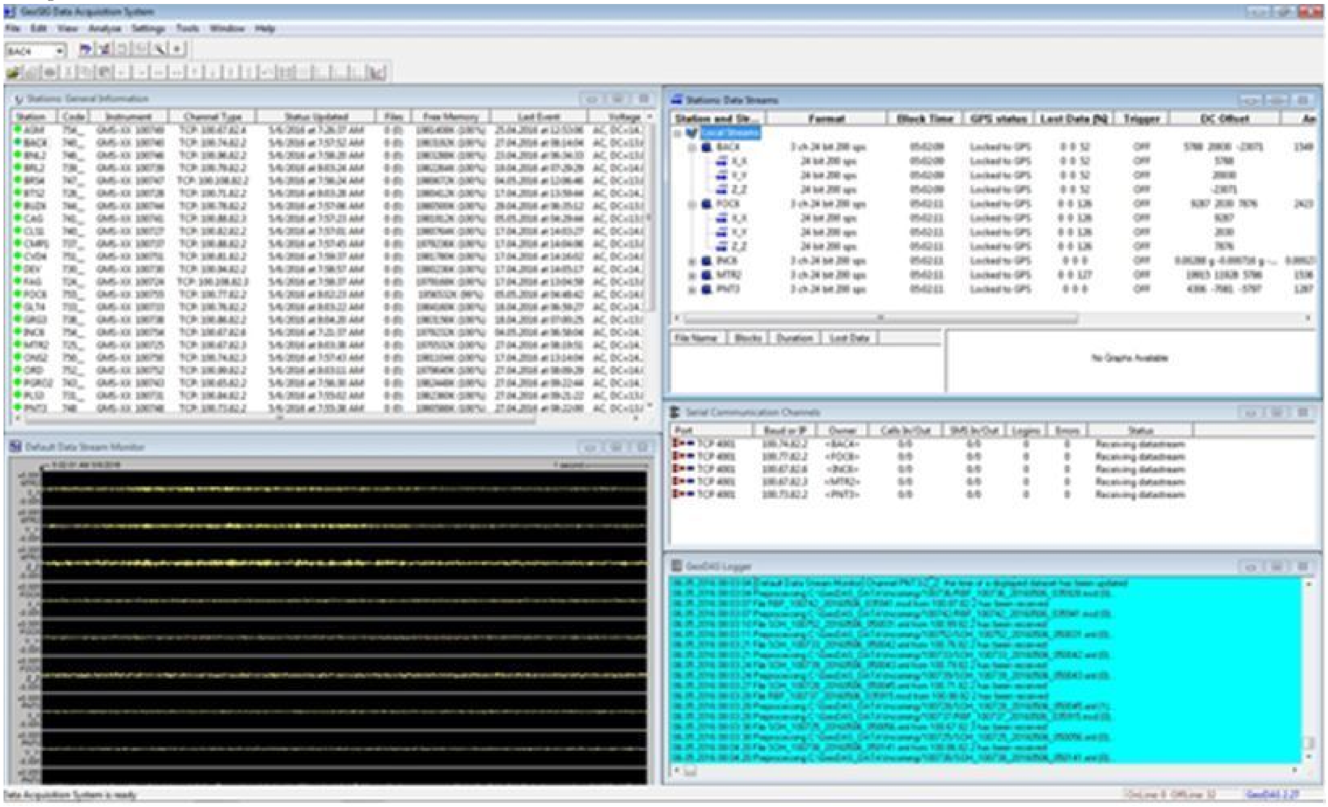


Fig. 3 – GeoDAS software for real time acquisition of seismic data provided from 32 digital stations

In Fig. 4, some types of monitored buildings of different heights and stiffness are presented.

