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ANALYSIS OF SEISMIC DATA FROM MODERATE INTENSITY EVENT OF 2022.11.03 RECORDED ON INSTRUMENTED STRUCTURES

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Abstract

There is a need for safer constructed medium in order to respond to the constant necessity for raising the security level of human society to earthquakes impact. In this respect the buildings monitoring in areas subjected to seismic site effects provides the possibility of getting immediate and reliable information on the status of certain structures, which enables decision makers to better allocate resources and to direct rescue operations. A procedure is implemented, which allows to perform real-time data acquisition, data exchange and data analysis from structures exposed to seismic excitation or under ambient vibration. The processed recordings are used to deliver information in real time about the seismic event. Engineering seismology parameters are computed: maximum acceleration, spectral acceleration, corresponding oscillation periods, etc., on both structures and free field. The output is conceived as a standard report on the characteristic response of the instrumented building. In the paper such an approach is described in an extended and thoroughly version, for two instrumented buildings, located in different areas, under the last year's strongest seismic event of 2022.11.03, $M_w = 5$ *that hit the Romanian territory.*

***Key words**: near-real time seismic analysis, moderate Vrancea earthquakes, structures monitoring performance.*

INTRODUCTION

Vrancea seismic region is the most important source of the seismic hazard for almost the entire country territory through its intermediate-depth earthquakes activity. There are also many superficial focal-depths seismic zones which, along with the Vrancea crustal one has their local area of influence. The seismic events belonging to the former location are the strongest that hit the Romanian territory during centuries. Their hypocentres roughly located deeper than 90 km, to 150 km or even more are confined to a certain volume recently described as consisting in an upper mantle seismic nest (Ismail-Zadeh et al. 2012).

Traditionally the main attention was given to the influence of the ground motion characteristics, its amplitude, duration and frequency content, on the potentially damage induced upon the constructed medium (Trifunac & Todorovska, 2000). With the more developing of the urban centres the interest was focused also on dynamic soil-structure interaction and soil-building resonance, important features being brought by new development of earthquake engineering regarding nonlinear behaviour of soils, dynamic of buildings and resonance implications (Apostol, 2017; Bratosin et al., 2017; Lomnitz, 1999; Takewaki, 2001; Todorovska, 2000; Wolf & Song, 2002; Balan et al., 2020a). Other studies are also focused on evolution of dynamic characteristics of buildings during and after earthquakes (Trifunac et al., 2001a; Trifunac et al., 2001b; Gallipoli et al., 2003a; Balan et al., 2019; Balan et al., 2022a,b) with impact to urban risk mitigation.

The aim has a many fold character, pursuing: - to contribute at enabling a system of both integrate observational and results in earthquake engineering and seismological data to issue warnings (alerts); - to assess near-real-time (i.e., right after a potentially damaging event and/or during its aftershock sequence) structure response-based status; - to give a contribution to seismic risk assessment, based on data acquired from buildings network, in cities exposed to different/various site effects.

These aims are to be accomplished by rapidly processing the recorded parameters of the earthquake in order to generate useful information about the seismic response, for civil protection needs and earthquake engineering purposes. This will also contribute at rising the security level in densely populated cities to the earthquakes impact and enable authorities to better allocate resources and to direct rescue operations.

SEISMOGENIC FEATURES OF THE INVOLVED AREAS

In this paper two urban areas are considered, both strongly affected by the previous damaging earthquakes generated by Vrancea-intermediate seismic source, hence with a quite high level of seismic hazard. The first town, Bucharest, the capital of Romania, is located at distances between ~120 and ~170 km from the epicentres zone, is a highly urbanized metropolitan area with a high risk posed by the constructed medium, which suffered a lot of damage and many human losses in the previous century as a consequence of last destroying earthquakes (Dilley et al., 2005; Bonjer et al., 2010; Kronrod et al., 2013). The second city, Focsani is located much closer to the epicentres, also exposed at crustal earthquakes generated by the neighbouring seismically active area.

