Mitigation of seismic risk through monitoring structures in Romania

Stefan Florin BALAN
National Institute of R-D for Earth Physics

sbalan@infp.ro

Alexandru TIGANESCU
National Institute of R-D for Earth Physics

alexandru.tiganescu@infp.ro

Bogdan Felix APOSTOL
National Institute of R-D for Earth Physics

apostol@infp.ro

Abstract

Objectives: *Presenting the importance of monitoring structures in cities exposed to seismic hazard of Romania, such as Bucharest and Focsani (Vrancea seismic zone). Will be presented the instrumented buildings and details of the procedures involved. The earthquakes on which were made the recordings will be mentioned with their characteristics.* ***Prior work***: *The authors have experience in the domain and have presented and published many papers on the subject.*

Approach: *Through the National Seismic Network (RSN) of the National Institute of R-D for Earth Physics were installed seismic stations on several buildings at ground floor, intermediate floors and top floors and the recordings were processed and analysed by the authors.*

Results: *will be parameters recorded on the structure, such as accelerations, response spectra, etc. parameters which characterize the response of a structure during a seismic event.*

Implications: *The study presents interest for researchers in the field because we analyse the structural response on a variety of case studies on*

seismic events that occurred during the last years, to civil engineering designers to have a test on their work and also could be useful for urban planners to understand better the behavior of a building during earthquakes, in different areas of the city.
Value: *New data about the response of structure from recent seisms, after 2010, could certify the behavior of buildings for even stronger events. The signals recorded could be used as input data for databases in future smart cities.*

Keywords: *Vrancea earthquakes, vulnerability of buildings, seismic accelerations, response spectra.*

1. Introduction

In the last half of century more and more cities in seismic area on the globe are seismic monitored, many of them having large numbers of seismic stations mounted in free field or on buildings. These activities are in the spirit of smart 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.

In Romania, National Institute of R-D for Earth Physics through the National Seismic Network (RNS) is monitoring the seismicity of Romania, country that experienced in the last century 4 strong earthquakes: 1940, November 10 with magnitude M_w = 7.5; 1977 March 4, with magnitude M_w = 7.4; 1986, August 30, with magnitude M_w = 7.1; and 1990, May 30 with magnitude M_w = 6.9. The first two produced many human victims around 800 (1940) and around 1500 (1977) and material losses (2 billion $, 1977 value).

The source of all these seismic events is in Vrancea region, ~ 160 km, N-E of Bucharest (see Fig. 1). After the earthquake of 1977, which had catastrophic effects on tall buildings of reinforced concrete built between the two world wars, in Bucharest, has begun a large-scale campaign to calculate the period of oscillation of various locations in the city. We consider that the dynamic response of certain structures is strongly dependent of the ratio between the natural period of the structure and the dominant period of the emplacement site. Starting from information comprised by data bases for soils and buildings existing in Bucharest were selected two types of structures. (Balan, 2015), (Marmureanu, 2016).

The paper intends to evaluate and analyze the response of the two tower type buildings, one in the Bucharest area (T1) and one in Focsani, (T2) to recent earthquakes (2014-2017) from Vrancea seismic zone.

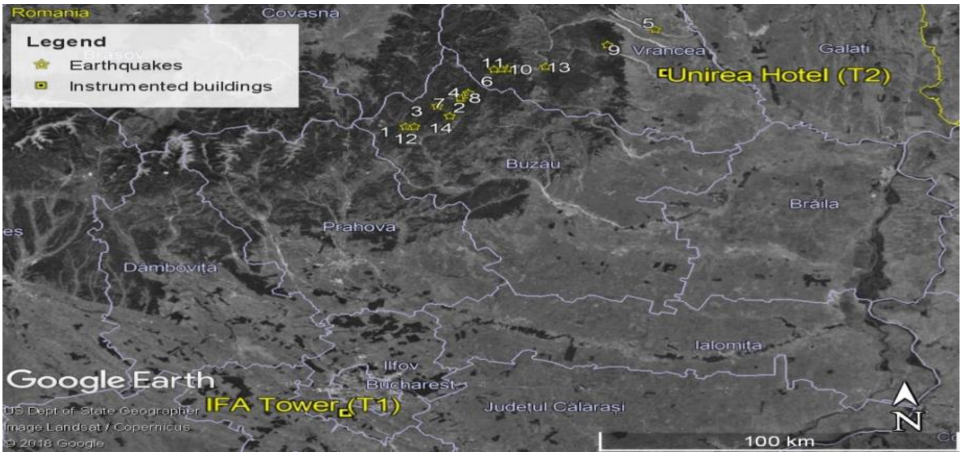

Figure 1. Location map of earthquakes and instrumented buildings (T1 and T2)
Source:*Balan 2018*

