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GROUND MOTION DATA QUALITY ASSURANCE: FUNDAMENTAL REQUIREMENTS AND THEIR PRACTICAL IMPLEMENTATION WITHIN THE NATIONAL NETWORK FOR THE SEISMIC MONITORING AND PROTECTION OF BUILDING STOCK, NIRD URBAN-INCERC, ROMANIA

Iolanda-Gabriela CRAIFALEANU[3, 1], Claudiu-Sorin DRAGOMIR[1, 2], Daniela DOBRE[3, 1], Emil-Sever GEORGESCU[1], Alexandra-Marina BARBU[1]

[1]National Institute for Research and Development in Constructions, Urbanism and Sustainable Spatial Development - URBAN-INCERC, 266 Pantelimon Blvd, District 2, Bucharest, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăști Blvd, District 1, Bucharest, Romania
[3]Technical University of Civil Engineering Bucharest, 122-124 Lacul Tei Blvd, District 2, Bucharest, Romania

Corresponding author email: i.craifaleanu@gmail.com

Abstract

The participation of the National Network for the Seismic Monitoring and Protection of Building Stock (RNMPSPC) at NIRD URBAN-INCERC in EPOS ERIC, the pan-European Research Infrastructure for Solid Earth Science, requires a rigorous framework for ensuring high-quality seismic data. This paper presents key criteria for seismic data quality assurance and their implementation within RNMPSPC, which operates a strong-motion network of 64 stations across Romania. We detail modern methodologies for seismic data acquisition, processing, and validation, emphasizing compliance with international standards. The practical application of these methods is illustrated using records from a recent ML 5.4 earthquake in the Vrancea seismogenic zone. The study highlights ongoing improvements in equipment, software integration, and data management to enhance the accuracy and reliability of ground motion records. These advancements support seismic hazard assessment and structural safety, reinforcing Romania's contribution to global seismological research.

***Key words**: seismic data, quality assurance, seismic network, Romania, research infrastructure.*

INTRODUCTION

Seismic monitoring is a key activity in informing pre-earthquake seismic hazard assessments, rapid identification of seismic damage in instrumented buildings and assisting post-earthquake decision making. From a broader perspective, data acquired from recording ground motions and the response of buildings to these actions provide an essential basis for advancing earthquake engineering science. Seismic networks have already a long history, dating from the late 1800s, when the British geologist, engineer and seismologist John Milne deployed the first international network of seismograph stations, consisting eventually of 30 instruments that recorded ground motion on photographic paper (ISC, 2018; Tripathy-Lang & Bohon, 2022a). Nowadays, seismographic networks maintained by organizations from various countries cover most of the Earth's surface and, given the advancements of sensor technology, not only provide data on ground motions and issue earthquake early warnings, but they are also used in tsunami warning systems (Tripathy-Lang & Bohon, 2022a). Strong-motion networks, equipped with accelerographs and developed from the need of recording potentially damaging ground motions, were first installed in the early 1930s, in the United States (USGS, 2025). Gradually, more and more countries deployed their own strong-motion networks. At present, thousands of accelerographs are deployed all over the world.
In Romania, the first seismographic station was installed in 1895, on Filaret Hill in Bucharest, by the physicist, astronomer and meteorologist Ștefan Hepites (INFP Archive, 2025). The first strong-motion network in Romania was established in 1967 by the National Institute for Building Research, INCERC. Starting from

2009, INCERC is part of the National Institute for Research and Development in Constructions, Urbanism and Sustainable Spatial Development - URBAN-INCERC. This seismic network has been in continuous operation since its establishment and provides ground motion records, as well as data from the monitoring of instrumented buildings. A history of the evolution of strong-motion networks in Romania is provided in (Craifaleanu et al., 2010).