Apart from the highly seismic risk of the two cities, they are experiencing quite important site effects, along with other seismic hazard exposed areas, during last medium-to-strong seismic events. The recordings, as well as data processed and spectral characteristics, show large values for the ground motion parameters and amplifications (Marmureanu, 2016; Marmureanu et al., 2021a; 2022).

A comprehensive background analysis was previously undertaken using strong motion data from earthquakes corroborated with observational damage and considering the evolution of the three generations of code-based spectral levels for the two cities (Balan et al., 2019). Herein a case-study for two densely populated Romanian cities (Focsani and Bucharest) is presented, using data from a 5 M_W earthquake (November 03, 2022, see Figure 1a). Its characteristics were as follows: triggered time 06.50:25 local time, lat. 45.4949 N, long. 26.5166 E, focal depth 148.8 km, 122 km and 48.33 km epicentre distances for Bucharest and Focsani respectively. The earthquake belongs to the intermediate-depth Vrancea seismic region and was felt with intensities about V on MSK scale in the epicentre area and III-IV in both cities, as well as in other cities over the country (Figure 1b). This seismic area has generated 11 earthquakes above 5 M_W in the last 23 years. The earthquake was recorded with high quality data at 132 accelerometers with North-East South-West directivity of the highest values, as well as in the Eastern part of the epicentre with maximum PGA = 48 cm/s^2 (INCDFP internal seismic report, www.infp.ro, ROMPLUS, 2022).

BUILDINGS SEISMIC NETWORK AND MONITORING PERFORMANCE

The improvement of the National Seismic Network (RSN) was a constant concern at National Institute of R-D for Earth Physics (INCDFP). An increase of the performance of seismic instruments was pursued, in order to record in the wide range of frequencies from very strong seismic movement to very weak vibrations.

In the last couple of decades, RSN has seen a remarkable development, so that currently, Romania has one of the largest and most modern seismic networks in Europe. Data recorded from 163 stations (Marmureanu et al., 2021b; Neagoe et al., 2011) which cover the entire country territory are transmitted in real-time to the main location (Magurele).

In the last decade, the National Institute for Earth Physics has deployed permanent instrumentation with accelerometers at key stories of six buildings in metropolitan cities areas that recorded the seismic motion. This activity was carried out and supported through different scientific projects, cooperation activities and research contracts (see, for example: URban Seismology Project CRC461, 2003; Ritter et al., 2005; NATO Project 981882, 2008; TURNkey Project, 2019; Balan et al., 2020b; Balan et al., 2022b). Within the Department of Engineering Seismology structures behaviour was studied, to better understand the influence of seismic movements on constructions. The recorded data are transmitted in real time to the National Data Centre (NDC) (BRTT, 2018).

The monitored buildings are Institute of Atomic Physics (TURN tower building, IFA), located in Magurele area, a locality near Bucharest city, completed in 1974 and partially damaged by the 1977 earthquake being retrofitted twice, and Hotel Unirea from Focsani (FOCR), Vrancea County, near to the Vrancea seismic source. Both are tall reinforced concrete structures.

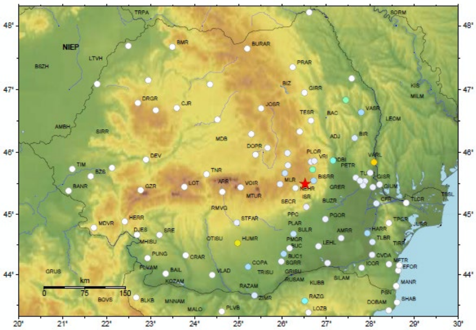


Figure 1a. Epicentre location and recorded velocities stations of 5 M_W earthquake, 2022.11.03 (after ROMPLUS, 2022 and INCDFP internal seismic report, 2022)