2.The Approach

Will be presented the monitoring of a tower type structure in Magurele (T1) (located in Bucharest metropolitan area) and a tower type structure in Focsani, (T2). The instrumentation consists of 3 accelerometers on each building: on building T1 are placed at basement, 6th floor and 10th floor, and on building T2 the sensors are installed at the basement, 4th floor and 8th floor; the data stream is transmitted in real time to the NIEP`s National Data Center.

The instrumented buildings are located at different epicentral distances and have different structural systems. T1 is an office building constructed in 1974 and retrofitted after 1990. Its structural system is represented by reinforced concrete shear walls, and its height is 10 floors. T2 is a hotel built in 1971, with 8 floors height and a structural system of reinforced concrete frames (Fig. 1).

The analyzed seismic events have magnitudes M_w ranging from 3.8 to 5.6 and depths between 40.9 km to 147.3 km (Table 1).

Table 1. Earthquake parameters

Eq. nr.	Date	Time	Latitude	Longitude	Depth[km]	M_w	Buildings
1	23.01.14	06:15:05	45.4877	26.2537	132.3	4.4	T1
2	29.03.14	19:18:05	45.6094	26.4709	134.4	4.6	T1
3	24.08.14	07:12:50	45.5684	26.3675	147.3	4.2	T1
4	10.09.14	19:45:58	45.5967	26.4532	106.1	4.3	T1
5	22.11.14	19:14:17	45.8683	27.1517	40.9	5.4	T1
6	24.01.15	07:55:47	45.7123	26.5712	88.4	4.3	T1
7	16.03.15	15:49:49	45.5991	26.4484	118.2	4.3	T1
8	29.03.15	00:44:58	45.6193	26.4780	145.4	4.3	T1
9	01.03.16	11:06:13	45.8075	26.9778	65.0	3.8	T2
10	23.09.16	23:11:20	45.7148	26.6181	92.0	5.5	T1, T2
11	27.12.16	23:20:56	45.7139	26.5987	96.9	5.6	T1, T2
12	08.02.17	15:08:21	45.4874	26.2849	123.2	4.8	T1, T2
13	19.05.17	20:02:45	45.7228	26.7547	121.6	4.5	T1, T2
14	02.08.17	2:32:13	45.5286	26.4106	131.0	4.6	T2

Source:*Romplus Catalogue*

First, a pre-processing technique was applied to the recorded acceleration time-histories. This process involved baseline correction of the signals and filtering using a 4th order Butterworth bandpass (0.2 – 25 Hz) filter. On the corrected data, two types of analyses were conducted.

The variation of the accelerations recorded on building T1 and T2, with respect to different earthquakes, with a large variety of magnitudes and depths. In Fig. 2 and 3 are presented examples of the acceleration time histories recorded on both buildings, T1 and T2, subjected to earthquake nr. 10. In addition, in Table 2 and Table 3are presented the maximum accelerations recorded on basement, intermediate floor and top floor of the buildings during all selected seismic events.

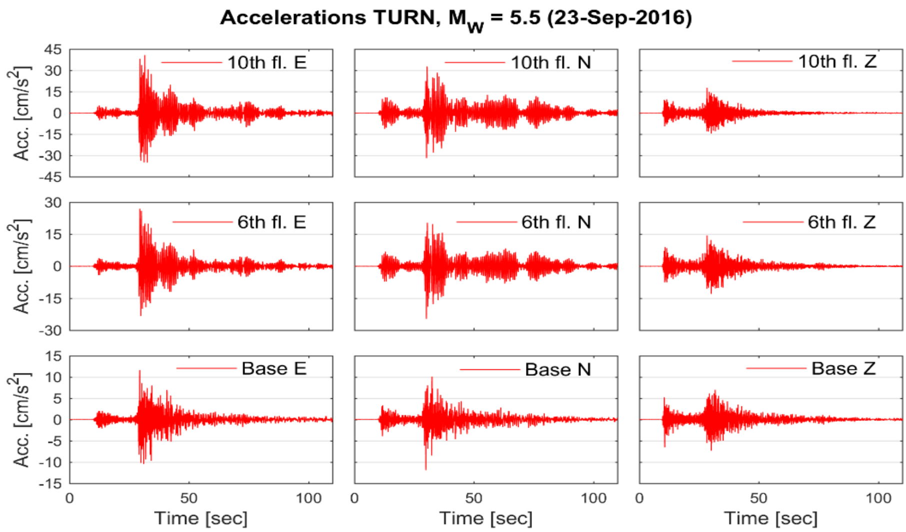

Figure 2. Acceleration time-histories recorded on building T1, at the basement, floor 6 and floor 10 (top) for earthquake nr. 10, on three components
Source:*Balan 2018*