At present, the strong-motion network of URBAN-INCERC consists of 64 digital accelerometers, located according to the main seismicity patterns of the country. Of these, 31 are Kinematics (U.S.) instruments and 33 are from GeoSIG (Switzerland), almost 80% being permanently connected online to the Data Center of the seismic network, by using transmission lines from the Romanian Special Telecommunications Service (STS) and from local GSM operators. The URBAN-INCERC seismic network is the central infrastructure of the National Network for the Seismic Monitoring and Protection of Building Stock (RNMPSPC), established in 2017, and which also includes components for experimental testing of building materials, elements and structures. In 2023, in recognition of its importance for a seismic country like Romania, RNMPSPC was granted the status of Infrastructure / Special Objective of National Interest (I.O.S.I.N.), which entitled it for receiving, from the Romanian Ministry of Education and Research, annual funding for maintenance, operation and exploitation.

Given its long existence, the seismic network of URBAN-INCERC has developed, over the years, durable relations with several universities, academic institutions and organizations in Romania and abroad. One of the most significant is collaboration, based on complementarity, with the National Research and Development Institute for Earth Physics, INCDFP, which also owns and operates a large national seismic network, with a focus on seismology. With worldwide recognition in its field, INCDFP is a member of the European Research Infrastructure Consortium EPOS (European Plate Observing System, https://www.epos-eu.org/epos-eric, the pan-European Research Infrastructure for Solid Earth Science), coordinating its Romanian branch, EPOS-RO (https://epos-ro.infp.ro/). EPOS ERIC has currently 19 member countries, and one country, Germany, participating as an observer. The Romanian branch, EPOS-RO, includes five research and development institutes and two universities.

At present, RNMPSPC provides seismic data to the EIDA node (www.orfeus-eu.org/eida) of INCDFP, which is directly connected to the EPOS data portal. The number of connected stations is expected to increase progressively.

Participation in the EPOS Consortium, as well as the need for providing accurate and standardized seismic data, imply, for RNMPSPC, conforming with several requirements, such as hardware and software performance, compatibility with similar worldwide infrastructures, rigorous procedures for seismic data recording, processing and archiving, connectivity with the EPOS data portal, and a structured management of the entire infrastructure. The actions conducted recently in this respect are presented below, with a particular focus on those dedicated to the quality assurance of seismic data. Additional insights into ongoing research and development activities at RNMPSPC can be found in (Dragomir et al., 2023; Mărmureanu et al., 2021).

MATERIALS AND METHODS

In recent years, numerous studies have focused on quality assurance in seismic data, driven by the growing importance of global seismological networks, the interconnection of earthquake monitoring infrastructures, and the increasing demand for high-quality ground motion data. These advancements are essential for seismology, earthquake engineering, and global seismic hazard assessment.

With the advancement of ground motion sensor technology and the automation of recorded data processing, even though human involvement has remained a necessity, the search for methodologies adapted to the automatic screening and quality verification of large amounts of data gained significant momentum. A review of common data processing techniques has revealed several aspects that can lead to distortions or unrealistic features in the processed signal. Several key studies (Douglas, 2003; Boore & Bommer, 2005; Akkar & Bommer, 2006; Akkar & Boore, 2009; Casey et al., 2018; Ravizza et al., 2019; 2021; Di Giulio et al., 2021) have identified critical issues in seismic data processing and proposed best practices to mitigate these errors. More recently, modern technologies such as machine learning and advanced signal processing techniques have been integrated to assist in the large-scale processing of seismic data (Bellagamba, 2019). Many of the findings of these studies were implemented within complex projects aimed at creating reference ground motion databases and leveraging international collaboration in the field, like RESORCE (https://www.resorce-portal.eu/; Akkar et al, 2013), NERA (Luzi et al., 2016) or SERA (http://www.sera-eu.org/en/home/index.html; Crowley et al., 2018). One of the most significant achievements in the field of seismic data infrastructures is ORFEUS (Observatories and Research Facilities for European Seismology), (https://www.orfeus-eu.org/), the European Infrastructure for seismic waveform data in EPOS. The EIDA data centres connect twelve European data archives, totalling 450 TB of data from almost 300 seismic networks (11000 seismic stations) (Strollo et al., 2021). Within EPOS, seismic data quality assurance is considered an essential prerequisite, covering all steps of the data recording, processing, archiving and distribution. The EIDA nodes and the associated seismological observatories are responsible for implementing their own procedures of data and metadata quality control, complying at the same time with the best international standards and practices (ORFEUS documentation, 2023; Schaeffer et al., 2024).

