POST-EARTHQUAKE ASSESSMENT FOR SEISMIC RISK MITIGATION IN ROMANIA: CASE-STUDIES BASED ON RECORDED DATA

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Abstract. The seismic recordings from certain types of buildings in urban areas during moderate earthquakes from Vrancea-intermediate depth focal region are processed and analysed. One of the most important element in hazard evaluation at national level is the seismic recording network which has been upgraded in the last years up to over 20 strong motion accelerometers in Bucharest and 135 in Romania with easy data handling (accelerations easy to transform in displacements). The general behaviour of reinforced concrete buildings in Bucharest Metropolis during destructive seismic events from Vrancea-intermediate depth focal region is briefly described. The analysis of the elastic response spectra is made for four buildings subjected to the two recent earthquakes with magnitude higher than 4.8, of October 28, 2018 and January 31, 2020 from Vrancea-intermediate depth seismic zone. The information consisting in maximum level of the pseudo-acceleration to which the buildings were subjected may be used to detect and quantify any exceedance of the code spectra of interest in near real-time. The recorded earthquakes data are transmitted in real time to the National Data Centre. The goal is to develop and implement modern techniques and tools able to estimate the effect of earthquakes on the built environment in the shortest time possible after a major earthquake.

Key words: continuously data recording, near-real time parameters estimation, post-earthquake analysis, response spectra.

1. INTRODUCTION

The seismic regime of the Romanian territory is characterized by a moderate to high earthquake activity, with many crustal seismic sources, and one known as Vrancea-intermediate depth seismic source. The Vrancea intermediate-earthquakes, characterized by focal depth roughly extended between 90 and 200 km, affect large epicentre areas. These areas, belonging to different geological structures, are characterized by distinct subsurface geology. The observational data, especially for strong earthquakes, show no clearly decreasing ground motion values tendency from the epicentre to the remote areas. Seismic hazard assessment and risk mitigation studies must take into account a large variety of factors, from focal depth and magnitude to macroseismic observation and specific local soil conditions. Based on deterministic modeling techniques, it may appear that the Vrancea earthquakes can produce ground displacements up to 30–60 cm, velocities up to 50–94 cm/s and peak accelerations towards 0.5 g [1–3]. Therefore Romania is considered a country with a high level of seismic hazard and in the perspective of a future strong earthquake the main risk-exposed area is Bucharest city [4, 5]. The observed peak ground acceleration (PGA) value for the destructive seismic event (March 4, 1977) was around 0.2 g and it was recorded at one single station, located in the South-Eastern part of the city. With a building stock of more than 131,000 buildings, ~30% of them being constructed before 1940, vibration and moderate seismic data recorded on the city buildings can provide very useful information for engineering community to assess their structural integrity and also for authorities, in case of emergency after a strong earthquake [6, 7].

In the last half of century more and more cities in seismic areas on the globe are seismically monitored, many of them having large numbers of seismic stations mounted in free field or on buildings. These activities are in the spirit of new sustainable cities because the data collected in free field and on buildings help design engineers, urban planners and other people interested in the mitigation of seismic risk in urban areas [7, 8].

The risk management consists of: (1) Risk mitigation by vulnerability or exposure reduction; and (2) Emergency preparedness. While the latter regards a near-real time action, the former consists of strategies which are typically mid-term (*i.e.* seismic retrofit of structures and infrastructures) or long-term actions (*i.e.* urban land use planning or development of appropriate design standards). A continuous near-real time surveillance of buildings and soil response data contributes to both of the above points.

Structural response information of the buildings may be employed in performance-based earthquake engineering methodologies for estimating probabilistic losses related to seismic performance [9–13]. Therefore one could take advantage from using them to automatically estimate in near-real-time the behaviour and potential damages of an instrumented building after the hit of the strong motion.

Through an appropriate integration with a structural monitoring system, a near-real time warning procedure in an earthquake engineering framework implies updating the knowledge of the seismic hazard input with the data gathered by the network.

In this paper a brief overview is done of the behaviour of some categories of structures located in the Bucharest metropolitan area during the strong and most destructive earthquakes of November 10, 1940, $M_W = 7.7$ and March 4, 1977, $M_W = 7.4$ [3], when seismic intensity exceeded with one degree or more the intensity existing in norms [14–18]. An application using data from the last two of strongest $M_W = 5.5$; 4.8 earthquakes (October 28, 2018, January 31, 2020) originating in Vrancea seismic zone is employed for buildings from different locations, one in Focsani city situated near the epicentre and another three different ones in the Bucharest extended metropolitan area ([19], see Fig. 1). The recorded earthquakes data are transmitted in real time to the National Data Centre (NDC) and consist in accelerations or velocities recordings that could be used for seismic hazard evaluation. The differences in seismic elastic response spectra is discussed for the buildings and free-field stations in their vicinity. A comparison is made between the two tower buildings presenting structural similarities, *i.e.* TURN1 and FOCR1 located in different cities, built in the same time period. The computed elastic response spectra can be employed for improving risk and damage maps [20, 21], more of them developed in near-real time. Also they are useful as input data for design regulations.