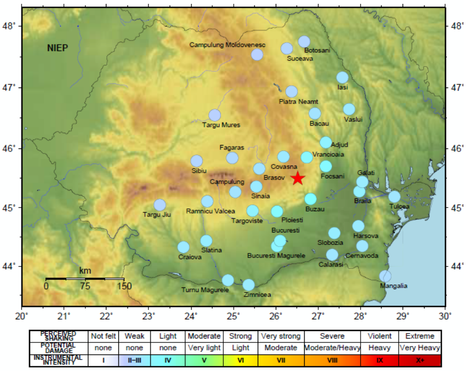


Figure 1b. Estimated intensities (MSK) of 5 M_W earthquake, 2022.11.03 (after ROMPLUS, 2022 and INCDFP internal seismic report, 2022)

The monitoring is achieved at building TURN with 3 accelerometers placed at underground (TURN1), 6th floor (TURN2) and 10th floor (TURN3), and at building FOCR with 3 accelerometers placed at basement (FOCR1), 4th floor (FOCR2) and 8th floor (FOCR3).

The TSA-100S tri-axial accelerometers and a 24-bit Digitizer (iDAS) transmitted data in real-time to the INFP' National Data Centre (NDC), for the purposes of archiving and post-processing.

The instrumented buildings of different design and at different epicentral distances have the following structural characteristics:

- TURN tower, a structure situated in the Southern part of the Bucharest city (10 floors high), on office building, of reinforced concrete with shear walls, built in 1974, retrofitted after 1990 (Figure 2, left).
- FOCR, Hotel Unirea, a tower structure in Focsani, located near the epicentral area, suits (8 floors high), of reinforced concrete frames, built in 1971 (Figure 2, right).

Figure 2. The instrumented buildings, TURN in Bucharest city (left) and Hotel Unirea in Focsani city (right)

The data recorded by free-field seismic stations located in Bucharest were used as reference motion, in order to assess the amplification or decreasing of the seismic waves when propagating in the structure. Acceleration and velocity data were previously analysed, both in time domain and in frequency domain, for selected frequency ranges (Balan et al., 2020b; 2021). In the framework of the previous studies on data recorded on buildings located in

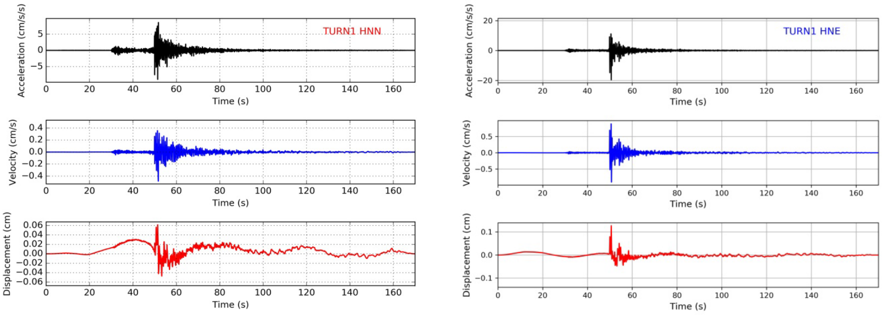
Bucharest, this study adds new valuable information and contributes to a better understanding of seismic response of buildings.

MATERIALS AND METHODS

One of the important activities of the engineering seismology is the evaluation of the site's response, and of the earthquake engineering, structure response at seismic loads and buildings response as overall. These characteristics and information can be used further to carry out seismic risk analyses, which must include (besides exposure data) the vulnerability of the structures.

