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EFFICACY OF THE SEISMIC ISOLATING SYSTEMS FOR HISTORICAL BUILDINGS UNDER MODERATE SEISMIC FORCES

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Abstract

National Institute of R-D for Earth Physics is in charge at national level with the task of monitoring the seismicity of the country. For this, it is used a well-developed seismic network with a good coverage of the Romanian territory. Beside the free field network of sensors, there is a number mounted on some buildings, used to evaluate their response to a large range of seismic events. The aim of the paper is to demonstrate the efficacy of the isolation systems of two buildings, situated in Bucharest, during earthquakes. The goals will be achieved through analyzing the seismic response in terms of engineering parameters given by the sensors located at key levels, i.e. under and right above isolating devices. The results show the reduction of the seismic loads above the isolators hence the successful use of this type of technique for older buildings of certain design, exposed to Vrancea seismicity and Bucharest subsoil specificity. Conclusions are drawn about the effectiveness of the isolation system on both structures, as part of a solution in specific cases for seismic risk mitigation.

Key words*: base-isolating technique, seismic response analysis, moderate Vrancea earthquakes, seismic isolated buildings.*

INTRODUCTION

Because of the Vrancea source, in the aftermath of the November 1940 seismic event of magnitude MW = 7.4, civil engineers begun to think of using seismic codes for buildings design and construction. Until this devastating earthquake all buildings were designed after German codes with only considering gravitational and wind forces (Beles, 1941).

Things improved even more after the March 4, 1977, earthquake (Vrancea source, MW= 7.2) with 1500 casualties and approximately 30 buildings collapsed in downtown Bucharest, and a lot of damage in N-E, E and S-E of the country (Balan et al., 1982; Dilley et al., 2005; Bonjer et al., 2010; Mandrescu, 1982; Trendefiloski et al., 2009). Since 1977 different editions of a modern and scientific seismic code were released, based on recordings from stronger 1977, 1986, 1990 and other seismic events (P. 100-78; P. 100-92; P. 100-1/2006; P. 100-1/2013). Were considered also other different factors linked to buildings: type, shape, function, local conditions of sites, etc., to improve their resilience to earthquakes. With a number of 99 broad band sensors, 184 stations with acceleration sensors (25 are installed in Bucharest-Ilfov) and 2 seismic arrays, the National Institute of R-D for Earth Physics (NIEP) records, archives, processes, interprets and disseminates all seismic data gathered from Romanian territory (Neagoe et al., 2011; Tiganescu et al., 2021).

The recordings from the strongest event of the last (two) years MW = 4.9, originating in Vrancea-intermediate depth seismic area are analyzed as they are offered by sensors deployed in certain buildings (ROMPLUS, 2023).

In a previous paper a similar analysis was performed for two tower-type buildings located in different areas, one nearer the epicentre, the other belonging to the Bucharest extended metropolitan area at (roughly) ~150 km. The characteristics of these buildings were described, their response and behaviour at this medium seismic solicitation evaluated, by considering the difference in the epicentre distances but similarity in design (Apostol et al., 2023; Balan et al., 2023; Tiganescu et al., 2019). At that time the moment magnitude for the considered seismic event was employed with the value as it was in the Internal Report, released just in the aftermath of the triggered event, MW = 5 (Internal Report, 2022).

Herein the approach is extended to older buildings that, during reinforcement action they supported, were endowed with base-isolators devices. The motivation was to take advantage from this performance as the structures were equipped with seismic sensors at interest levels. The goal pursued in this paper is to prove the efficacy of this certain type of anti-seismic isolating technique applied to old/historical structures located in the Bucharest downtown. The response of the buildings is considered under medium intensity earthquake and the performance of isolators devices are highlighted in terms of engineering parameters.