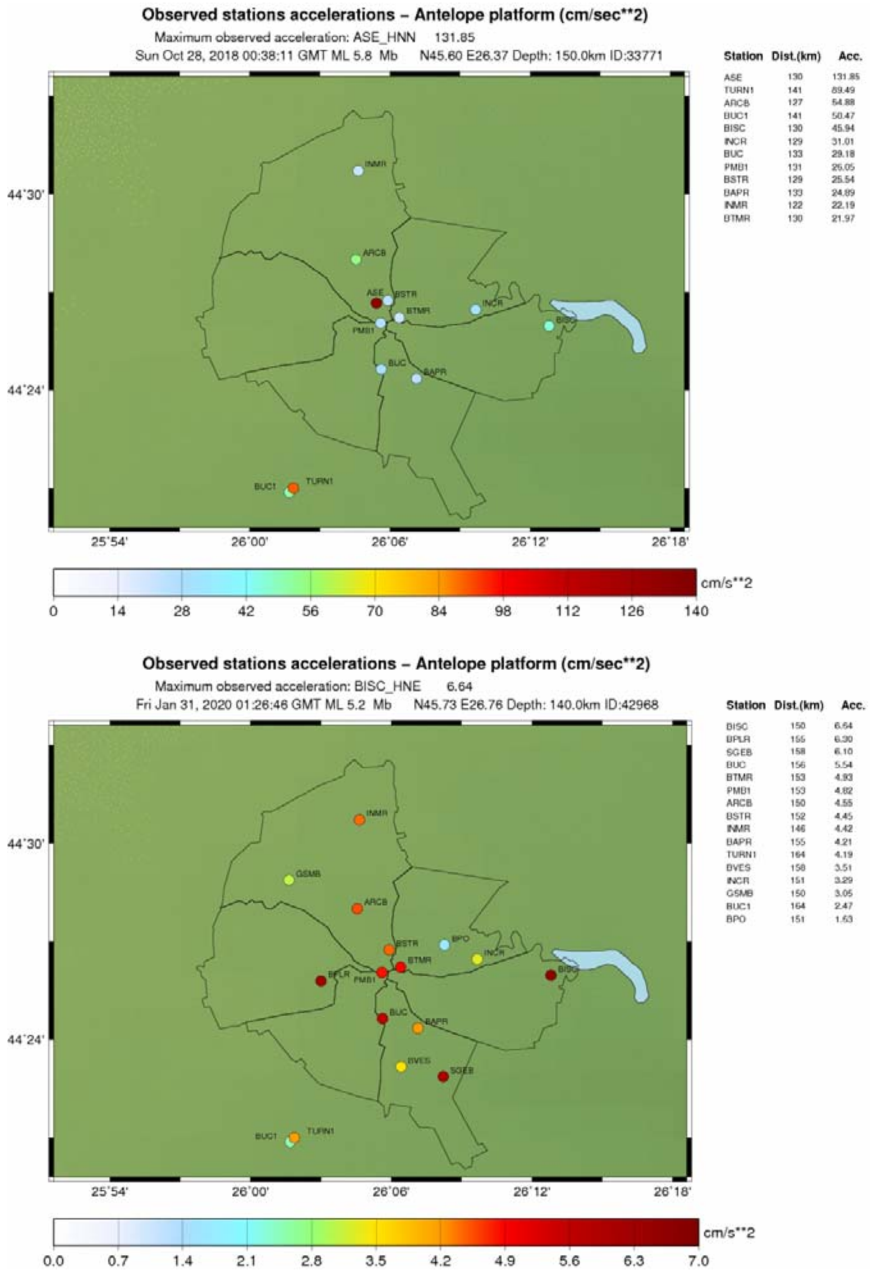


Fig. 1 – Monitored buildings and free-field sensors location on city map involved in BIGHHORN application for the two considered earthquakes [22].

Data recorded in buildings were analysed and have confirmed that no structural damage occurred within the two cities. The procedure employs an automatic algorithm provided by Boulder Real Time Technologies [22] used for real-time data processing. The software supports the collection, archiving, integration, and processing of environment sensors, particularly seismic sensors. For the computation of the elastic response spectra of the recorded seismic events the Antelope Environmental Monitoring System is employed herein. The algorithm is also able to detect and quantify any exceedance of the code spectra of interest in near real-time and offer elementary information about possibility that building could be affected. For future strong seismic events, this tool can provide useful information of the possible effects of the earthquake on structures in the most exposed areas. The procedure enables a consistent approach for processing the input data and ensuing ground motion features based on measurements made on the earthquakes aftermath and Rapid Response to Earthquakes. It involves the recording and processing of acceleration, velocity, displacement towards free-field ground motion and structural response evaluation.