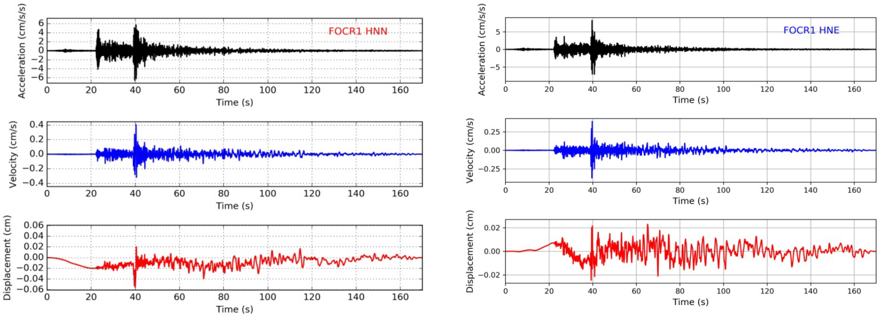
It is important to ensure the data flow and make them available in a shorter time after the earthquake, to the authorities, civil protection, decision makers. Following the most accurate and rapid evaluation of the engineering parameters, information is obtained about the behaviour of the respective structure, certain type of buildings, or of group of buildings in the area under the respective seismic demand. Nowadays in Bucharest there are more than 40000 buildings erected before 1940, which is an alarming fact. The recorded acceleration time histories are pre-processed: baseline corrected and filtered using a 4th order Butterworth bandpass (0.2-25 Hz) filter. The limits were set for obtaining a good signal to noise ratio, and a taper function was applied on the data to allow the Fourier spectra calculation.

In Figure 3 are shown the recordings for the studied earthquake in terms of acceleration and corresponding computed velocity and displacement, at the underground or basement of the buildings, on the horizontal directions, i.e., N-S and E-W. In the case of a medium or strong earthquake, the seismic recordings sent in real-time to the processing centre underpin a standard report which is generated based on regular procedure for the buildings seismic instrumentation.



TURN1 N-S, underground

TURN1 E-W, underground



FOCR1 N-S, basement

FOCR1 E-W, basement

Figure 3. Recordings on two buildings, at the underground TURN1 (up) and basement FOCR1 (down) sensors, on two horizontal components (N-S, left, and E-W, right)

It consists mainly in seismic, engineering and damage related parameters such as maximum recorded acceleration, spectral acceleration, corresponding fundamental and oscillation periods belonging to elastic response spectra, Fourier spectra and acceleration recordings waveform. This information is of concern mainly for civil protection purposes and a possible spatial distribution and degree of expected damages are assessed where is the case. Once this spectrum is computed, it is compared with the code spectrum used to design that building or for the area. The received data are processed and integrated for a quick assessment of the structural situation in a given area. The Antelope software package, from Boulder Real-Time Technologies (BRTT, 2018) is undertaking the analyses, archive and exchange of the seismic data. It is the main tool for collecting and exchanging seismic data. The Bighorn module is an extension module of the Antelope package, performing real-time computations of spectral acceleration exceedance and issues alarms accordingly (Skolnik et al., 2014). The main program can continuously compute strong motion response spectra for sets of 3-component waveforms for many stations and then release parameter file spectra packets. These packets are fed to a strong motion response spectra alarm detector, which compares the actual response spectra to a set of exceedance limit spectra and displays them (more precisely: near-Real-time calculation of pseudo-spectral acceleration - PSA exceedance and alarm dissemination).

RESULTS AND DISCUSSIONS

Near-real time analysis and results

The Fourier Spectra analysis reveals approximately same ranges for frequency amplification for both buildings, as well as for the amplitude peaks. Only one peak differs in amplitude, on EW component at TURN1 being the highest value (Figures 4a and 4b). From these data one can conclude there are some similarities between buildings response in frequency domain, especially in amplification range, including corresponding amplitude peaks and even amplitudes level for three out of four spectra.