Fig. 4 – Types of buildings of different heights and stiffness and the equipments which they are monitored

2. In-situ seismic structural instrumentation/monitoring of buildings. Case studies of two instrumented new buildings from Bucharest

First of the buildings presented in this paragraph is the new Bucharest City Hall. Due to the extensive retrofitting and rehabilitation works required by the old Bucharest City Hall, da-ting from the beginning of the 20th century, the offices were temporarily moved in a new building.

This 17-storey high, two-basement reinforced concrete building (Fig. 5) formed the object of the case study presented in the following, and in which the procedures and techniques for structural vibration monitoring, as well as of real-data transmission and data processing were applied.

Besides its importance as an administrative institution, the new City Hall is of particular interest from the earthquake engineering point of view due to its location and structure type. The building is located on the bank of the Dambovita River, which flows through Bucharest from West to East. Due to the several modifications of the river bed over the time, thick layers of alluvial soil are present in its vicinity. These soft soils, together with a specific source mechanism of the subcrustal M = 7.2 March 4, 1977 earthquake, were identified as the main cause of the long predominant period (Tp ≈ 1.6 s) of the ground motion recorded in Bucharest during this seismic event. The 1977 earthquake affected especially medium- and high-rise buildings, with periods approaching the spectral amplification range in the vicinity of this long period. It is significant to mention that, after the earthquake, the design spectrum in the Romanian seismic design code was radically modified, by extending its horizontal segment up to T = 1.5 s (and later to 1.6 s) for Bucharest and a large surrounding area in the Romanian Plain. Moreover, the recently enforced seismic code, P100 1/2013, has introduced special provisions for Bucharest, requiring that an additional increase of 20% is applied to the dynamic amplification factor, β0, for buildings with fundamental periods in the 1.4 … 1.6 s range and for which the equivalent lateral forces method is used in seismic design. These provisions were not in force, however, when the new City Hall was designed; moreover, the level of de-sign seismic forces was lower, according to the previous edition of the seismic code, P100-1/2006. It is thus of particular importance that such a building, with a two-fold potential seismic vulnerability, is instrumented and monitored during its entire service life.

Fig. 5 – City Hall building in Bucharest

The building was monitored for vibrations produced by various dynamic sources (micro-seisms/seismic noise/ambient vibrations). The digital records of acceleration obtained by using triaxial accelerometers placed on the building were processed using the original software packages for the processing of records (Strong Motion Analyst and GeoDAS) provided by the manufacturers of the vibration recording equipment, Kinemetrics, Inc., USA, and GeoSIG Ltd., Switzerland. The data acquisition equipments installed on the site were GeoSIG GMS-18 and Kinemetrics Granite digital stations.

Using accelerometric records of the building response to a moderate intensity Vrancea earthquake that occurred during the monitoring period and from other dynamic and non-seismic sources, various data processing, such as floor spectra, Fourier spectra, amplitude amplification functions etc were obtained. [3, 4, 5, 6].

Figure 6 shows accelerograms recorded, during the M = 3.9 March 18, 2016, Vrancea earthquake, by the GMS-18 GeoSIG digital accelerometer with internal triaxial sensor installed on the ground floor of the monitored building. In Fig. 7, acceleration time-histories recorded by the Granite multichannel station, with two sensors installed on the 4-th floor and on the roof of the building, are displayed. Each figure shows also the corresponding response spectra.