The aim is to provide warnings regarding the severity of impending earthquakes as the information regarding the characteristics of the ground motion, at least on the response spectrum may be given soon after a certain seismic event took place. The integration of (near-)real-time seismology with performance-based earthquake engineering allows for providing the information useful for design of engineering applications.

2. THE IMPACT OF THE DESTROYING EARTHQUAKES ON DIFFERENT TYPES OF BUILDINGS

The twentieth century was marked from the very beginning by the use of reinforced concrete in constructions, which brought about the accomplishment of numerous large buildings of this material, but vulnerable to earthquakes if not properly designed. During this period, the most important development takes place by laying the foundations of modern studies directly applied to the specific conditions in Romania, in seismology and earthquake engineering. The last century was marked by four powerful seismic events with significant loss of human lives and material damage. The earthquake of November 10, 1940, magnitude $M_W = 7.7$ caused material damage to the Vrancea area (Panciu city destroyed almost entirely), and to Bucharest (the collapse of the Carlton block and other buildings). [2 and references therein, 3] The documents of the day mention hundreds of victims. During the strong earthquake of March 4, 1977, $M_W = 7.4$, hundreds of buildings were destroyed in Bucharest and in the country (the region outside the Carpathian Arc from Suceava to Craiova) and about 1,500 victims (mostly in Bucharest) were counted. At the end of the century were also the seismic events of August 30, 1986, $M_W = 7.1$ and May 30, 1990, $M_W = 6.9$.

The period between wars led to a strong impetus in the construction industry, then the great boulevards in Bucharest were built, which still exist today. The 1940 earthquake alerted the Romanian designers who produced a regulation in December 1941 following the Italian rule (of 1938), which considered a basic seismic force equal to 5% of the gravitational forces, evenly distributed on the floor of the building. With the end of the global conflagration, the concerns of Romanian engineers in relation to earthquake safety will result in continuous work, to this day, to make regulations as safe and complex as possible.

The March 4, 1977 (M_W = 7.4) earthquake had severely affected almost the whole outside area of the Carpathians Arch. In the capital of the country, Bucharest city, as well as in other areas, seismic intensity exceeded with one grade and more the intensity existing in norms [14, 17].

Residential buildings built between 1950 and 1977 included a great variety of design solutions to meet the high demand for housing in this period; blocks with multiple levels built before 1977 represented 2/3 of total achieved since then. Designers adopted standardized solutions that enabled industrial development. For these buildings no important damage was observed. There were local failures such as: pillars, beams, etc. predominantly in multi-story buildings, with long periods of vibrations. Administrative buildings and socio-cultural, reinforced concrete frames type, built before World War II: 4 of them had major damage in Bucharest and in other cities requiring more rehabilitation today and many collapsed.

Administrative and social cultural buildings after World War II with reinforced concrete frame had little structural damage, even when the intensity/acceleration was greater than that of the zone in the norms in force at that time. Important buildings designed for 8 degree of intensity on MMI scale had a good behaviour (*e.g.* National Theatre, Palace Hall, etc.).

3. DATA ACQUISITION AND MONITORED BUILDINGS DESCRIPTION

The seismic monitoring of buildings can give a rapid damage assessment after a strong seismic event, based on the level of accelerations the buildings experienced [23–25]. Therefore, mitigating the seismic risk for densely populated is an issue of high importance. Accelerometers data recordings from several buildings during earthquakes are near-real time processed, and a comparison with respect to the free-field data is performed. An analysis of the amplification, in the Fourier domain, from the base to the top of the building was previously performed, for specific frequency intervals [26].

A recent earthquake with a moment magnitude around 5.5 occurred on 28th of October, 2018 in the Vrancea area, and was felt, according to the national agency reports [27], on a large area of the S-E of the country. Another more recent $M_W = 4.8$ earthquake from the same focal region happened on 31st of January, 2020, though was never felt at the same intensity [19]. All the data were processed using the same filtering (bandpass 0.2–25 Hz 4th order Butterworth) and the same techniques, in order to keep the results uniform and comparable. For the buildings considered herein the structure response data were analysed as they are obtained at the basement sensors. The first instrumented building is the Institute of Atomic Physics building (TURN1), of reinforced concrete with shear walls, located in Magurele, considered as belonging to Bucharest metropolitan area. The building was completed in 1974, partially damaged by the 1977 earthquake and it was retrofitted twice. The second is Hotel Unirea (FOCR1), a tower structure in Focsani, located close to the Vrancea epicentre area, of apartments and single rooms (8 floors high), of reinforced concrete frame, built in 1971. The other two buildings, Bucharest City Hall building (PMB) and Victor Slavescu building (ASE) are located in the Bucharest city downtown. They were retrofitted and equipped with base-isolators and dampers (the first one in 2016 and the second one in 2008) since were constructed at the beginning of XXth century, when no seismic design regulations were in force. For the Bucharest City Hall, all the sensors are installed above the seismic damping system, one of them at the ground floor. At ASE building, both sensors are located at the ground level, one under the seismic isolator, coupled with the ground, and the other one above the isolator, coupled with the structure. A free-field seismic station located 1.1 km away (BTMR) from PMB has been used as reference, as well as one in the ASE vicinity (BSTR) [8].

