Insights from the management of a large research infrastructure in Romania: National Network for the Seismic Monitoring and Protection of Building Stock at NIRD URBAN-INCERC

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Abstract. The National Network for the Seismic Monitoring and Protection of Building Stock is a key infrastructure of the National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development “URBAN-INCERC” in Romania. This infrastructure includes at present, among other research facilities, a strong-motion network of 64 permanent seismic stations, to which other temporary stations are added for various short-term vibration monitoring projects. Since its establishment in 1967, the seismic network has played an essential role in recording the earthquakes that affect Romania. Today, the seismic stations are distributed all over the country, according to its characteristic seismicity patterns. Most of them use state-of-the-art recording and communication equipment, being permanently connected online to the Data Center in Bucharest. The management of the network implies conducting a complex set of activities, centered on the recording, processing, analysis and interpretation of natural- and human-induced vibrations. All of these are seconded, in parallel, by various maintenance, reporting, logging, communication and dissemination tasks. The logistic and financial management also plays an important role. A rational and efficient administration of the seismic network cannot be acquired without a rigorous organization of data flows pertaining to the various activities performed. The paper provides insights from the organization of the network, highlighting the intercorrelation between the hierarchical levels of its functionality and the logical course of operation. A brief review of the challenges and solutions gradually developed and implemented by the members of the network team, in order to provide the required functionality, is presented.

1. Introduction
In seismic-prone areas, ground motion monitoring is a crucial activity for acquiring data on the local and regional earthquake hazard. Starting with the installation of separate instruments in a relatively small number of locations, ground motion monitoring has evolved to the deployment of several stations, forming a seismic network, in which collected data is joined and processed together [1]. The progress of seismic networks occurred gradually, as technological advances allowed for higher precision sensors,
real-time communication systems, automated data processing and advanced storage solutions. The types of recording instruments have also diversified, depending on the type of monitored ground motions and on the scale at which the network is deployed. Today, there are several local or national networks, but also global networks, that record earthquakes from the whole world, as the Global Seismographic Network [2] or the International Federation of Digital Seismograph Networks, FDSN [3].

A large number of seismic networks are nowadays installed in most earthquake-prone areas, covering large surfaces and implying the management and maintenance of tens or hundreds of instruments and of the associated communication lines and equipment. The obtained ground motion records, often totaling huge amounts of data, have to be undergo various processing phases, which are required for their correct analysis and interpretation. These operations require specialized software, high-end computers, dedicated storage capacities and qualified personnel. Once the processing completed, data classification and backup has to be done, for easy retrieval and distribution. The entire management of a seismic network requires thus the coordination of several interconnected activities, which concur to the proper functioning of the entire system.

Even though the technical solutions used and the general organization of existing seismic networks in various countries have at present many things in common and tend to become standardized, there are however several aspects that depend on specific conditions and on the historical evolution of each network. The paper presents some insights on the organization and management of the seismic network of the National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC" (NIRD URBAN-INCERC) in Romania.

2. The seismic network of NIRD URBAN-INCERC

The seismic network of NIRD URBAN-INCERC has been in continuous operation since its establishment in 1967 [4]. Over the years, the network contributed with essential seismic records to the characterization of the seismicity of the country. The most important record was the unique accelerogram of the catastrophic M = 7.2 earthquake that occurred in the Vrancea (Romania) seismic zone on March 4, 1977. The analysis of the unusual features revealed by this record and the general lessons learned from the earthquake led to a radical change of the Romanian seismic design code, which was significantly revised after the earthquake.

During the more than five decades of operation, the network went through several transformations, evolving both technologically and in terms of area coverage. Today, together with other related research facilities, the seismic network is part the National Network for the Seismic Monitoring and Protection of Building Stock (IOSIN), a key infrastructure of NIRD URBAN-INCERC [5]. It operates 64 permanent accelerometric stations. Most stations use state-of-the-art recording and communication equipment, a large number of them being permanently connected online to the Data Center located at the INCERC Bucharest Branch of the institute. The stations are installed in various locations across the country (figure 1), the sites being selected according to the particular characteristics of the seismicity of Romania and taking into account the various seismogenic sources.