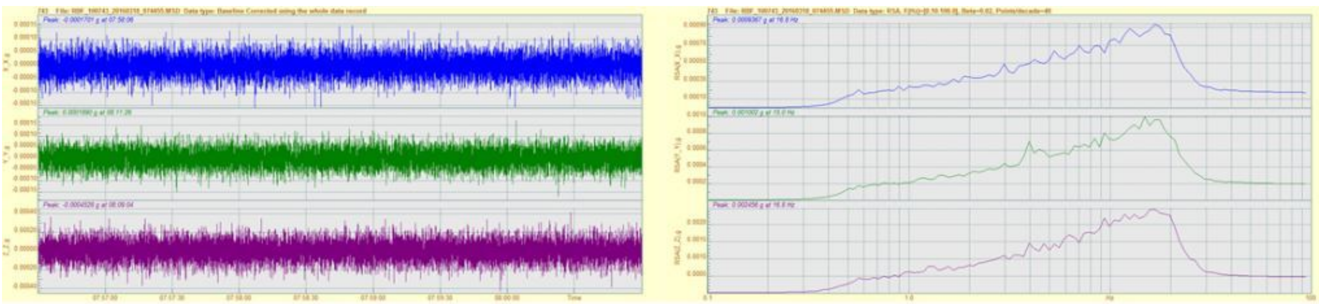


Fig. 6 – Acceleration time histories recorded in the three orthogonal directions X, Y and Z on ground floor of the City Hall building (3/18/2016 M = 3.9 Vrancea earthquake, GMS-18 GeoSIG digital accelerometer) and the corresponding acceleration spectrum