All the data are transmitted in real-time to the National Data Centre (NDC, Magurele location – NIEP) and a system for automatic analysis of data and reporting was recently implemented (*i.e.* Bighorn module, [22]). In Tables 1 and 2 the data are presented, recorded by accelerometers during the earthquakes, with respect to the free-field data, corresponding to each building.

The “Post Seismic Alarm System” (PSAS) used herein consists of accelerometers installed at the basement of the structures, that transmit recorded data to servers to perform quick and reliable automatic analyses. The data can be processed in real-time, online, with a triggering system, or offline (to be effective, the recording and processing durations should be small). PSAS also provides valuable information that can help authorities to take quick and effective decisions, during the critical and difficult moments immediately following an earthquake.

Though the analysis is applicable to buildings where the date of construction and the seismic code used for design are known here it is checked the possibility whether functioning for older structures, that experienced strong earthquakes and weren’t rise according to appropriate design codes.

4. DATA PROCESSING AND CASE-STUDY RESULTS FOR BUILDINGS. RESULTS AND DISCUSSION

Real-time data acquisition, data exchange and data processing, are performed by an automated Antelope seismological system, [22] installed at the National Data Centre (NDC) of the National Institute for Earth Physics, in Magurele [28].

A three-component accelerometer is used, installed on the ground floor and in the proximity to the building, so that the measurements can be representative for other buildings in the immediate vicinity. It is considered that there are no significant variations in the geotechnical structure and local geology within a few hundred meters around the recording point. In the case of a medium or strong earthquake, the seismic recordings are sent in real-time to the processing centre where the acceleration response spectrum of the earthquake is calculated. Once this spectrum is computed, it allowed the comparison with the code spectrum in force for the area (or, more exactly, its characteristics can be compared to a certain interest level of ground shaking and range of fundamental period) [29–32]. An important feature of this program is its capability to issue an alarm after it compares the response spectra to a set of exceedance limit spectra and displays them. The Bighorn module [22] was also used to analyse previously recorded seismic events. Given low-to-moderate intensity their shaking level or spectral amplitudes were completely encompassed by the current regulations though the procedure may bring damage level details for stronger earthquakes.

Herein this analysis is tested on the seismic events of 2018.10.28, local time 03:38:11, lat. 45.60, long. 26.40, depth = 148 km, $m_L = 5.85$ and 2020.01.31, local time 01:26:48 lat. 45.714 long. 26.696, depth = 118 km, $m_L = 5.24$ for the two urban areas: Bucharest and Focsani. The intensity on the Mercalli scale was VI and IV respectively, in the epicentre zone [27].

Figures 2–9 show the results for the two cities placed at different epicentre distances and different position from epicentre. First a location is considered in the Focsani city, towards North-Eastern direction from the epicentres. The seismic sensor is mounted at the basement of Hotel Unirea (FOCR1), a tower structure located closer to the Vrancea epicentre area (epicentre distances 61.9 km and respectively 39 km), roughly even at its margin. Then the extended Bucharest metropolitan area is considered, at ~140–160 km South-West from the epicentres. In this case there are the three different-type buildings with sensors located at the basement of the structures.

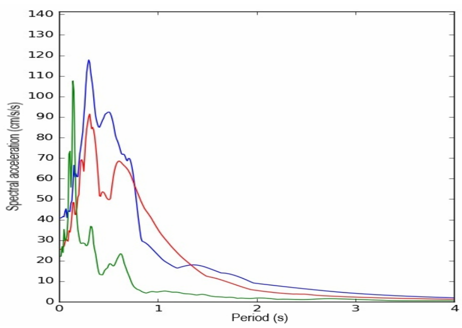
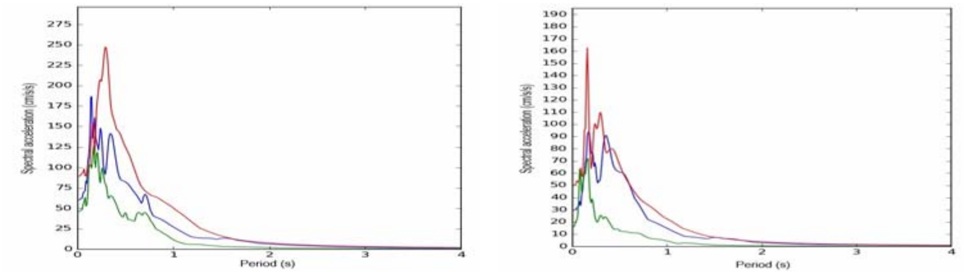
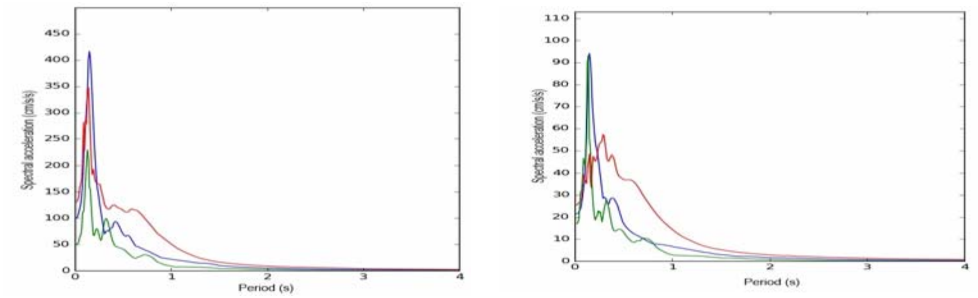