To comply with the requirements coming from the participation of RNMPSPC in the EPOS-RO/ EPOS ERIC consortium, several actions were taken in the recent period, as presented in the following. These actions are in line with the requirements of the ORFEUS Quality Assurance (QA) documentation (ORFEUS, 2023).

1. Extending and upgrading the infrastructure

a) The seismic network was extended with new stations and accelerometers in existing stations are being gradually replaced with state-of-the-art equipment, with superior capabilities. The accelerometers used in the network come from worldwide trusted manufacturers (Kinemetrics, GeoSIG). Best practices are followed for the placement of accelerometers, typically in small buildings, with low influence on recorded signal. For instrumented buildings, at least two sensors are placed (bottom and top of the building), accompanied, when possible, by a free-field type station, following the COSMOS Guidelines (COSMOS, 2001). It should be noted that instrument deployment must be first agreed with the owner of the space, which induces some restrictions on location selection.

b) Starting from 2023, the year when RNMPSPC received the status of Special Installation/Objective of National Interest (IOSIN), funding for maintenance and reparation of existing equipment, as well as retrofitting of the spaces of the Data Centre is provided, in a large measure, by the Executive Unit for Financing Higher Education, Research, Development and Innovation (UEFISCDI), within the Programme “Research Infrastructures”, PN-IV-P5.5-IOSIN-1. Figure 1 shows the newly retrofitted RNMPSPC Data Centre.

c) Most of the data transmission equipment is installed and maintained by the Romanian Special Telecommunication Service. For some additional seismic stations, data transmission is made over GMS lines. All communication channels are functional 24/7 and potential issues are promptly addressed by the providers.

d) The SeisComP (https://www.gempa.de/products/seiscomp/) seismological software for data acquisition, processing, distribution and interactive analysis was implemented at the RNMPSPC Data Centre in Bucharest, starting from 2021. SeisComP uses the SeedLink protocol for communication, a protocol which today practically represents a worldwide standard. With the upgrading of ground motion recording and telecommunication equipment, RNMPSPC stations are gradually connected to SeisComP and to the EIDA node of EPOS. In addition, the *sigma* module (gempa GmbH) is used for advanced data processing, mapping, visualisation and interpretation.

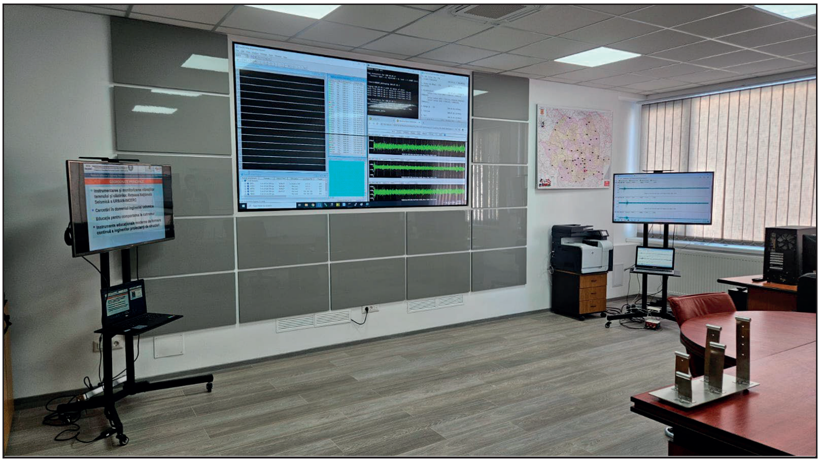

Figure 1. The RNMPSPC Data Centre, with real-time monitoring of seismic activity

2. Seismic data and station metadata curation, storage, archival and dissemination

a) A key condition for data quality assurance is the rigorous specification of station metadata, which ensures accurate interpretation of recorded data. The configuration of stations connected to the SeisComP system was done providing detailed specifications of digitizer and sensor characteristics, locations and orientations. The IRIS DMC Library of Nominal Responses for Seismic Instruments was used, as available in the Station Management Portal created by gempa (https://smp.gempa.de/). The information already available in the seismic station database maintained at the RNMPSPC Data Centre was also used, for all stations. The upgrading and extension of the seismic network were done concomitantly with the upgrading and revision of both databases.

