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ANALYSIS IN TERMS OF STRUCTURAL DISPLACEMENTS AND ACCELERATIONS FOR SOME TOWER BUILDINGS UNDER MODERATE MAGNITUDE EARTHQUAKES

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Abstract

The paper presents displacements and accelerations of two tower type buildings, one near the epicenter zone, Vrancea and one South of Bucharest (~150 km from epicenter zone). Displacements and accelerations were computed from the processed recorded accelerograms. Were used 3 "Triaxial Seismic Accelerometers" on 3 levels of each building. The displacements and accelerations on the analyzed structures were a result of Vrancea medium earthquakes between 2014-2017 years with magnitudes M_w *ranging from 3.8 to 5.6 and depths between ~ 41 km to 147 km. A discussion of structural response was made concerning each building (one on 12 seismic events, the other on 6 ones and both on 4 that are common). The recorded data will contribute to a better understanding of the structures responses, even subjected to medium magnitude seismic events, and to the mitigation of seismic risk for densely populated areas.*

Key words*: tower structure, seismic records, structural displacement, building monitoring, Vrancea epicentre area.*

INTRODUCTION

Romania is a seismic country, subjected to strong intermediate-depth earthquakes, which affect especially its Eastern and Southern parts. The earthquakes hypocenters are located in a certain volume, and consisting of confined focal sources, in the Vrancea region. This seismogenic area is characterized of both superficial earthquakes, but also of deep ones, attaining even 200 km focal depths.
The Bucharest city is located at ~160 km epicenter distance. In the XXth century were four major 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;
- 1990 May 30 with magnitude M_w = 6.9.

Bucharest city was seriously affected with 600 (in the year 1940) and almost 1400 (in the year 1977) deadly causalities and many totally collapsed buildings. All these four seismic events had over 90 km focal depth (ROMPLUS Catalog, 2018).
This paper intends to evaluate and analyse the influence of the recent earthquakes (2014-2017) from Vrancea source on some buildings in the Metropolitan Bucharest area and Focsani (town in Vrancea near the seismic source). At the same time is trying to find similar trends and differences between the responses of the buildings, given different epicentre distances, and correlations of the earthquake parameters (magnitude, depth) with building response.
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 (Bratosin et al., 2017; Cioflan et al., 2018).
Starting from information comprised by data bases for soils and buildings existing in Bucharest were selected two types of structures (Balan et al., 2015).

MATERIALS AND METHODS

The monitoring processes

National Institute of Research and Development for Earth Physics from Magurele is conducting monitoring for 6 instrumented buildings (Since 2011).

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However, the recorded earthquakes data are transmitted in real time to the National Data Centre. Therefore, the earthquakes catalogue (http://www.infp.ro/romplus) is continuously set up and up dated.
The input data are consisting in accelerations or velocities recordings that could be used for seismic hazard evaluation.
The structural seismic response is computed and employed for developing risk and damage maps (Marmureanu G., 2016; Marmureanu et al., 2011), more of them in near-real time. Also, they are useful as input data for design regulations.
In this paper are presented the results of the continuous monitoring with “Triaxial Seismic Accelerometers” mounted on different floors, in order to characterize the structural behaviour of the following structures: a tower type structure (T1) in Magurele (South Bucharest city) and a tower type structure in Focsani (T2) (Figure 1).
The monitoring is achieved at building T1 with 3 seismometers placed at basement, 6th floor and 10th floor, and at building T2 with 3 seismometers placed at basement, 4th floor and 8th floor; the data being transmitted in real time to the NIEP`s National Data Centre.
The recordings are on three directions, two horizontal N-S and E-W, and one vertical, Z.
The considered earthquakes in the analysis (No. 1-14) had magnitudes M_w ranging from 3.8 to 5.6 and a large variety of depths between ~ 41 km to 147 km.