In Bucharest 3 buildings were seismically isolated: Victor Slavescu building belonging to Bucharest University of Economic Studies (ASE), the Bucharest Town Hall (PMB) and the Triumph Arch (a historic monument). NIEP deployed seismic sensors on all these buildings installed at different times. In this paper only buildings endowed with sensors under and above the isolation system are considered. The point of novelty consists that in one building a sensor under the isolating level was recently installed, hence it exhibits similarity to the other, allowing for an analysis in the same conditions.

MATERIALS AND METHODS

Buildings overview and processed data

The ASE structure, a historical monument was built between 1905 and 1908 of brick masonry with truss roof; it consists of underground, ground floor, two floors and an attic. The building was consolidated after the year 2011, when the seismic isolation system was introduced. It is monitored with two accelerometers, located in the basement below / above the seismic insulators.

The other building, the PMB is also a historical architectonic monument, was built between 1906 and 1908, with brick masonry, reinforced concrete floors with turned caissons. The consolidation procedure started in 2010 and, taking advantage of this, a similar isolated system was introduced. The levels of the structure consist of underground, ground floor, 3 floors and an attic. It is real-time monitored with 4 accelerometers mounted at ground floor, floors 2, 3 and attic. It should be noted that all of these are placed above the seismic isolation system of the building. Some years ago two accelerometers were added, under and above the seismic isolated system.

This paper attempts to a preliminary evaluation of the recordings on these isolated structures, as offered by the November 3, 2022, Vrancea earthquake.

The characteristics of this seismic event were: data and time triggering 2022/11/03, 04:50:25.81, Latitude: 45.4895°, Longitude: 26.5262°, hypocentral depth H = 149.0 km, M_W = 4.9 (M_L = 5.3) (ROMPLUS, 2023).

The available data belonging to one of the recent strongest earthquakes are analysed and processed in order to highlight the efficacy of the base isolation system at this structural type in Bucharest city area. The level of the hazard assessment parameters, geotechnical features and local effects in terms of site response are compulsory features that have to be taking into consideration when one decides to perform this type of anti-seismic technique. All these issues were referred to in other papers (Aki, 1993; Ishihara, 1996; Bard & Riepl-Thomas, 1999; Panza et al., 2001; Balan et al., 2019; Mandrescu et al., 2004; 2007; Marmureanu et al., 2021; 2020; Marmureanu, 2016) with emphasis on city geophysical local specificity and structural response (Lungu et al., 1999; Moldoveanu and Panza, 2000; Moldoveanu et al., 2004; You et al., 2009; Su et al., 2006).

The processed data are used for elastic response spectra computations which are discussed in terms of peak amplitude parameters and predominant periods or spectral ranges of interest. The outcomes are those related to buildings structural behaviour, health monitoring and resonance phenomenon (Tiganescu et al., 2022; Balan et al., 2020). Also, the data transmission and near-real time assessment are provided and pursued during buildings monitoring process.

The operation is targeted on the possibility to assess the buildings behaviour during and immediately after an earthquake. A rapid response is evaluated, and the output can be implemented in general procedures that can be applied for end-user use-cases and a sustained flow of information is ensured (Balan et al.,

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2023; Apostol et al., 2023). Following the rapid evaluation of the engineering parameters, information is obtained about the behaviour of the respective structure or certain type of buildings in the area under the certain seismic demand. These actions, involving the data collected in free field and on buildings help designers, urban planners and authorities interested in the mitigation of seismic risk in urban areas (Tiganescu et al., 2021; 2022).