b) The recorded seismic data is stored on NAS (Network-Attached Storage) units and backed-up on a regular basis. In addition, the own data storage system of SeisComP, SDS, is used for the stations connected to this software. Storage capacities are extended as necessary.

c) The seismic network of RNMPSPC was registered at the International Federation of Digital Seismograph Networks, FDSN (https://www.fdsn.org/), with the RQ code (Figure 2).

d) The dissemination of data and research results is done by publishing in peer-reviewed journals, as those mentioned in the "Introduction" section of this article.

3. Structured management of operations

The structured management of seismic network operations was implemented ever since its establishment and evolved continuously with its expansion and modernization. The organization gained additional momentum with the acquirement of the IOSIN status, which imposed the implementation of rigorous procedures for management and reporting.

Figure 2. The seismic network of RNMPSPC, as displayed on the FDSN website

An important role in leveraging the activities dedicated to the assurance of the quality of seismic data is played by the various research projects conducted by the RNMPSPC team. The requirements imposed by these projects, as well as the development possibilities they provide, represent an additional incentive. One of the most recent projects is PN 23 35 01 01, aimed at the development of an integrative digital concept for recording, transmitting, processing and analysing data resulting from seismic monitoring of territory and buildings, based on the implementation of state-of-the-art hardware and software tools, in order to efficiently and operationally identify the destructive potential of earthquakes occurring in Romania and adjacent regions, and at the creation of an open access database for instrumented buildings, set up in accordance with the Open Access, Open Data and FAIR principles and following the best practice models of similar European infrastructures.

RESULTS AND DISCUSSIONS

To demonstrate the practical application of the previously discussed principles, the following section presents examples from recent activities within the seismic network.

Figure 3 displays a screenshot from the SeisComP software, showcasing tests conducted to verify the operational accuracy of seismic stations. The BTH station, featured in the figure, is installed on an instrumented building and is complemented by a free-field accelerometer nearby. This setup is located at the Faculty of Biotechnologies, University of Agronomic Sciences and Veterinary Medicine of Bucharest. Several tests of this type are performed on a regular basis at RMPSPC, for all instruments. For the stations connected to the SeisComP system, values are checked in parallel in SeisComP and in the software applications provided by the instrument manufacturers.

The most important result of quality assurance activities consists in obtaining accurate seismic data and information. The following figures provide an illustration of ground motion records and of seismic data processing and mapping for the largest-magnitude event recorded in Romania in 2024, i.e. the ML=5.4 Vrancea earthquake of September 16th, 14:40:22 UTC.

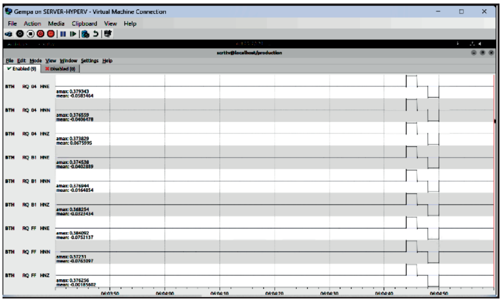

Figure 3. Tests for the verification of station operation. Station BTH (Faculty of Biotechnologies, USAMV, Bucharest). Screenshot taken from SeisComP software

Figure 4 presents a map of the RNMPSPC stations that recorded the ML 5.4 Vrancea earthquake on September 16, 2024, generated using the *sigma* module.