Fig. 2 – Response spectra for the 28th of October 2018 (5.5 M_W) earthquake at the basement of Unirea Hotel basement (FOCR1) in Focsani, on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.



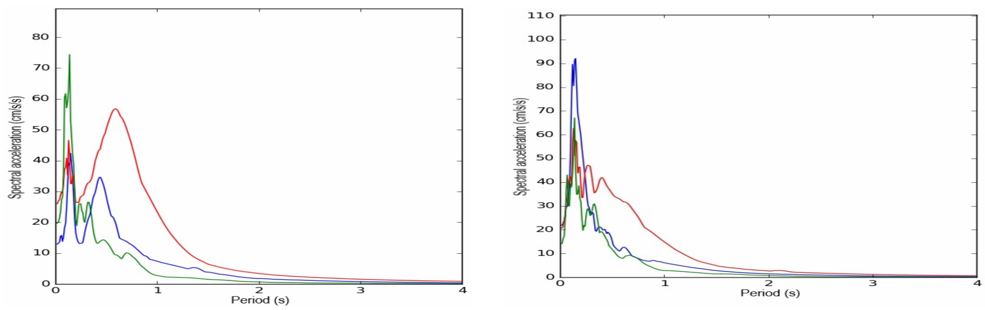
a) Atomic Physics building (TURN1) b) Free-field Magurele seismic station (BUC1)

Fig. 3 – Response spectra for the 28th of October 2018 ($M_W = 5.5$) earthquake at the basement of Magurele Turn building: a) compared to nearest free-field BUC1; b), on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.



a) Victor Slavescu building (ASE) b) Free-field BSTR seismic station

Fig. 4 – Response spectra for the 28th of October 2018 ($M_W = 5.5$) earthquake at the basement of (ASE) building (a) compared to nearest free-field BSTR (b), on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.



a) Bucharest City Hall building (PMB) b) Free-field BTMR seismic station

Fig. 5 – Response spectra for the 28th of October 2018 ($M_W = 5.5$) earthquake at the basement of PMB building (a) compared to nearest free-field BTMR (b), on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.

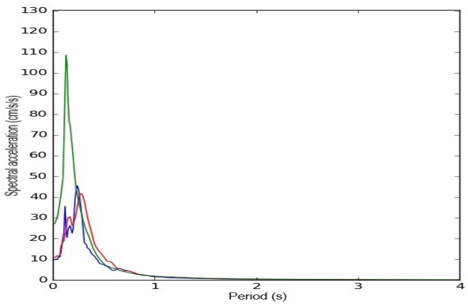
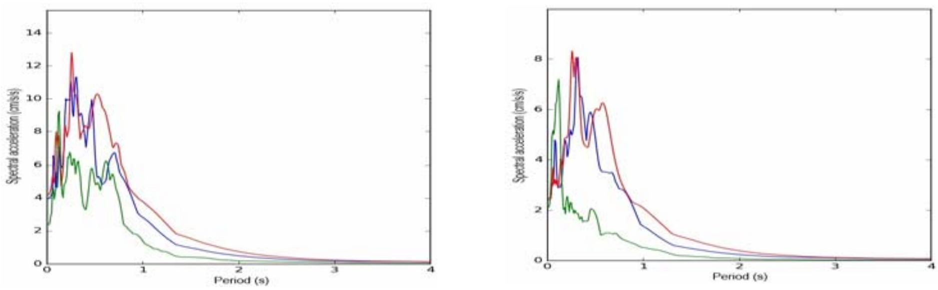


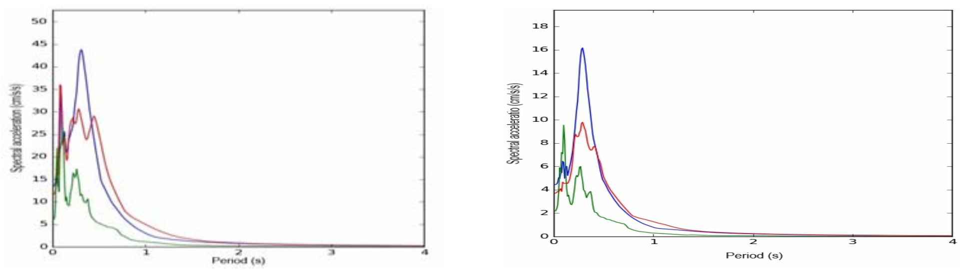
Fig. 6 – Response spectra for the 31st of January 2020 (M_W = 4.8) earthquake at the basement of Unirea Hotel basement (FOCR1) in Focsani, on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.