Figure 1. Location map of the instrumented buildings (T1 and T2)

The instrumented structures are tower type of different design and at different epicentre site distances: T1, tower structure situated in the Southern part of Bucharest city (10 floors high), office building, of reinforced concrete with shear walls, built in 1974 and T2, tower structure in Focsani, located close to the Vrancea epicentre area, apartments and single rooms (8 floors high), of reinforced concrete frame, built in 1971.
We shall analyse and discuss the effects of magnitudes and epicentre distance on displacements induced on these buildings, by the considered seismic events (No. 1-14). From Tables 1 to 6 could be observed the 4 common recorded earthquakes (events 10-13).

RESULTS AND DISCUSSIONS

The recorded acceleration time-histories were pre-processed: baseline corrected and filtered using a 4th order Butterworth band pass (0.2-25 Hz) filter. The limits were set for obtaining a good signal to noise ratio, and for small earthquakes where the signal was strongly affected by noise the calculus was not performed (building T1, event No. 9 of magnitude M_w = 3.8). Having the corrected acceleration time-histories, the corresponding velocity and displacement time-histories were obtained through time-integration, using the trapezoidal rule. For acceleration values, sampled at a small-time interval (0.01 s or 0.005 s), the integral can be approximated by the area under the plot, assuming a linear function from one point to the next one. Consequently, the velocity was integrated in the same manner to obtain the displacement.

Table 1. Maximum displacements in [mm] for building T1 at base (B), floor 6 (F6) and floor 10 (F10), direction N-S, for the corresponding earthquakes magnitudes (M_w) and depths

No.	Depth [km]	M_w	Direction N-S		
			B	F6	F10
1	132.3	4.4	0.16	0.45	0.65
2	134.4	4.6	0.20	0.31	0.61
3	147.3	4.2	0.04	0.09	0.14
4	106.1	4.3	0.05	0.11	0.16
5	40.9	5.4	0.90	2.51	3.70
6	88.4	4.3	0.02	0.05	0.09
7	118.2	4.3	0.08	0.17	0.27
8	145.4	4.3	0.11	0.18	0.23
10	92.0	5.5	0.70	2.12	3.00
11	96.9	5.6	1.25	2.77	4.04
12	123.2	4.8	0.36	0.83	1.20
13	121.6	4.5	0.07	0.18	0.30

Table 2. Maximum displacements in [mm] for building T1 at base (B), floor 6 (F6) and floor 10 (F10), direction E-W, for the corresponding earthquakes magnitudes (M_w) and depths

No.	Depth [km]	M_w	Direction E-W		
			B	F6	F10
1	132.3	4.4	0.12	0.28	0.44
2	134.4	4.6	0.25	0.57	0.86
3	147.3	4.2	0.07	0.12	0.20
4	106.1	4.3	0.05	0.09	0.14
5	40.9	5.4	1.56	1.95	2.85
6	88.4	4.3	0.04	0.08	0.12
7	118.2	4.3	0.09	0.22	0.34
8	145.4	4.3	0.33	0.53	0.75
10	92.0	5.5	1.69	3.25	4.78
11	96.9	5.6	1.95	3.95	5.52
12	123.2	4.8	0.23	0.50	0.73
13	121.6	4.5	0.05	0.12	0.15

Table 3. Maximum displacements in [mm] for building T1 at base (B), floor 6 (F6) and floor 10 (F10), direction Z, for the corresponding earthquakes magnitudes (M_w) and depths

No.	Depth [km]	M_w	Direction Z		
			B	F6	F10
1	132.3	4.4	0.06	0.07	0.05
2	134.4	4.6	0.06	0.08	0.08
3	147.3	4.2	0.01	0.02	0.02
4	106.1	4.3	0.04	0.04	0.04
5	40.9	5.4	0.59	0.59	0.61
6	88.4	4.3	0.02	0.02	0.02
7	118.2	4.3	0.03	0.04	0.06
8	145.4	4.3	0.06	0.08	0.10
10	92.0	5.5	0.42	0.46	0.42
11	96.9	5.6	0.46	0.60	0.44
12	123.2	4.8	0.10	0.15	0.10
13	121.6	4.5	0.02	0.03	0.02

From the displacement time-histories, the maximum values were extracted and represented in Tables 1-6, for buildings T1 and T2. The same analysis was conducted in order to compute maximum values for accelerations at the same levels.