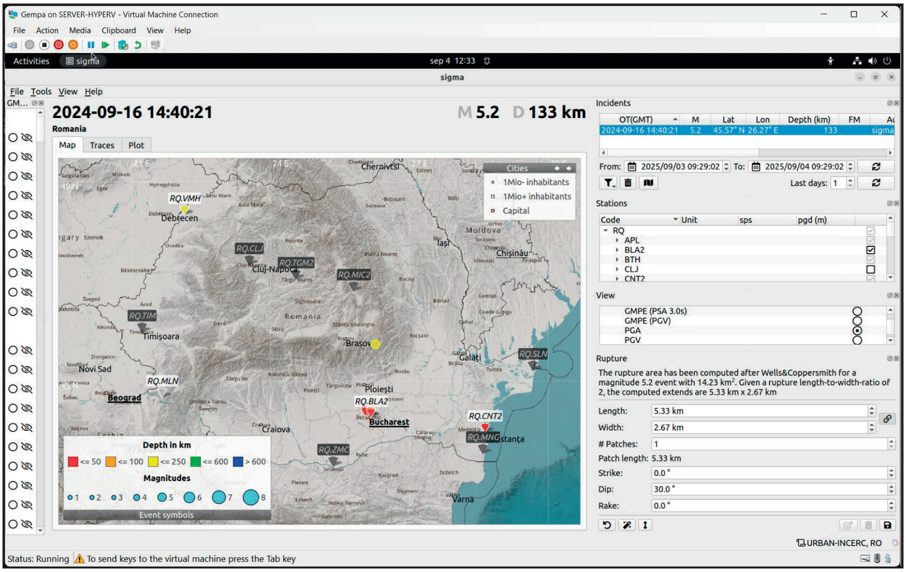

Figure 4. Map of the RNMPSPC stations that recorded the 16.09.2024 Vrancea earthquake, created with the *sigma* module

Figures 5 and 6 display the seismic records from this event and their subsequent processing, both performed with the *sigma* module, ensuring accurate data visualization and analysis. Figure 7 shows the spectrogram representation of the INC6 record from the ML5.4 Vrancea earthquake on September 16, 2024, processed using the *sigma* module. The displayed magnitude is that of the initial estimation in FDSN-SW.

Figure 5. Records of the 16.09.2024 Vrancea earthquake, visualised with the sigma module

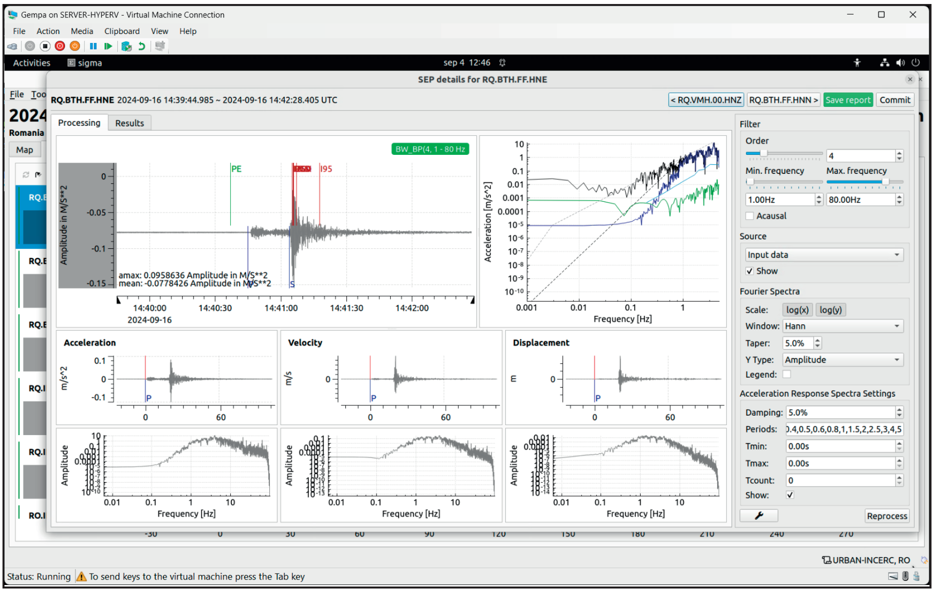

Figure 6. Processing of the 16.09.2024 Vrancea earthquake BTH record, performed with the sigma module