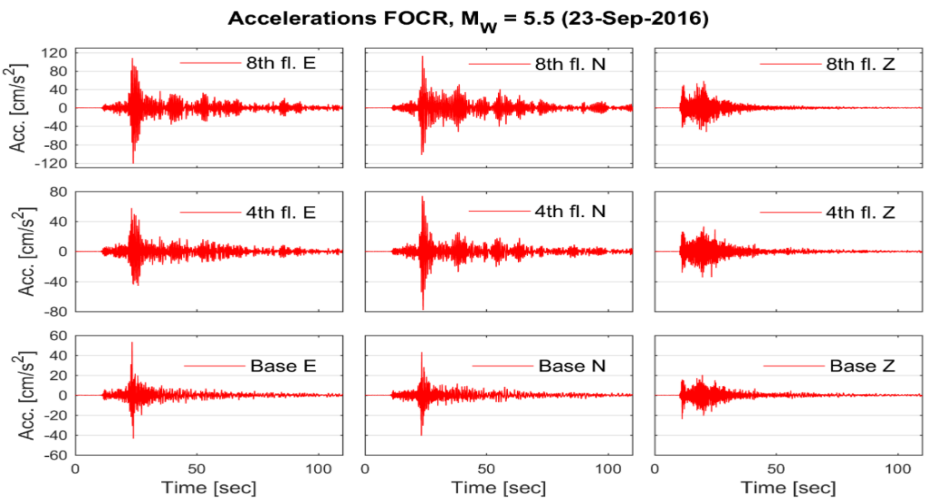

Figure 3. Acceleration time-histories recorded on building T2, at the basement,
Source*:Balan 2018*

floor 6 and floor 10 (top) for earthquake nr. 10, on three components.

To highlight the impact of the earthquakes on the built environment were computed the acceleration response spectra (the second analysis) for earthquakes 10 and 11, for the horizontal components recorded at the base (Fig. 4).

3. Results

In Tables 1 and 2, are presented maximum accelerations recorded on structures T1 and T2, corresponding to the earthquakes listed in Table 1.

Table 2. Maximum accelerations for the building T1 in cm/s²

Eq. nr.	M_W	N-S			E-W			Z		
		B	F6	F10	B	F6	F10	B	F6	F10
1	4.4	4.38	4.47	6.74	3.26	5.32	8.46	1.65	4.23	5.93
2	4.6	3.53	3.17	4.94	3.43	7.21	11.32	2.12	3.26	4.12
3	4.2	1.18	2.28	3.85	2.43	2.22	4.60	0.73	1.67	1.90
4	4.3	1.27	1.68	2.37	1.64	1.56	3.28	1.90	3.56	4.05
5	5.4	6.28	18.65	28.68	6.54	11.64	20.45	3.25	6.16	5.43
6	4.3	0.71	0.87	1.46	0.75	1.27	1.95	0.85	1.65	2.15
7	4.3	2.10	3.37	5.54	2.84	4.32	6.95	1.37	2.75	3.19
8	4.3	5.55	6.25	8.92	16.95	16.35	35.20	5.26	8.81	11.21
10	5.5	11.89	24.75	32.85	11.61	27.00	40.75	7.34	14.50	17.80
11	5.6	10.22	21.91	33.59	12.90	43.46	55.11	8.54	18.12	21.44
12	4.8	10.63	11.08	19.22	4.99	8.02	12.96	4.05	7.40	7.98
13	4.5	1.78	2.69	4.85	1.84	3.33	5.25	1.28	3.02	2.98

Source:*Balan 2018*

Legend: B – basement; F6 – floor 6; F10 – floor 10.