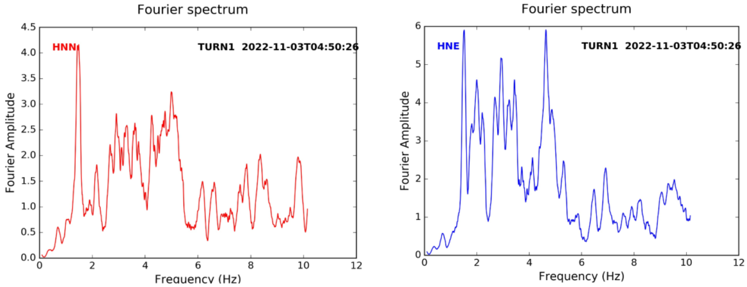


Figure 4a. Fourier spectra at building TURN, underground sensor TURN1, on NS (left) and EW (right) components

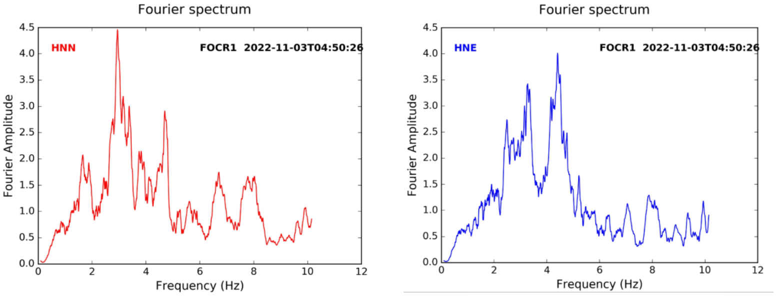


Figure 4b. Fourier spectra at building FOCR, basement sensor FOCR1, on NS (left) and EW (right) components

The processing of the data releases elastic response spectra in terms of spectral pseudo-acceleration, with 5% damping. In Figures 5a and 5b the information is presented as engineering parameters, that are maximum acceleration a_{max} recorded on three directions (two horizontal, NS, EW, and one vertical Z), maximum spectral acceleration (SA_{max}) from elastic response spectra, and corresponding oscillation periods T_0.

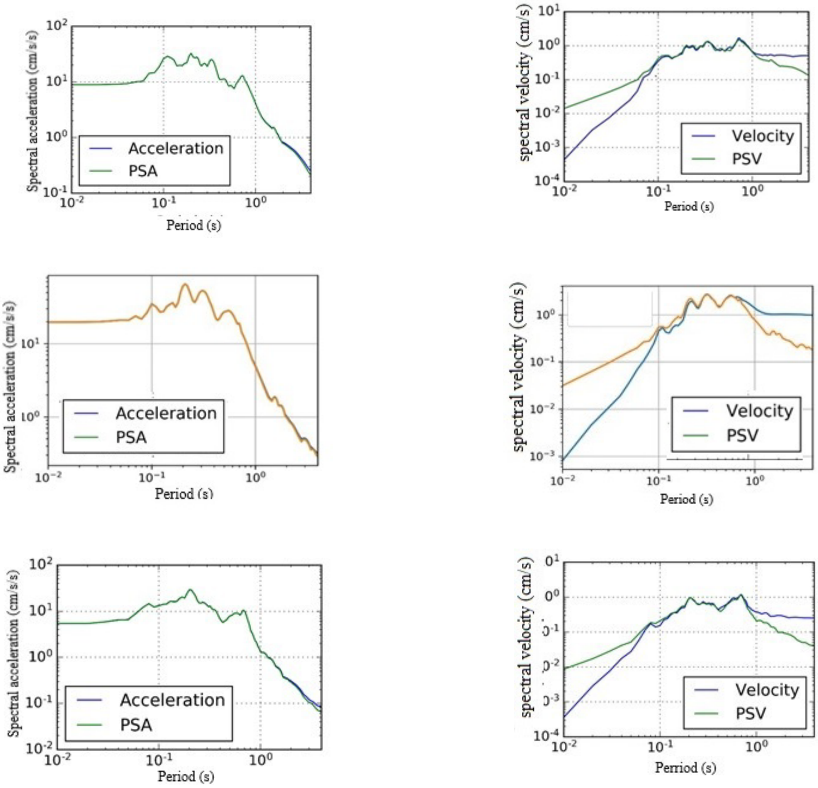


Figure 5a. Acceleration (left) and velocity (right) spectra at the underground sensor TURN1, on NS (up), EW (middle), Z components (down)

The sensors that yield these parameters are located at the underground or basement of the two buildings (TURN1 and FOCR1) located in Magurele, a town near Bucharest, being part of its metropolitan area, and Focsani city. From Table 1 could be observed that maximum accelerations in two buildings are spanning on a low values interval, between ~5-20 cm/s^2, therefore one could not imply differences due to the focal localization or epicentral distances.