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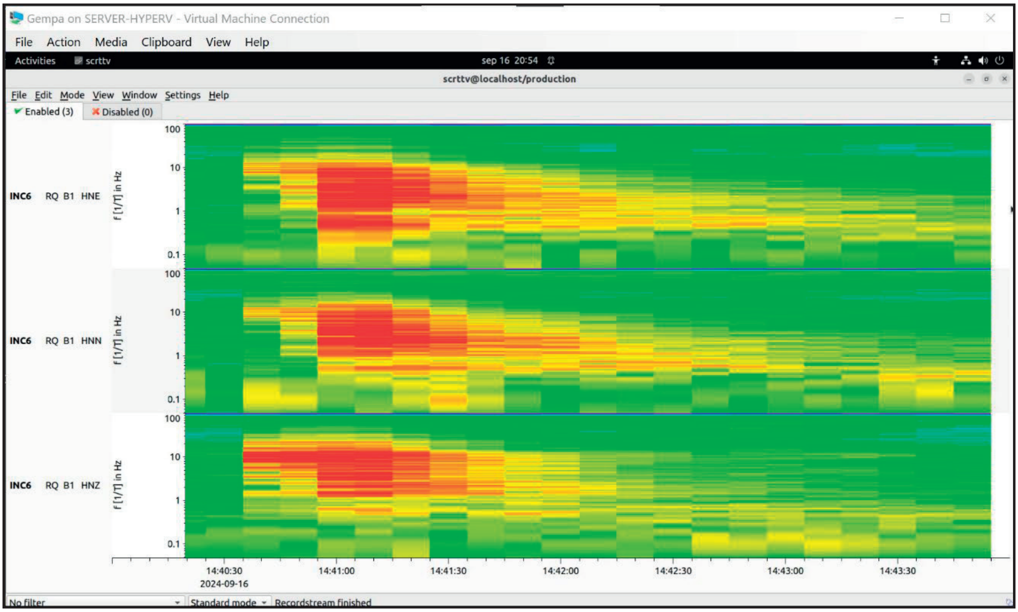

Figure 7. Spectrogram representation of the INC6 record of the 16.09.2024 Vrancea earthquake, obtained with the *sigma* module

Additionally, Figures 8, 9 and 10 illustrate the seismic data recorded at station FOC6, located in Focșani, near the earthquake's epicentre. These figures present the raw seismic record in Figure 8, the acceleration response spectra computed for the three components in Figure 9, and the FFT magnitude plots corresponding to the same record in Figure 10.

The recorded data, acquired using a GMS-18 accelerometer, was processed with the GeoDAS software from GeoSIG, the instrument manufacturer, ensuring high accuracy and compliance with seismic data processing standards.

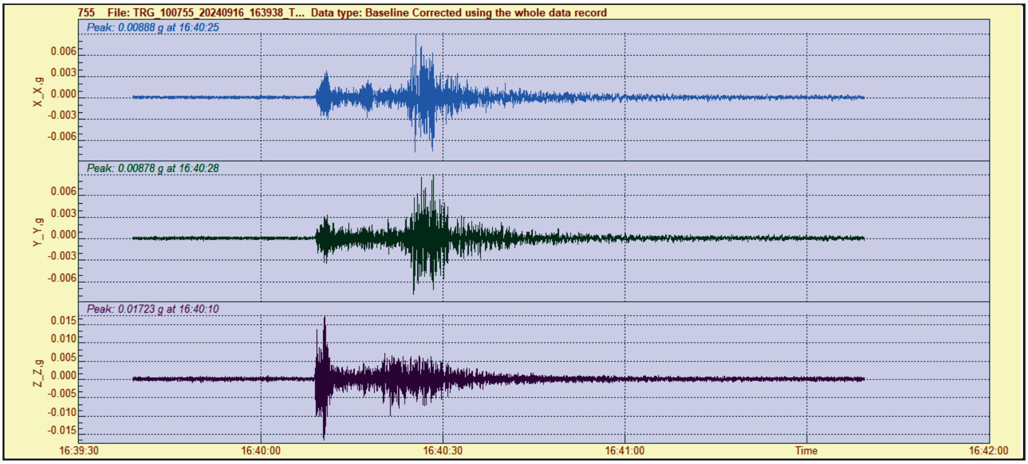

Figure 8. Acceleration record from the M_L=5.4 Vrancea earthquake on 16.09.2024. Station FOC6