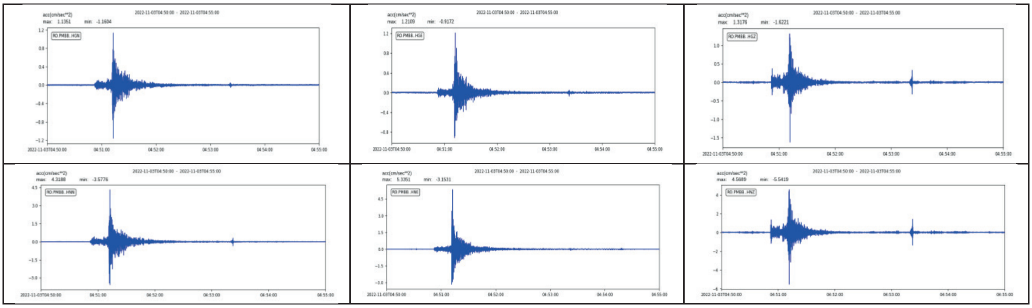

Figure 1. Acceleration on three components (from the left to the right N-S, E-W, Z) at PMB building recorded by sensors located above (upper panel) and below (lower panel) the insulating devices

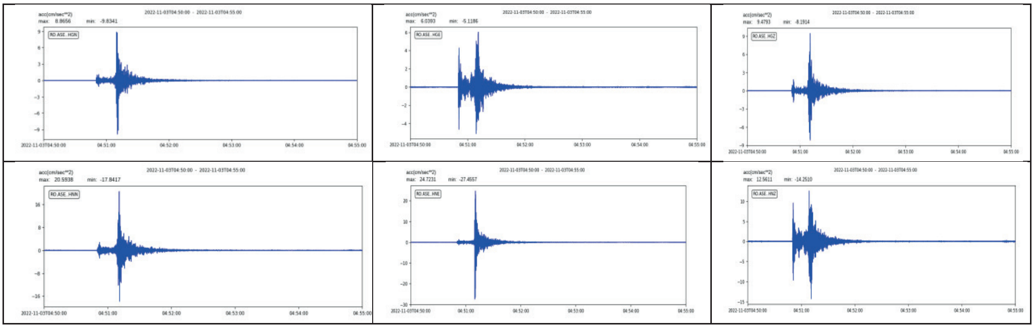

Figure 2. Acceleration on three components (from the left to the right N-S, E-W, Z) at ASE building recorded by sensors located above (upper panel) and below (lower panel) the insulating devices

Figures 1, 2 show the recorded accelerograms at key levels, below and right above the isolating layer, during the 03.11.2022 seismic event, of moment magnitude M_W = 4.9, in the retrofitted structures. Accelerometers data recordings on the buildings during earthquakes are near-real time processed, using the same filtering (bandpass 0.2 Hz - 25 Hz, 4^{th} order Butterworth) and the same techniques, in order to keep the results uniform and comparable (BRTT, 2018).

Base - isolated devices performance analysis

In Figures 3, 4 the elastic response spectra are shown with 5% damping for spectral pseudo-acceleration computed at two levels of interest in PMB and ASE buildings. For the computation of the elastic response spectra of the recorded seismic events the Antelope Environmental Monitoring System is employed herein (BRTT, 2018; Internal Report, 2022). In Table 1 the maximum values are shown, from the recordings on ASE, PMB buildings, under and above the isolated system, on three mutual perpendicular components (two horizontal North-Souths, East-West and one vertical Z). The parameters of engineering interest are maximum acceleration, velocity and spectral acceleration, processed through dedicated software and shown as seismograms and elastic response spectra (Figures 1 to 4).

In Table 2 the reduction of seismic amplitudes is shown in terms of maximum recorded accelerations, in order to have a quantitative representation for the outcome of the employed technique. The reduction coefficient represents the ratio for under/above values and the reduction percentage stands for its corresponding percent in the considered weight. As seen, the reduction in percentage is over 50% for all components, for both buildings. One could notice the stronger reduction percentage for the PMB building, for which the recorded values are in general much lower. Also, the reduction is slightly higher on the E-W component, again for both buildings.