All the recordings were compared to the specific code spectrum recommended by the seismic design codes for Bucharest and Focsani: P 100-1978, P 100-1992, P 100-2006 and P 100-2013 [29–32].



a) Atomic Physics building (TURN1) b) Free-field Magurele seismic station (BUC1)

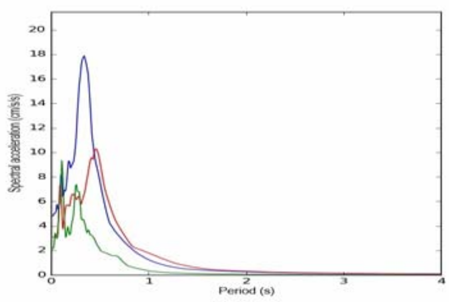
Fig. 7 – Response spectra for the 31st of January 2020 (M_W = 4.8) earthquake at the basement of Magurele Turn building (a) compared to nearest free-field BUC1 (b), on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.



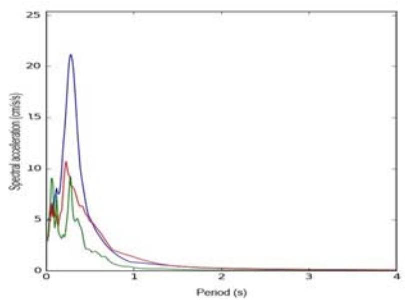
a) Victor Slavescu building (ASE) b) Free-field BSTR seismic station

Fig. 8 – Response spectra for the 31st of January 2020 (M_W = 4.8) earthquake at the basement of (ASE) building (a) compared to nearest free-field BSTR (b), on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.

In addition to recordings in the specified buildings there are data from the same sensors-type located in the free-field in the proximity of each building, respectively (*i.e.* BUC1, BSTR, BTMR). For the Focsani city, near epicentre area, unfortunately there were no free-field recordings to compare with.



a) Bucharest City Hall building (PMB)



b) Free-field BTMR seismic station

Fig. 9 – Response spectra for the 31st of January 2020 (M_W = 4.8) earthquake at the basement of PMB building (a) compared to nearest free-field BTMR (b), on three components N-S (red), E-W (blue), Z (green) for 0.05 damping.

According to the values depicted in Figures 2–9 and Tables 1 and 2, none of the components of the response in the example are in the vicinity of the code spectra for these moderate seismic events.

Table 1

Response spectra parameters for selected stations in Bucharest and Focsani buildings for 2018.10.28 seismic event M_W = 5.5 (normal case represents values for buildings, italics for free-field and bold for maxima)

Station	City	Component								
		N-S			E-W			Z		
		a_{max} (cm/s^2)	SA$_{max}$ (cm/s^2)	T_{max} (s)	a_{max} (cm/s^2)	SA$_{max}$ (cm/s^2)	T_{max} (s)	a_{max} (cm/s^2)	SA$_{max}$ (cm/s^2)	T_{max} (s)
TURN1	Magurele	87.47	247.20	0.29	60.82	186.61	0.15	46.08	126.51	0.17
BUC1	*Magurele*	*50.45*	*162.65*	*0.16*	*29.87*	*93.82*	*0.17*	*16.03*	*72.01*	*0.17*
FOCR1	Focsani	25.56	91.86	0.31	40.81	117.82	0.30	22.19	107.59	0.14
ASE	Bucharest	**131.77**	**347.53**	**0.14**	**100.42**	**416.61**	0.15	**50.64**	**228.89**	0.13
BSTR	Bucharest	*25.53*	*57.28*	*0.29*	*21.52*	*94.19*	*0.15*	*17.01*	*93.14*	*0.14*
PMB	Bucharest	26.04	56.83	0.59	12.92	42.38	0.15	19.80	74.41	0.14
BTM R	Bucharest	*20.70*	*62.70*	*0.13*	*21.96*	*90.03*	*0.15*	*14.14*	*67.09*	*0.14*

A summary of the results, in terms of maximum recorded accelerations values (a_{max}) and maximum spectral accelerations (SA$_{max}$) together with the corresponding period (T_0), is presented in Tables 1 and 2. For the stronger earthquake the $a_{\max}$ values recorded in Bucharest are generally higher for the N-S direction, whereas for Focsani the maximum acceleration recorded is for the E-W direction. For the smaller earthquake the situation would be the opposite, with amplitudes quite small and confined in the 2.40–10.73 cm/s^2 range in Bucharest, though the highest values were recorded on ASE building, 11.69 on N-S and 13.34 on E-W, and the highest value in Focsani is of 11.01 cm/s^2 (N-S). If this is correlated with the low amplitudes of $a_{\max}$ for the stronger seismic event in Focsani one could infer the possibility for directional effects and the position of the two cities with respect to the epicentre.