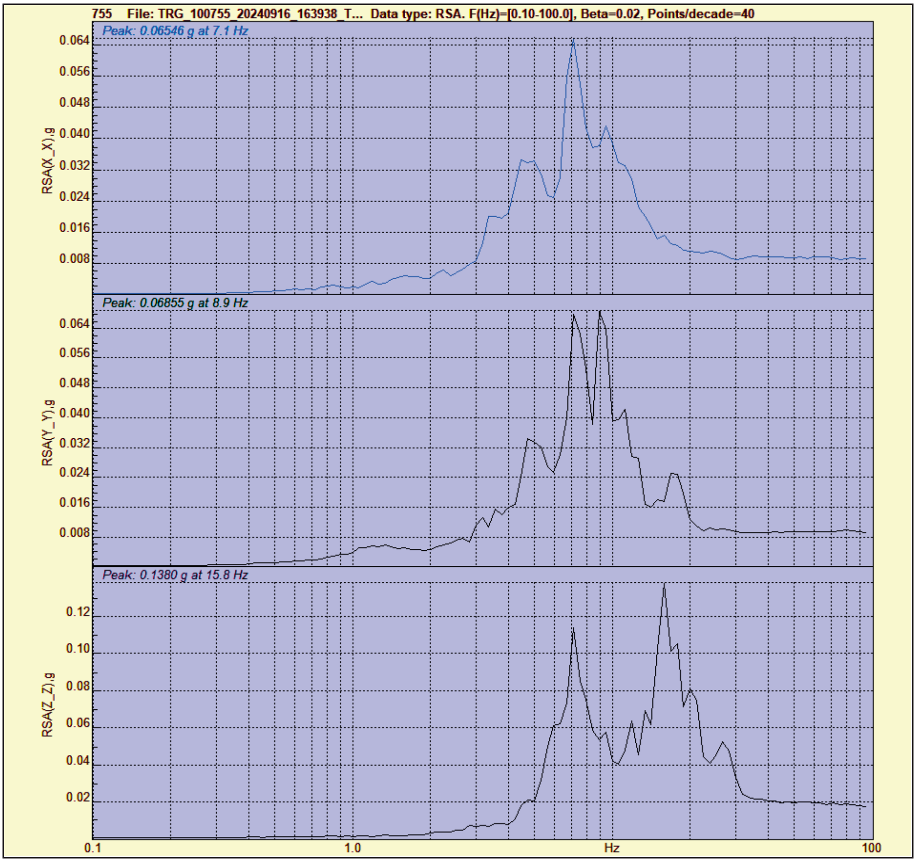

Figure 9. Acceleration response spectra for the three components of the FOC6 ground motion record. Event: 16.09.2024 Vrancea earthquake

Figure 10. FFT magnitude plots for the FOC6 ground motion record. Event: 16.09.2024 Vrancea earthquake

CONCLUSIONS

This study provided an overview of the fundamental principles of seismic data quality assurance, highlighting their significance in the context of major international research initiatives. The implementation of these quality assurance measures within the National Network for the Seismic Monitoring and Protection of Building Stock (RNMPSPC) at the National Research and Development Institute URBAN-INCERC was examined, detailing compliance with international standards and best practices. The role of RNMPSPC as a Special Installation / Objective of National Interest (IOSIN) within the EPOS European Research Infrastructure Consortium was also emphasized.

Furthermore, the study demonstrated the practical application of these methodologies through the recent ML 5.4 Vrancea earthquake (2024), showcasing the effectiveness of the current seismic monitoring infrastructure, including state-of-the-art software and hardware solutions. These findings reinforce the critical importance of continuous advancements in data acquisition, processing, and validation to enhance the reliability of seismic records and contribute to global earthquake research and hazard assessment.

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