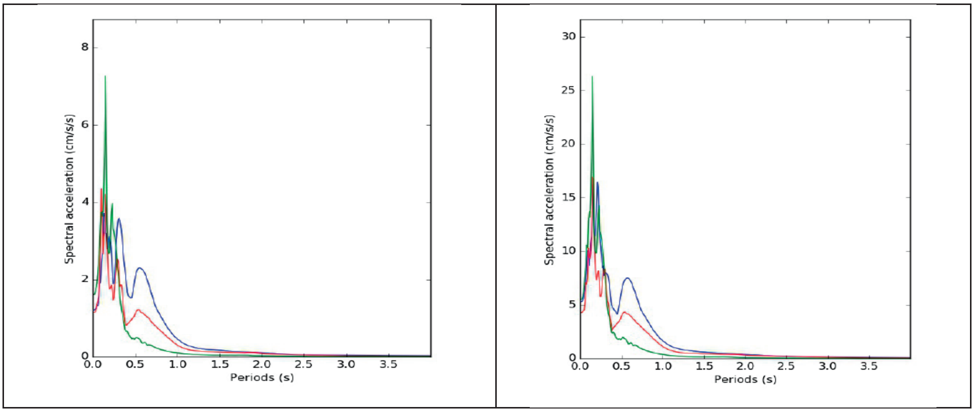

Figure 3. Elastic response spectra for the PMB building above (left) and under (right) isolator layer from recordings of the 03.11.2022 earthquake M_W= 4.9

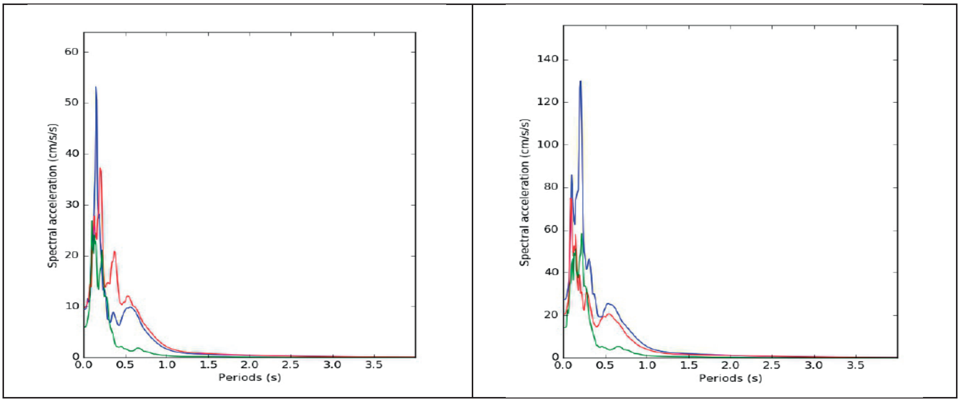

Figure 4. Elastic response spectra for the ASE building above (left) and under (right) isolator layer from recordings of the 03.11.2022 earthquake M_W = 4.9

Legend colors: red: N-S, blue: E-W, green: Z (vertical) components of recording

Table 1. Maximum values recorded on ASE and PMB under and above the isolated system. The parameters are maximum acceleration, velocity and spectral acceleration

Buildings code, recorded parameters	Sensor under isolation system			Sensor above isolation system		
ASE	**N-S**	**E-W**	**Z**	**N-S**	**E-W**	**Z**
Acceleration [cm/s^2]	20.594	**27.456**	14.251	**9.834**	9.479	6.039
Velocity [cm/s]	0.75	**1.24**	0.39	**0.44**	**0.44**	0.16
Spectral Acc. [cm/s^2]	74.95	**130.08**	58.28	37.29	**53.24**	26.85
PMB	**N-S**	**E-W**	**Z**	**N-S**	**E-W**	**Z**
Acceleration [cm/s^2]	4.319	5.3351	**5.542**	1.160	1.211	**1.622**
Velocity [cm/s]	0.16	**0.25**	0.17	0.04	**0.08**	0.04
Spectral Acc [cm/s^2]	19.95	16.45	**26.36**	4.35	3.72	**7.28**

Table 2. Base-isolated device performance in terms of reduction coefficient (for acceleration) and corresponding reduction percentage for the two buildings