However, for the Focsani city the highest value is on vertical component (Z, 13.38 cm/s^2), the other two horizontal ones having lower values (6.55 cm/s^2 on NS and 8.22 cm/s^2 on EW). The same situation is valid for spectral acceleration too, as oscillation periods are higher for the horizontal components, with 0.23 s the higher on EW direction.

In the case of the other building (TURN1), the situation is quite the opposite, with higher values of acceleration on horizontal directions, the stronger 19.63 cm/s^2 and on EW component. This value is however stronger than those in Focsani, which is closer to the epicenter. The same for SA_{max} with 65.08 cm/s^2 (EW). The spectral characteristics display oscillation period value in a restricted range for building TURN1, with much closer values around 0.21 s. For the building FOCR1 the values are much disperse, between 0.07 s (Z) and 0.23 s (EW).

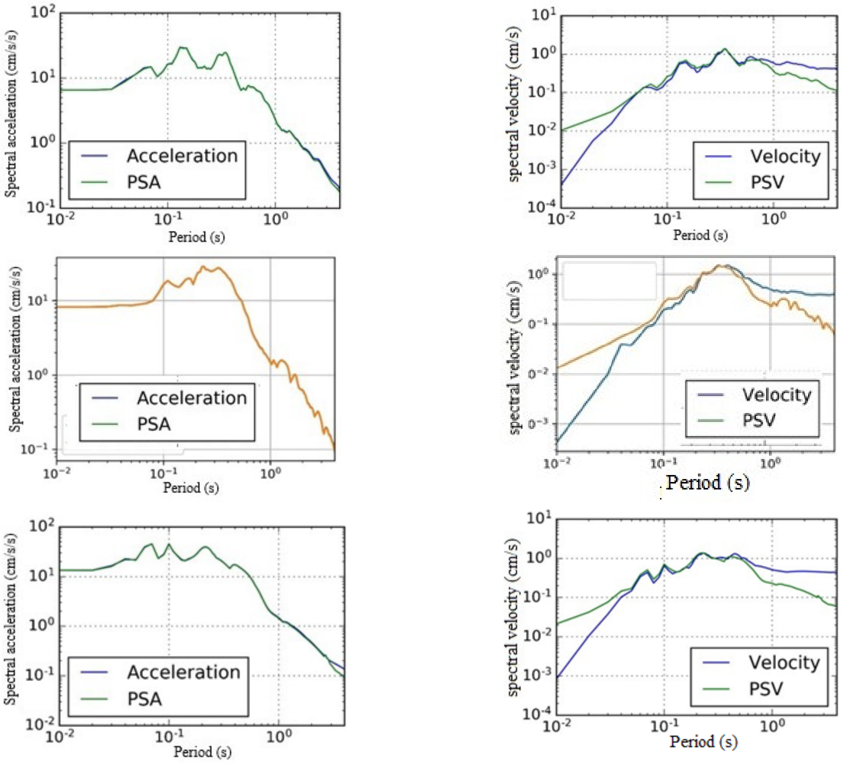


Figure 5b. Acceleration (left) and velocity (right) spectra at the basement sensor FOCR1, on NS (up), EW (middle), Z components (down)

Table 1. Engineering parameters (maximum recorded acceleration, maximum spectral acceleration, oscillating period) for three components at both buildings