Table 3. Maximum accelerations for the building T2 in cm/s²

Eq. nr.	M_W	N-S			E-W			Z		
		B	F4	F8	B	F4	F8	B	F4	F8
9	3.8	1.63	4.38	5.30	1.11	2.05	4.13	3.71	6.94	13.80
10	5.5	43.15	78.26	112.93	53.38	58.05	120.91	24.07	34.73	58.32
11	5.6	36.74	38.44	60.21	42.17	35.99	70.24	21.21	37.03	50.99
12	4.8	3.52	5.95	11.79	6.11	6.73	13.60	7.45	13.06	23.85
13	4.5	5.58	10.07	13.88	3.43	6.39	7.70	5.15	12.17	16.89
14	4.6	4.00	7.51	10.99	4.73	10.39	13.62	2.11	3.57	6.10

Source*:Balan 2018*

Legend: B – basement; F4 – floor 4; F8 – floor 8.

For the earthquakes where data were available for both buildings (earthquakes 10, 11, 12 and 13), a comparative analysis was performed, in order to understand if there is any correlation between the response of building and the earthquake parameters, given that they are located at different epicentral distances (see Fig. 5 and 6). The datasets were split in two subsets, one for earthquakes with M_W< 5.0 and one for earthquakes with M_W> 5.0.

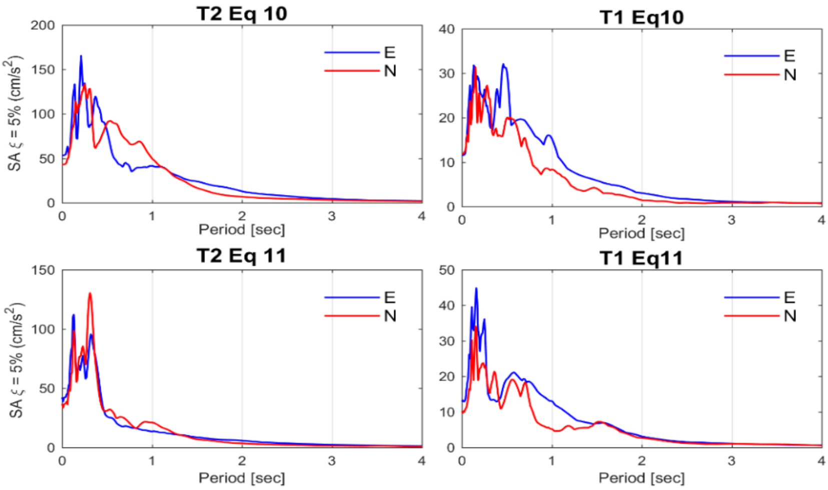

Figure 4. Acceleration response spectra at basement of buildings T1 and T2 on horizontal directions (N-S and E-W) due to earthquakes 10 and 11 (see Table 1).

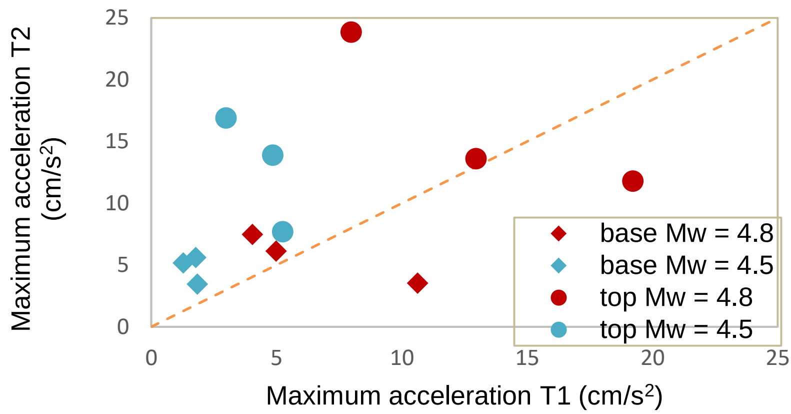

Figure 5. Maximum accelerations for earthquakes recorded on both buildings (12, 13 earthquakes) with Mw < 5.0