Table 2

Response spectra parameters for selected stations in Bucharest and Focsani buildings for 2020.01.31 seismic event M_W = 4.8 (normal case represents values for buildings, italics for free-field and bold for maxima)

Station	City	Component								
		N-S			E-W			Z		
		$a_{\max}$ (cm/s^2)	SA$_{\max}$ (cm/s^2)	$T_{\max}$ (s)	$a_{\max}$ (cm/s^2)	SA$_{\max}$ (cm/s^2)	$T_{\max}$ (s)	$a_{\max}$ (cm/s^2)	SA$_{\max}$ (cm/s^2)	$T_{\max}$ (s)
TURN1	Magurele	4.19	12.81	0.26	3.96	11.33	0.31	2.41	9.23	0.13
BUC1	*Magurele*	*2.40*	*8.32*	*0.26*	*2.46*	*8.06*	0.32	*2.12*	*7.19*	*0.12*
FOCR1	Focsani	11.01	41.69	0.28	10.03	45.59	0.34	27.26	108.65	0.13
ASE	Bucharest	**11.69**	**36.02**	**0.08**	**13.34**	**43.81**	0.31	**6.24**	**26.49**	0.11
BSTR	Bucharest	*3.71*	*9.81*	*0.29*	*4.45*	*16.18*	*0.29*	*2.19*	*9.55*	*0.10*
PMB	Bucharest	3.08	10.31	0.46	4.82	17.89	0.34	2.12	9.34	0.11
BTM R	*Bucharest*	*3.24*	*10.73*	*0.23*	*4.93*	*21.16*	*0.28*	*2.94*	*9.23*	*0.28*

The higher values of maximum spectral accelerations (SA$_{\max}$) are encountered for stronger seismic event at ASE station on both horizontal components, 347.43 cm/s^2 N-S and 416.61 cm/s^2 E-W while for the smaller seismic event the higher values are clearly at Focsani, much close to the epicentre. However, the amplitudes of the spectral accelerations are rather scattered for both earthquake and cities.

Peaks were not observed for the long-periods (> 1.0 s), as compared to the case of the strong 1977 earthquake, when high spectral accelerations were recorded for periods longer than 1 s. It can be noticed that, for TURN1 sensor, for the two horizontal components (N-S and E-W), the maximum spectral acceleration for the strongest earthquake correspond to different periods (0.29 s and 0.15 s), while for FOCR1, the periods are consistent for both components (0.30–0.31 s respectively).

The same situation is for the PMB building, with a peak on N-S component at 0.59 s and at 0.15 s on E-W component. For the less strong seismic event this situation is encountered for ASE building: 0.08 s on N-S and 0.31 s on E-W. For the rest of the stations the fundamental and predominant periods are confined in the range 0.23–0.46 s for the horizontal components, and lower for the vertical component (0.11–0.28 s). Given the magnitude of the case-study earthquakes

($M_W = 5.5$, $M_W = 4.8$) and the depths (148 km and 118 km), it is not surprising that the values do not indicate structural integrity problems for the monitored constructed areas, since they all fall far below the code spectra. However, the code spectra could be exceeded by a future strong event.

When comparing the behaviour of the tower buildings located at different epicentre distances, the amplitudes value for the stronger earthquake are clearly higher at the TURN1 building than FOC1. This does not happen for the less strong seismic event, where the amplitudes closer the epicentre is clearly higher than for TURN1 building. This could be possible due to the much closer location of the less strong earthquake to the Focsani city (shorter epicentre distance, 39 km and an upper focal depth 118 km).

We can emphasize the usefulness of near-real time seismic input processing in performance-based earthquake engineering (PBEE) for risk reduction applications. Its role is not only to maximize the warning time, as in the Earthquake Early Warning Systems (EEWS), but to calibrate the alarm thresholds and the decisional rules in order to maximize loss reduction following the decision. The Earthquake Early Warning Systems (EEWS) applicability seems to be suited for the protection of critical systems and to significantly help to reduce the losses subsequent to a catastrophic event and to increase the resiliency of communities to earthquakes. As for the Bucharest city the Earthquake Warning Systems (EWS)-type procedures were successfully implemented [33, 34], for Focsani city location, much close to the epicentre area, these systems are not quite suitable. Therefore the method employed herein based on exceedance of amplitude levels is more effective for both cities, regardless their epicentre distance. This automatic algorithm processing of the input data contributes to methods and procedures for the rapid estimation of earthquake damages and ensuing ground motion features based on measurements made on the earthquakes aftermath. For further development and reliable data availability it is necessary to increase the potential of regional seismic sensor networks for site-specific applications.