The management of the seismic network implies conducting a complex set of activities, centered on the recording, processing, analysis and interpretation of natural- and human-induced vibrations. All of these are seconded, in parallel, by various maintenance, reporting, logging, communication and dissemination tasks. The logistic and financial management also plays an important role. A rational and efficient administration of the seismic network cannot be acquired without a rigorous organization of data flows pertaining to the various conducted activities.

The seismic network is managed based on a set of customized hierarchical procedures, which has been gradually developed by the members of the network team, during a work spanning over several years. The procedures have to be periodically updated, in order to respond to the contemporary needs generated by the specific layout, configuration and functionality requirements.
3. Seismic network management data flows
The current structure of data flows [6] within the seismic network of NIRD URBAN-INCERC is shown in figure 2.

**Figure 1.** The National Seismic Network of NIRD URBAN-INCERC, Romania, and the locations of the regional research facilities of the National Network for the Seismic Monitoring and Protection of Building Stock (Bucharest, Cluj-Napoca, Iaşi and Timișoara).

**Figure 2.** Current structure of the data flows within the NIRD URBAN-INCERC seismic network.
3.1. Data acquisition
The main data provider is the data acquisition equipment, consisting of strong motion accelerometers. There are three types of seismic stations in the network, according to their location and to the position of the instruments:
   a) stations installed in free-field or in small buildings - the latter similar to the Strong-Motion Reference Station: Small Building (SMRS-SB) in the ANSS classification [7];
   b) stations installed in higher buildings, on the base floor of the building, similar to the Strong-Motion Building Reference Station: Densely Urbanized Area (SMBRS-DU) in the ANSS classification [7];
   c) instrumented buildings.
   According to the way in which data is transmitted to the seismic network data center, the stations in the seismic network of NIRD URBAN-INCERC are either connected online or without a connection. In the second case, recorded data is retrieved by site inspections. Most of the online stations use the dedicated network of the Special Telecommunications Service (STS); however, a small number are connected through commercial mobile phone networks.

   Based on the above, two distinct data flows are shown in figure 2: Data Flow 1 (yellow), for online stations (STS network with continuous line and mobile data operators with dotted line), and Data Flow 2 (light blue), for the other stations. Given that the seismic network uses Kinematics and GeoSIG accelerometers, the type of connection for each of the two equipment providers is shown in the figure.

   Temporary stations are also used occasionally, for various vibration monitoring projects. These do not have generally an online connection; thus, the acquired data is transferred to the Data Center through Data Flow 2.

3.2. Data center operations
Once the recorded accelerograms have reached the Data Center, processing, conversion and consolidation of the data have to be done. Given the different types of instruments in the network, data is provided in various formats. The first processing steps are carried out using specific software from each equipment provider, i.e. SMA for Kinematics [8] and GeoDAS for GeoSIG [9].

   For the structural health monitoring of instrumented buildings, the SVIBS ARTeMIS software is used [10-13] (figure 3).

![Figure 3](image)

**Figure 3.** Use of records obtained on instrumented buildings in SVIBS ARTeMIS. Case study on the structural health monitoring of a residential building in Bucharest.

To use the processing results in subsequent research and analyses, data is converted in general formats and consolidated in a unified form. All the above operations address data pertaining to Data Flow 3 (marked with light green arrows in figure 2).
3.3. Data backup and document archival
Raw data (Data Flow 4), as well as processed data (Data Flow 5), are backed up to dedicated storage media (lavender arrows in figure 2). Data is organized primarily on a chronological basis. In addition, a codification system is used, to allow quick data retrieval for specific locations. Thus, each station is identified by a unique three-letter code, a system that is compatible with other internationally and nationally used approaches. To this code, a one-digit number is added in the case of more stations existing at the same location. Strong-motion records with magnitude larger than 5, envisaged for inclusion in the URBAN-INCERC reference database [14], are identified by a code created through the concatenation of the year of the earthquake, the reference number of the seismic event and the station code. Given the huge amount of data, this is a critical step, both in terms of data organization and in terms of ensuring redundant and reliable storage.