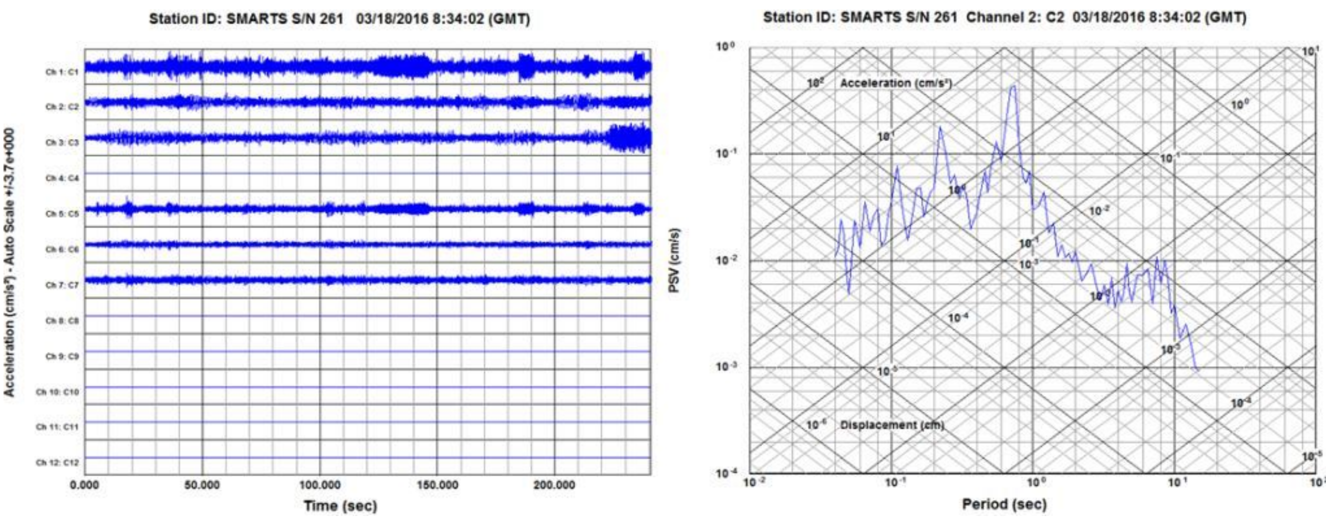


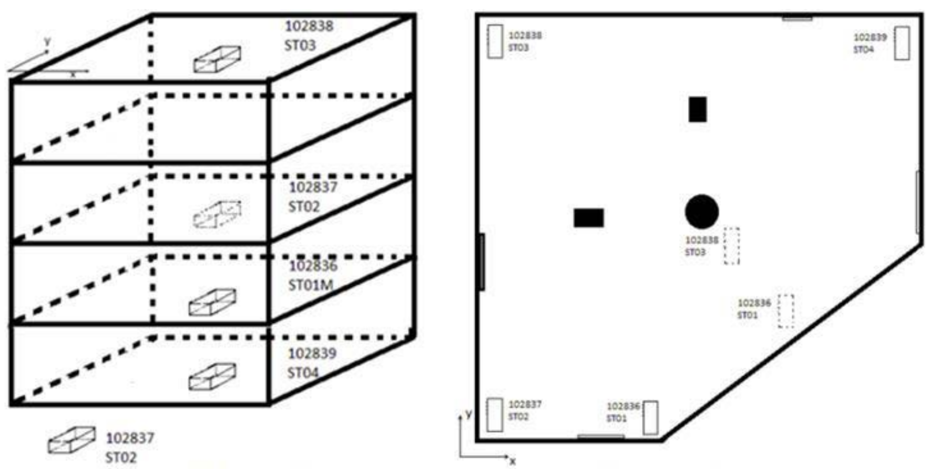
Fig. 7 – Acceleration time histories recorded by two triaxial sensors located at the 4th floor and on the roof of the new City Hall building (orthogonal directions X, Y and Z, 3/18/2016 M = 3.9 Vrancea earthquake, multichannel station Granite) and the corresponding response spectrum

The second study case presented in Fig. 8 is of the Biology Faculty building from Bucharest. In-situ seismic structural instrumentation/monitoring of a new built building of Biology Faculty, based on permanent micro-seismic agitation of soil/ambient vibration, in which the input data are the actual records for the response and the output are the dynamic characteristics for this structure was obtained.

All recordings have been obtained at the site, following the acquisition of data, from seismic monitoring equipment in the building, by transmission in real-time to the main server. The structural system of this building, Fig. 8, with basement, ground floor and 2 levels (B+G+2F), is made of reinforced concrete frames (columns and beams) and reinforced concrete structural walls, slabs and stairs. It has a semi-circular shape and the levels over ground are in cantilever related to those from the lower level.

Fig. 8 – The acquisition system with four GMS Plus digital seismic stations used for temporary seismic instrumentation of the new building of Biology Faculty from Bucharest, B+G+2F (5 bays of 5.00 m and 5 openings of 5.00 m; $H_{ground\ floor}$ = 3.80 m, H_{levels} = 4.10 m)

In Fig. 9, a schematic plan with the equipment positioning is presented (location sensors). Scheme 1: first option, with sensors in free-field, basement, ground floor and terrace level and, in the second option, one sensor is moved from free-field to level 1 (dotted line). Scheme 2: first option, with all sensors on terrace level of building, at corners, and in the second option two sensors are moved in another position (dotted line). By this seismic investigation, the effects as bending, torsion, horizontal stiffness of the floors; vibration frequencies etc are monitored.



Scheme 1 *Scheme 2*

Fig. 9 – GeoSIG GMS Plus equipment positioning vertically and horizontally

For estimating the fundamental period of this building, the following formulae is used: $T_1 = C_t\, H^{\wedge}0.75 = 0.15s$, where: $C_t = 0.075/\sqrt{(A_c)}$, A_c = the total effective area of structural walls on the 1st floor (approx. 13 m^2, on both directions), H = the height of building (12.85 m).