Date/ Magnitude M_W/ Depth	Station	Component								
		N-S			E-W			Z		
		a_{max} (cm/s^2)	SA_{max} (cm/s^2)	T_0 (s)	a_{max} (cm/s^2)	SA_{max} (cm/s^2)	T_0 (s)	a_{max} (cm/s^2)	SA_{max} (cm/s^2)	T_0 (s)
2022.11.03 M_W=5, 148.8 km	TURN1	8.95	32.53	0.2	19.63	65.08	0.21	5.41	28.92	0.2
	FOCR1	6.55	29.43	0.13	8.22	28.65	0.23	13.38	45.30	0.07

Considering higher median value for the former, one can assume strictly the two buildings design specificity, though they are of almost same high, construction material, being typical representatives of structures build under seismic codes in the Romania `70s.

Moreover, building TURN1 is twice retrofitted, as it suffered damages under two strong seismic event of 1977 and 1986, hence one may substantiate the success of these interventions.

CONCLUSIONS

In the aftermath of the 2022.11.03 earthquake the developed methodology was validated through a robust procedure for an impact analysis of the involved systems (near-real time) toward improvement of the community resilience to earthquakes. The application was implemented and proved for two risk-endangered cities.

The network consisting in structures or free-field deployed sensors has undertaken an appropriate integration of its data in the national seismic network thus improving local and regional seismic monitoring. It secures and demonstrates the real-time streaming of various seismic markers in a consistent data format to the central server through continuously feed parametric data from the buildings' sensors to the platform that enables a consistent approach to improved post-Earthquake Warning and Rapid Response to Earthquakes. The present study is focused on two tower buildings presenting structural similarities, i.e., TURN1 and FOCR1 located in different cities, built at the same time. For the purpose of this work are basically used recordings from three-component accelerometers, installed on 3 levels at each building (see Figure 3, upper panels, black). The accelerations recorded on the analysed structures were a result of Vrancea medium magnitude earthquake of 2022.11.03, with magnitudes Mw 5, and focal depth 148.8 km (ROMPLUS, 2022). An analysis of structural response was made concerning each building, and acceleration response spectra, Fourier spectra at the underground (TURN1) or basement of buildings (FOCR1) are calculated. The recorded data and subsequent analysis aim to contribute to a better understanding of the structure's responses, even subjected to medium magnitude seismic events, and to the mitigation of seismic risk for densely populated areas.

Fourier amplitude spectra data show highest level of amplification, with amplitude around 6 for EW component at building TURN1, therefore at longer epicentral distance. The corresponding frequency range is between 1.5 and 4.5 Hz, with ordinate peaks at its limits. The first peak corresponds on the NS component too, but at a lower amplitude level, slightly above 4, as well as amplification on frequency range (~1.5-5 Hz). At closer epicentral distance, the building FOCR1 the peaks are observed at 4.2 Hz on EW direction and ~3 Hz on NS, as the amplitudes are in the range 4-4.5 for both components. The response spectra analysis suggests that the amplitudes values, ranges and structural behaviour are not quite different from the previous studies in respect with this earthquake-type characteristics, i.e. Vrancea intermediate-depth source, localization, magnitude range (moderate), epicentral distances, for the instrumented buildings located in both cities, including their design characteristics (Balan et al., 2018; 2019; 2021; 2022a, 2022b).

At the same time with the National Seismic Network development the buildings monitoring network has been designed and implemented – for pursuing the main objective of an acceleration network that is to provide, information to calculate the event parameters (BRTT, 2018). The procedure implemented by INCDFP relying on an automatic near-real-time report provides valuable information for the decision making authorities (Balan et al., 2019; 2021; 2022a, 2022b; Tiganescu et al., 2021).

Further developments of this application at larger scale implies a continuously enhancing of the equipment quality for seismic shaking monitoring, especially at buildings, data processing and sensing level performance enabled for permanent surveillance and temporarily experiments assessing.

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