The structures were chosen in this study for seismic response evaluation because of their specificity and purpose (high-rise structures, unique social cultural and administrative buildings), age, different design, and not in the last for the isolation systems of which some of them beneficiate. Regarding this latter point, as it was aforementioned, two of the buildings are seismically isolated, namely ASE and PMB. From the recordings one can see that the highest amplitude values are encountered on ASE, as the lowest on PMB structure. However, the issues with regard to the performance of the insulating system were discussed in previous papers (*e.g.*, [8]). The selected buildings are typical representatives of structures build under different seismic codes from 1930's to 1990's, and for some of them the seismic vulnerability is unknown. The structural intervention as rehabilitation or isolations, some of them undertaken, may change their response to seismic input. Through monitoring we can obtain the new parameters of these structures, and so we could judge if these interventions in their structure was beneficent to withstand future strong seismic movements.

Overall, slightly different behaviours and trends were observed, depending on the structure characteristics (material, height, structural system) or location. The stronger earthquake produces much higher amplitude, as expected, at all seismic station, in both cities, either free-field or on structures. We could note high maximum acceleration and spectral values for the less strong earthquake at the Focsani building in comparison to all Bucharest' recordings, especially higher for the vertical component (Z) that approaches the range of the values for the stronger seismic event. This is probably due to this city proximity to the epicentre area, and of shorter hypocentre distance. As regards the structures behaviour in the Bucharest metropolitan area, the general tendency is towards higher amplitudes than for the free-field stations. One exception is at the Bucharest City Hall on the E-W component, where the free-field station (BTMR) attains slightly higher values for the stronger earthquake, while for the smaller earthquake this is happening for all components. We could infer the variability of the local soil condition due to the distance of almost 1.1 km from the free-filed station. However the stronger response belongs to the ASE building, where higher amplitudes are encountered for both earthquakes on all components.

The seismic response of structures subjected to earthquakes represents a basic concept of seismic design, by assessing the dynamic behaviour of certain types of structures and defining engineering parameters that influence building response (acceleration, velocity, spectral acceleration). The procedure adopted herein, although rather simple, can provide in a very short time a quantitative indication of the earthquake's effects in a particular area, for different building typologies depending on the construction period. It contributes to the safety of people and business continuity, concerning the degree of danger and exposure to a strong seismic event.

5. CONCLUSIONS

The paper presents a near-real time analysis of data recorded on instrumented buildings and corresponding free-field seismic stations during magnitude 5.5 Vrancea earthquake (October 28th, 2018) and 4.8 Vrancea earthquake (January 31st, 2020), respectively. The two earthquakes share the same (extended) epicentre area and depth range. The location of the cities is oriented on opposite sides of the epicentre area, on the NE-SW direction. Though the stronger earthquake is of the largest one in the last 20 years, the peak values have not produced any damages and the buildings response are not in the dangerous range values (under seismic code provision values). Even so, the data collected from both seismic events are very important for the research community and for the engineering community as well.

We may conclude that all the earthquake characteristic parameters, *i.e.* magnitude, focal depth, relative epicentres location to the two cities influence the structural behaviour of all buildings. We should add the directivity, source effects, and design specificity of each structure.

The procedure used herein optimizes the real-time streaming of data from sensors located either at basement of the buildings or in free-field. It proposes a consistent approach to instrumentation, offering a useful processing that gives reliable information regarding structures behaviour under seismic movement. The aim is to develop a platform involving as early as possible warning through near-real time seismic ground motion data processing and structural monitoring, near-real time computed parameters, structure response and forecasting. The approach provides continuous events and station parametric data to the platform for the various measures of near-real time earthquake effects, impact, loss estimation and risk. Boulder Real Time Technologies (BRTT, 2018) produces the Antelope Environmental Monitoring System, which is used by several country for near-real time earthquake monitoring. This technique is suitable for a wide range of seismotectonic conditions, earthquake hazard levels, spatial extents, levels and types of existing monitoring systems, especially for population high densities and various vulnerable infrastructures.

The procedure employed proved its efficiency through unimpeded data flow from all seismic station, regardless their location on buildings or free-filed, or the epicentre distance. The recordings were transmitted in due time and successfully processed. The output was evaluated allowing to issue or not an alarm. All the data recorded on instrumented structures during these seismic events, together with the subsequent analysis, can represent a reference study for future earthquakes with similar or higher magnitude. The information regarding building behaviour and its differences from free-filed amplitude level are useful for rapid estimation of the possible damages.

In authors' opinion it is more useful to deliver a proper messaging to the authorities and people than warnings that lack information about actions that should be taken but which are ineffective. There is a need for quantitative information specifying the level of ground motion amplitude or building response near-real time processed and conveyed data.

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