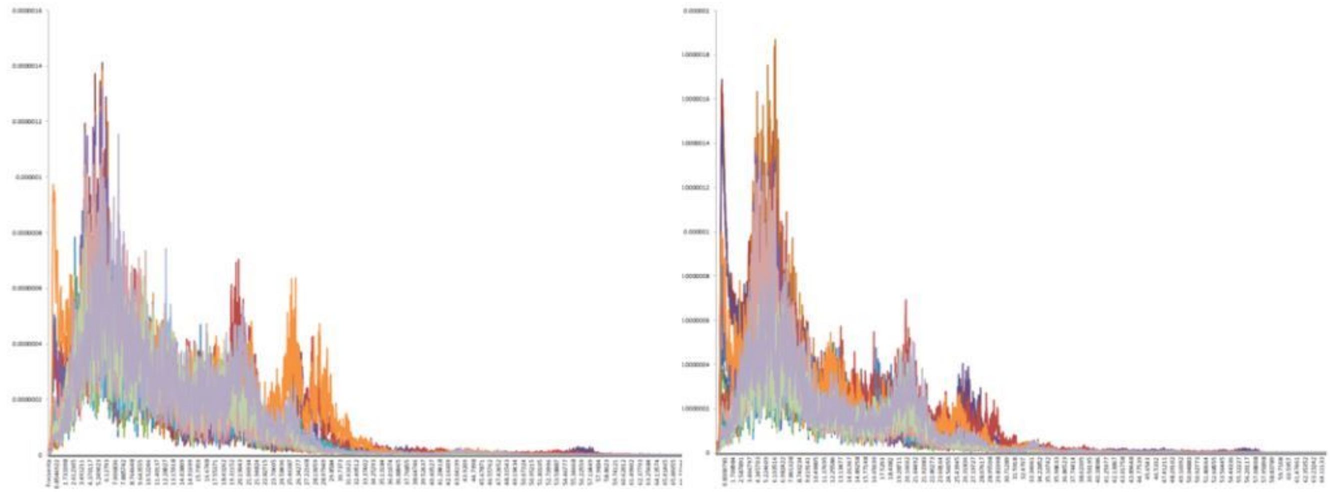


Fig. 10 – Fourier Response spectra, corresponding to the direction X and Y, from several series of recordings. Predominant frequency f_1= 5.47 Hz (T_1= 0.18 s)

For the validation of the FFT value f_1= 5.47 Hz (Fig. 10) the ARTeMIS software was used and the results of f_1= 5.08 Hz are emphasised in Fig. 11.