Table 4. Maximum displacements in [mm] for building T2 at base (B), floor 6 (F6) and floor 10 (F10), direction N-S, for the corresponding earthquakes magnitudes (M_w) and depths

No.	Depth [km]	M_w	Direction N-S		
			B	F4	F8
9	65.0	3.8	0.04	0.09	0.13
10	92.0	5.5	5.44	12.08	12.42
11	96.9	5.6	2.86	4.30	3.51
12	123.2	4.8	0.10	0.27	0.55
13	121.6	4.5	0.17	0.26	0.37
14	131.0	4.6	0.34	0.54	0.55

Table 5. Maximum displacements in [mm] for building T2 at base (B), floor 6 (F6) and floor 10 (F10), direction E-W, for the corresponding earthquakes magnitudes (M_w) and depths

No.	Depth [km]	M_w	Direction E-W		
			B	F4	F8
9	65.0	3.8	0.02	0.07	0.11
10	92.0	5.5	7.28	11.10	18.74
11	96.9	5.6	3.02	4.21	6.66
12	123.2	4.8	0.19	0.28	0.49
13	121.6	4.5	0.09	0.18	0.35
14	131.0	4.6	0.32	0.75	1.23

Table 6. Maximum displacements in [mm] for building T2 at base (B), floor 6 (F6) and floor 10 (F10), direction Z, for the corresponding earthquakes magnitudes (M_w) and depths

No.	Depth [km]	M_w	Direction Z		
			B	F4	F8
9	65.0	3.8	0.03	0.04	0.05
10	92.0	5.5	1.59	1.57	1.70
11	96.9	5.6	0.71	0.72	0.77
12	123.2	4.8	0.07	0.08	0.10
13	121.6	4.5	0.06	0.06	0.08
14	131.0	4.6	0.06	0.08	0.07

Regarding the structural responses, in order to highlight the impact of the earthquakes on the built environment, acceleration response spectra at the basement of buildings are calculated for two strongest earthquakes, and spectral ratio (top/base) for three, respectively two strongest seism's (Figures 2 and 3). There was achieved an analysis regarding the influence of the magnitude for the considered earthquakes on maximum displacements of buildings T1 and T2 (Tables 1 to 6). The analysis is made for building T1 at basement, floors 6 and 10 and for building T2, at basement, floors 4 and 8.

For building T1 the largest maximum displacements are observed at floor no. 9 for the following three seismic events: 5, M_w = 5.4, depth = 40.9 km (direction N-S = 3.70 mm, direction E-W = 2.85 mm), event 10, M_w = 5.5, depth = 92 km (direction N-S = 3.00 mm, direction E-W = 4.78 mm) and event 11, M_w = 5.6, depth = 96.9 km (direction N-S = 4.04 mm, direction E-W = 5.52 mm).

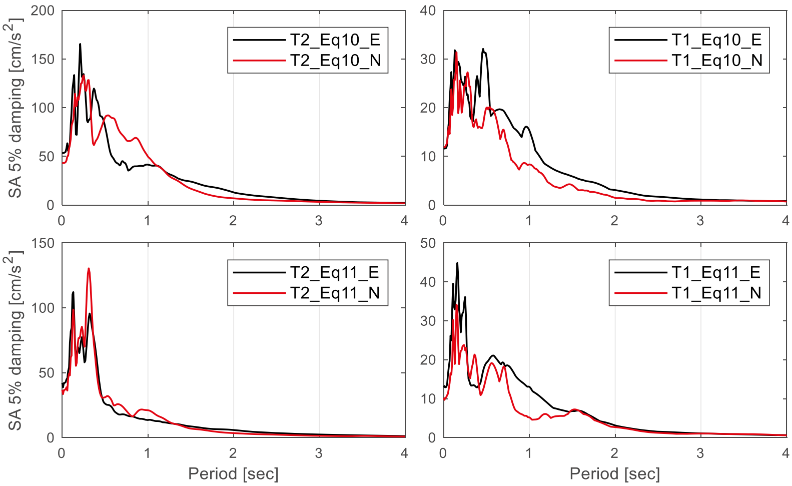

Figure 2. Acceleration response spectra at basement of buildings T1 and T2 on horizontal directions (N-S and E-W) due to earthquakes 10 and 11