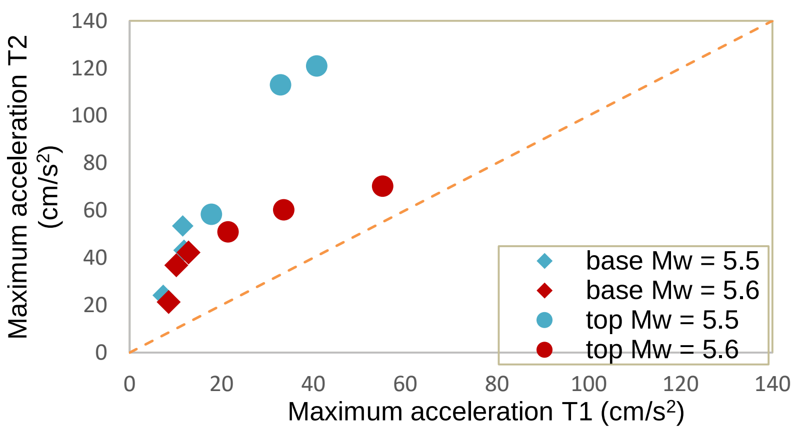

Figure 6. Maximum accelerations for earthquakes recorded on both buildings (10, 11 earthquakes) with Mw > 5.0

4. Conclusions and Discution

For the building T1 first observation is that the maximum acceleration recorded at the top, on horizontal component, is higher with the increase of depth and magnitude. This is valid for earthquakes nr. 5, nr. 10 and nr. 11, with M_W higher than 5, where the top recorded acceleration on N-S direction are 28.68 cm/s^2, 32.85 cm/s^2 and 33.59 cm/s^2. On E-W direction the recorded accelerations are 20.45 cm/s^2, 40.75 cm/s^2 and 55.11 respectively. For the earthquakes with the same magnitudes, but lower than 5, the recorded accelerations are also increasing with depth (M_w=4.3, earthquakes nr. 4, 6, 7 and 8). For example, the maximum acceleration values recorded for the shallowest earthquake (nr. 6) are 1.46 cm/s^2 on N-S direction and 1.95 cm/s^2 on E-W direction, while for the deepest one (nr. 8) are 8.92 cm/s^2 and 35.20 cm/s^2.

For the N-S direction, the building T2 at the top, for earthquake 10, has maximum acceleration 112.93cm/s^2 (M_W = 5.5), whereas the value is 60.21cm/s^2 for earthquake 11 (M_W = 5.6); for E-W direction the values are maximum acceleration 120.91cm/s^2 (earthquake 10) and 70.24cm/s^2 (earthquake 11). In the authors' opinion, this rather big differences couldn`t yet be interpreted, and a more extensive study is needed, the epicenters being also relatively close.

The computation of the acceleration response spectra with 5% damping (Fig. 4) from earthquakes nr. 10 and 11 (horizontal components recorded at the base of the structures), revealed that the highest amplitudes of spectral accelerations in Magurele fall in the range of periods 0 – 0.8s, while in Focsani the range is 0 - 0.5s. However, the corresponding acceleration level does not exceed 160 cm/s^2 in Focsani and 50 cm/s^2 in Magurele, therefore no structural damage should occur. Overall, the spectral acceleration values, for the same earthquake, are much higher closer to the Vrancea seismic zone.

As expected, when comparing the base and top accelerations recorded on T1 and T2 during the same earthquake (Fig. 5 and 6), the general tendency is that T2 experienced larger acceleration values compared to T1, both for earthquakes with magnitudes lower and greater than 5.0. However, it is noticed that for the earthquakes with magnitude M_W = 4.8, the N-S component is higher for T1, compared to T2 (Table 2 and 3, Fig. 5).

These types of analyses contribute to a better understanding of the behavior of the structures when subjected to earthquakes. The seismic monitoring of buildings can give also a rapid damage assessment after a strong seismic event, based on the level of accelerations the buildings experienced, therefore mitigating the seismic risk for densely populated areas in Romania. In fact, all these tools can help our society to move toward smart buildings, and, why not, toward smart cities, as an inter-connected system.

Acknowledgements

This paper was carried out within Nucleu Program 2018, supported by Ministry of Research and Innovation, project numbers: PN **PN18150101.**

References

[1] Balan, S.F., Apostol, B.F. (2015), *Mitigation of seismic risk considering soil-structure interaction analysis for Bucharest Metropolis*, 15th International Multidisciplinary Scientific GeoConferences SGEM 2015, Bulgaria, pp. 903–910.

[2] Balan, S.F., Tiganescu, A., Apostol, B.F., (2018), *Seismic Monitoring of Structures Subjected to Medium Intensity Earthquakes*, 18-th International Multidisciplinary Scientific GeoConferences SGEM 2018, Bulgaria, p: 955-962.

[3] Marmureanu, G., (2016), *Certainties /Incertainties in Vrancea Hazard and Seismic Risk Evaluation*, Romanian Academy Publishing House.

[4] ROMPLUS, (2018), National Institute for Earth Physics, Earthquake Catalog.