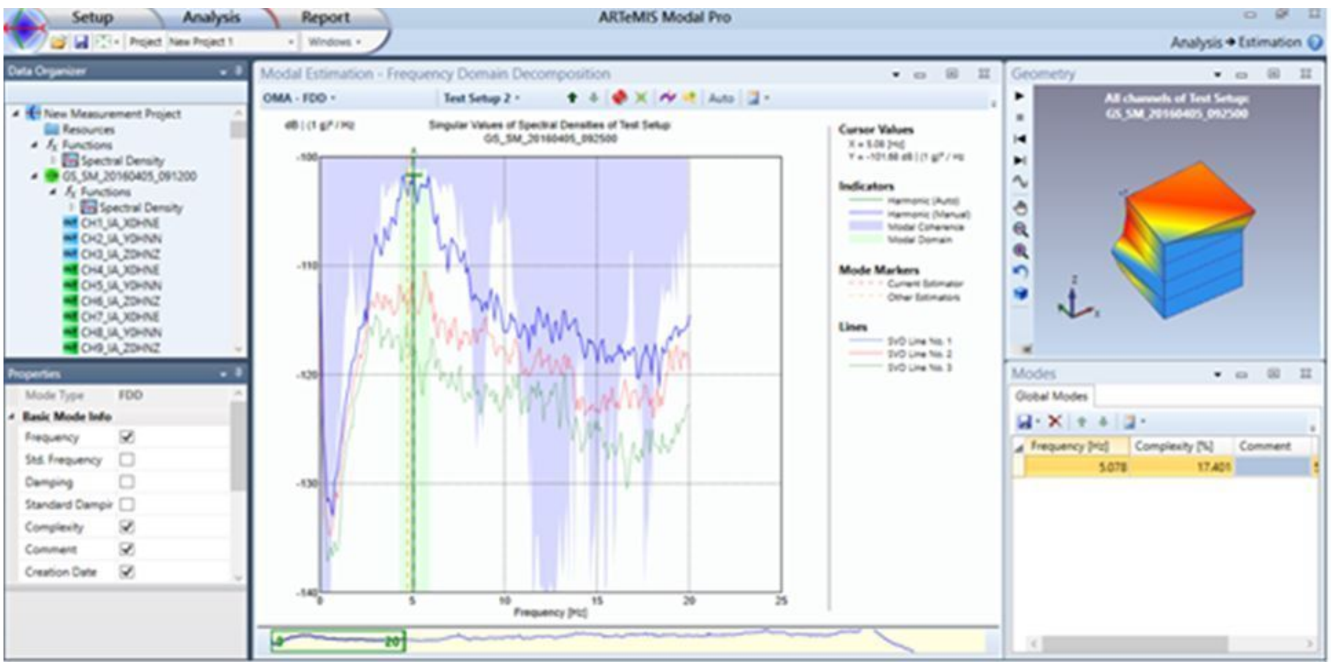


Fig. 11 – The results obtain following the Operational Modal Analysis, FDD technique

The allowable values of vibrations are distributed generally in a relatively wide band of values: the level of allowable strength of the vibrations, 17...20 vibrars; velocity instantaneous maximum oscillation for soil, 3 ... 25.4 mm/s; velocity instantaneous maximum oscillation for structure, 8 ... 25.4 mm/s, and they are monitored because of the impact on overall building performance and on those who live there. The vibration values obtained in the cases of these buildings are within these limits.

It is necessary also more experimental research related to types of soils and geological conditions, the control vibrations and control strategies for seismic energy dissipation, the fillers influence on the self-compacted concrete properties of construction materials etc., in order to get a better interpretation of seismic performance level of a building.

3. Integrated investigation methods of building performance

By real-time data transmission, the integration of two approaches, the monitoring of structural characteristics and behavior and the earthquake early warning / alert, is aimed. The concept of integrating these two systems, EEW (Earthquake Early Warning or Alert) and SHM (behavior/state monitoring of building structures), could use their basic features and the direct possibility, already adopted in some countries, of the correlation of acquired information.

In this context, the National Strong-Motion Network of URBAN-INCERC has developed a plan for enhancing integration with the seismic network of the National Institute for Earth Physics, NIEP. Close collaboration relationships with this research and development institute exist ever since its establishment, in 1977, and several joint research projects were carried out over the years. A number of data exchange protocols were also established. However, given the absence of real-time data transmission capabilities in the URBAN-INCERC network, many aspects of integration, especially the contribution to the regional early warning system that is in process of being implemented at NIEP [8], could not be put in practice. Rather recently, with the support of the Special Telecommunications Service in Romania (STS), these capabilities were acquired.

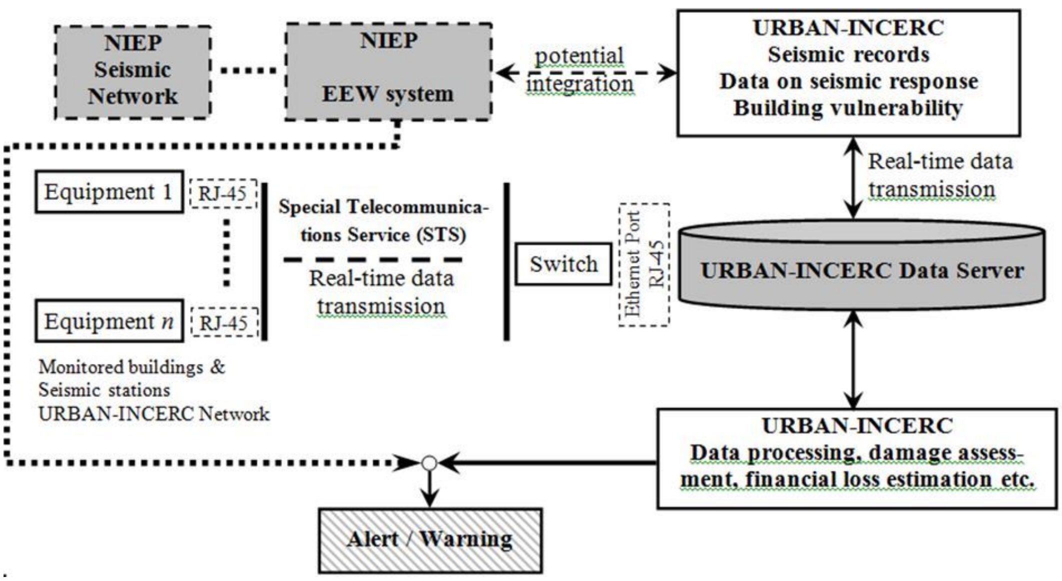


Fig. 12 – A proposed system for the real-time transmission and integration of recorded seismic data