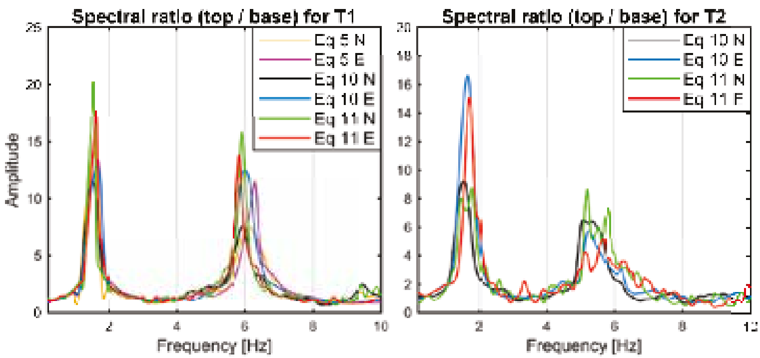

Figure 3. Spectral ratio for building T1 (left), for earthquakes 5, 10 and 11, and for building T2 (right), for earthquakes 10 and 11, on two horizontal components

These were the greatest seismic events recorded at building T1. In general, could be observed an increasing tendency of displacements with magnitudes, and a less influence or correlation of the focal depths.

The values for the vertical displacements have an approximately similar behaviour on all the monitored floors.

At building T2, near the epicentre, is observed that the greatest maximum displacements (at level no. 8) are by far also for the strongest events: 10, M_w = 5.5, depth = 92 km (direction N-S = 12.42 mm, direction E-W = 18.74 mm) and event 11, M_w = 5.6, depth = 96.9 km (direction N-S = 3.51 mm, direction E-W = 6.66 mm).

As regarding the influence of the epicentre distance, by comparing the maximum displacements on the upper floors of the recorded largest earthquakes at both tower-type buildings, it is observed that larger horizontal and vertical displacements are on building T2 near the Vrancea epicentre, for almost all seismic events. The exception for this general tendency could be attributed either to inherent recording errors, or to the seismogenic particularities of the Vrancea active focal region or even to the type of soils beneath the buildings.

The analysis of the acceleration response spectra (Figure 2) from earthquakes no. 10 and 11 exhibits that the significant amplitudes of spectral acceleration (5% damping) for T1 are in the range of periods 0-1 s, while for T2 is in the range of 0-0.5 s. One shall keep in mind that the corresponding accelerations does not exceed 160 cm/s^2 in T2 and 50 cm/s^2 in T1, therefore was no danger regarding structural damage.

For building T1, the spectral ratio was computed for three earthquakes with magnitudes M_w larger than 5 (no. 5, 10 and 11), and the results show a good consistency for the peaks, despite different focal depths. Their mean value for the fundamental period is 0.63 seconds (1.59 Hz, Figure 3, left).

For the building T2, a larger dispersion of the results regarding the second peaks was observed (Figure 3, right). However, the mean value for the fundamental periods is 0.61 seconds (1.64 Hz), and compared to T1 building, which is 2 stories higher, the two fundamental periods are close (0.61 and 0.63 seconds). This could be explained by the fact that the two structural systems are different, shear walls and frames, and by the fact that T1 was retrofitted after the 1977 earthquake.

CONCLUSIONS

The buildings are not identical and stand on very different grounds type, both in densely populated regions. All these recordings and observations have their importance because could represent a checking possibility for the earthquake engineer in modelling the structural analysis. At the far away building from the source, T1, is observed the direct influence of magnitude over maximum displacements. In the near from source, at building T2 is observed the depths of around 90 km and magnitude over 5 giving maximum displacements. However, for the both buildings the magnitude influence appears to be much decisive. The largest displacements are, as expected, at the top floors on all directions.

Therefore, many parameters could affect the structural response of a building, such as: focal depth, magnitude range, epicentre distance.

These types of analyses contribute to a better understanding of the behaviour 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. The results are aiming to contribute to a better understanding of the structures responses, even subjected to medium magnitude seismic events and to the mitigation of seismic risk for densely populated areas in Romania.

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