3.4. Maintenance and logistics
To support the main operations, various additional activities are required. These address data center software upgrade and maintenance, as well as site inspections for equipment check, repair and replacement. The activities require rigorous management and planning, as well as reliable logistics. Moreover, all operations should be logged and archived, to provide traceability and to comply with the internal procedures and the generally applicable legal framework. Various other activities, as those related to procurement, accounting and general management are here involved. The data associated to the entire set of the above activities forms Data Flow 6 in figure 2 (magenta arrows).

3.5. Reporting and dissemination
Periodic reports on various aspects of seismic network activity are compiled and sent to the management staff and superior hierarchic departments, according to internal procedures. The communicated data is shown in figure 2 as Data Flow 7 (blue arrow).

A special data flow is dedicated to data and information communication and dissemination. After each significant earthquake, seismic reports are prepared, including ground acceleration data, maps and comments on the characteristics of the event. Moreover, given that the seismic network is a central infrastructure of a research institute, acquired ground motion data is directly used within studies performed in the frameworks of national and international research projects. Results are presented in scientific events and published in conference proceedings and journals. While these types of information are disseminated to academia, professionals or authorities on a regular basis, other specific actions are dedicated to raising seismic risk awareness and to the education for seismic risk mitigation of citizens, decision factors, business owners and other audience categories. Several activities of the latter type were carried out during recent years by the European Center for Buildings Rehabilitation (ECBR) in URBAN-INCERC as, for instance, those in the project “Seismic risk preparedness and disaster risk reduction – DRR training for vulnerable groups of populations, school students and volunteers in neighborhoods in Romania” [15].

These activities are reflected in Data Flow 8 (red arrow), shown in figure 2.

4. Implementation and perspectives
To ensure the efficient operation of the network infrastructure and a proper data flow, various functional issues have to be tackled with. These can arise for every type of data flow presented in the previous section and specific solutions apply.

Some of the most frequent issues occur with regard to recording and communication equipment, as this requires permanent maintenance and repair and, if needed, updating. This involves not only technical operations, but also mobilizes some activities associated to other data flows, such as procurement, reporting and logging, as shown in Sections 3.4 and 3.5 above. If these operations are not carried on in a timely manner, equipment malfunction can lead to the irretrievable loss of data in case of a seismic event. For this reason, ensuring the functionality of Data Flows 1 and 2 in figure 2 is a central point, as it impacts the functionality of the entire network and its main goal of providing as much
as possible quality data from seismic stations and instrumented buildings. It is worth mentioning that, if communication issues occur during the transmission of recorded data from online instruments to the server, data will not be lost, given that it is stored locally, in the instrument. Consequently, data can be downloaded once the connection is re-established or, in the worst case, it can be recovered by a site inspection. The redundancy of data recording is thus ensured. In addition, raw and processed data is backed up systematically on reliable media, within the Data Center (see Data Flows 4 and 5 in figure 2).

The activities in the Data Center involve complex processing (Data Flow 3 in figure 2) and many of them are performed, at present, by human operators. Not only the data comes in various formats, given the different types of instruments that provide it, but, in addition, different goals are associated to free-field and SMRS-SB recordings and to structural health monitoring, respectively. One of the ways of improving the efficiency of Data Center operations is to increase, as much as possible, the automation of all processes.

The functionality of the network also relies, in a large measure, on the proper coordination of all activities and on a systematic organization of underlying operations, including logging, reporting and document archival for traceability. Collaboration is a key word for the success of the entire process.

The gradual increase of the number of stations and their rational spatial distribution, according to the specific of the country’s seismicity, are among the main objectives for future development, aiming to achieve an improved seismic instrumentation of the whole territory of the country, by coordination also with other Romanian networks [13]. The extension of building instrumentation, in terms of building number, significance and covered typologies are another important objective. Finally, no less important are the focus on the quality of seismic records, the upgrading of the equipment and the implementation of a higher degree of automation for all network management operations.

5. Conclusions
The acquisition, processing and interpretation of strong ground motion and vibration data are among the main activities conducted within the National Network for the Seismic Monitoring and Protection of Building Stock at NIRD URBAN-INCERC. The efficient management of the very large amounts of data generated within these specific activities is a key condition of a systematic and organized process, in which an effective valorization of these data can be achieved. Beyond the intrinsic value of the acquired information, this serves the major purpose of saving lives and of minimizing losses in future earthquakes, contributing as well to providing a safe and sustainable built environment.

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