The flowchart in Figure suggests a system in which the specific data, information and infrastructures of the two institutes, URBAN-INCERC and NIEP, could be integrated, following a complementarity - and interdisciplinarity - based approach. This will favor also the integration at European and global scale, allowing the collaboration in large research and development infrastructures, consortia and international organizations.

4. Conclusions

The strong-motion network of URBAN-INCERC is officially included among the Romanian infrastructures related to seismic risk reduction. Its functions are aimed to support emergency situations and monitoring of the territory of Romania for seismic and other actions that can be hazardous for constructions and infrastructure. The network delivers reports with recorded and processed data to the competent authorities, in case of events with impact on constructions and infrastructure, according to the attributions established by the Romanian Ministerial Committee and the Operative Centre for Emergency Situations.

From the financial point of view, the purchase of the network equipment has meant 600000 euro, while the installation, maintening and operating, data transmission, processing and archiving, support research work using these data, dissemination etc. aprox. 45000 euro per year. Buildings taken into account in order to enter into a program of seismic instrumentation and monitoring are the buildings for the public utility (mayors, hospitals, universities buildings), in time being included also the others.

In the discussed case studies, the fundamental frequencies of the buildings can be estimated from spectral representations and by applying a theoretical formula from Romanian Seismic Design Code P100-1/2013. The received vibrations are amplified by building corresponding to its frequencies of oscillation. It can be seen that there is a small difference between the derived values, in case of Biotechnology Faculty building.

5. Acknowledgements

This paper is based on results obtained in Programme: Integrated researches for resilience, efficiency and comfort of built environment – CRESC, PN 16 10.01.01.

6. References

[1] http://www1.infp.ro/local-seismicity/romanian-seismicity.

[2] Romanian Seismic Design Code P100-1/2013.

[3] Georgescu E S & Borcia I S (2005): Monitoring of buildings in seismic areas, *Journal of Constructions*, Year I, Issue 9, October 2005, ISSN: 1841-1290 (in Romanian).

[4] Borcia I S & Georgescu E S (2005): Seismic monitoring of buildings: prerequisites, case study and perspectives, Informative Bulleting of the National Commission "In Siu Behavior of Buildings", CISC, year IX, Issue 4 and 5, Bucharest, 2005, ISSN: 1584-6687 (in Romanian).

[5] Borcia I S (2006): Processing of strong motion records specific for the territory of Romania, *Ph D Thesis, Technical University of Civil Engineering*, Bucharest, Romania.

[6] Georgescu E S, Borcia I S, Praun I C & Dragomir C S (2014): State of the art of structural health monitoring in seismic zones of Romania, Proceedings of MEMSCON 2014.

[7] Craifaleanu, I G, Borcia I S & Praun I C (2011): Strong-Motion Networks in Romania and Their Efficient Use in the Structural Engineering Applications". In S. Akkar, P. Gülkan & T. van Eck (eds), *Earthquake Data in Engineering Seismology. Predictive Models, Data Management and Networks*: 247-259. Dordrecht, Heidelberg, London, New York: Springer.

[8] Marmureanu A, Ionescu C, Cioflan C, Elia L, Zollo A, Colombelli S & Martino C (2012): Towards an Integrated Regional Early Warning System for Romania - Vrancea Earthquakes: Test and Performances. *AGU Fall Meeting*, San Francisco, USA.