Buildings	Component N-S		Component E-W		Component Z	
	Reduction coefficient	Reduction percentage	Reduction coefficient	Reduction percentage	Reduction coefficient	Reduction percentage
ASE under/above isolator	2.09	52%	**2.89**	**65.5%**	2.35	57.9%
PBM under/above isolator	3.72	73.15%	**4.40**	**77.28%**	3.42	70.73%

RESULTS AND DISCUSSIONS

The available seismic recordings for the most recent $M_W \geq 4.9$ earthquake are analysed and processed in order to highlight the efficacy of the base isolation system at this type of structure in Bucharest city area.
The aim is to check the performance of the base isolating solution in the context of soil specificity characteristics and response to seismic forces as induced by the Vrancea earthquakes. The work is based on the data collected on seismic isolated buildings in Bucharest, i.e. the ASE (Victor Slavescu building belonging to Bucharest University of Economic Studies) and the PMB (the building of the Town Hall of Bucharest), from the earthquakes recorded in the Bucharest metropolitan area. The latest sensors installed at PMB as part of a continuous activity through a campaign of structure surveillance across the city offer the possibility to add new data and perform a more appropriate evaluation (from a new perspective).
At the ASE building the larger recorded values under isolation system are on E-W component of recording for accelerations, velocities and spectral accelerations. These values filtered through the isolation system remain the largest on E-W component for velocities and spectral accelerations, though the maximum acceleration is now in N-S component (Table 1).
At the PMB building the largest value under isolation concerning accelerations is in Z direction, E-W direction for velocities and Z direction for spectral accelerations. These values filtered thereby reduced through the isolation system remain the higher for acceleration and spectral acceleration in Z direction, as for velocities on the E-W direction is recorded the maximum value (Table 1).
The analyzed seismic event being of moderate magnitude also the response in accelerations, velocities and spectral accelerations, on all recorded directions are in accordance with this level of seismic intensity. Their maximum amplitudes are contained in the regular ranges as for many of these types of seismic events. The corresponding spectral domain in which the oscillating periods are attained is also in low range as a typical behavior for the structure's response in the considered area at low-to-medium magnitudes (Figures 3, 4).
The work is intended to bring a contribution to the mitigation of the seismic risk over the city area and in this way to set up a more resilient urban community.
The approximate resemblance of the two structures in regard of age, design, retrofit, anti-seismic devices and seismic sensors deployment led us to perform an evaluation of the behavior under seismic solicitations. According to the expected behavior all data recorded above the isolated system are of lower amplitude than those under the isolation (Table 2). One should conclude that this specific anti-seismic technique, i.e. base isolation has reached its desired initial objective in reducing the solicitations on structures exposed to seismic movement and vibrations.

CONCLUSIONS

This study is restricted to only two structures properly instrumented regarding the sensor deployment, out of three endowed with base isolation system, from Bucharest, the outcomes may support this type of intervening method on such constructions.

One can add the importance of the local effects and uppermost stratified layers and geophysical features as factors of major importance to be considered when deciding for such accomplishments. Also, the avoidance of the dangerous spectral ranges of the higher oscillating periods as they correspond to the fundamental period over the local area is a desirable accomplishment for circumventing possible damage-causing resonance phenomenon.

Comparison was made for maximum values of the recorded accelerations, velocities and spectral acceleration as emerged from processed recordings and elastic response spectra (Figures 1 to 4). A short discussion that can be made regarding the oscillating periods as they correspond to the maximum spectral amplitudes supports the previous findings and related assertions (Apostol et al., 2023; Balan et al., 2020; 2023; Tiganescu et al., 2022) according to which it was found that they show quite a low range (up to 0.22 s for this parameter, see Figures 3 and 4). Therefore, the issue of resonance phenomenon is excluded at this seismic load level. Of course, the dynamic behavior and spectral response for much stronger magnitudes should be considered in the context of actual local soil geology, local effects and hazard level, encountered and generated over the Bucharest area.

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