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AN ANALYSIS OF THE USABILITY OF STRONG GROUND MOTION RECORDS OBTAINED FROM STATIONS LOCATED IN DENSELY URBANIZED AREAS IN ROMANIA

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ABSTRACT

The usability of ground motion records obtained, during the strong Vrancea earthquakes of 1986 and 1990, in the basement or at the ground floor of eighteen medium-rise instrumented buildings was investigated. The buildings match rather well the description of the SMBRS-DU stations in the COSMOS 2001 classification, being located in densely urbanized areas of county administrative centres in Romania. Given the lack of ground motion records available from the above earthquakes for certain areas of the country, the use of records from SMBRS-DU stations could provide essential information. Maps of the spatial distribution of peak ground acceleration, generated by considering all stations, were compared with those obtained without the inclusion of the considered SMBRS-DU records. It was shown that by assuming, in the first instance, that the spatial distribution determined in the second variant provides a reasonable approximation of the free-field motion, various informations could be obtained both on the effects of the inclusion of SMBRS-DU records and on the potential influence of buildings on the "free-field" ground motion. Further investigations are needed, in the future, to complete the information on the considered stations, in order to apply more advanced assessment methods.

INTRODUCTION

The first strong-motion network in Romania was established in 1967, by the National Institute for Building Research, INCERC. At the time of the March 4, 1977 (M_w = 7.4) earthquake, nine accelerographs and two seismoscopes were installed on various locations outside the Carpathian arc bend, including the capital city, Bucharest (Balan et al, 1982, Berg et al., 1980). After 1977, several accelerographs were installed across the country, in an effort to improve seismic instrumentation. This allowed obtaining a large number of ground motion records from the strong earthquakes of August 30, 1986 (M_w = 7.1) and May 30, 1990 (M_w = 6.9), which, given that no comparable seismic events have occurred until the present time, are still a reference for the study of Romanian Vrancea earthquakes.

Many of the accelerographs in the INCERC seismic network were located in densely urbanized urban areas, in small and medium-rise buildings. The characteristics of these seismic stations match rather well the SMRS-SB and SMBRS-DU categories in the COSMOS classification (COSMOS, 2001). The instruments installed in buildings were typically located in the basement or on the ground floor. In the case of taller buildings, for medium-rise multi-storey buildings, a second instrument was

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installed on the top floor. Most of the instruments that recorded the 1986 and 1990 earthquakes were Kinemetrics SMA-1 accelerographs. More information on the history and evolution of seismic networks in Romania can be found in (Craifaleanu et al., 2009).

Research performed during the past decades on Vrancea earthquakes has systematically excluded records from stations located in multi-storey mid-rise buildings. However, there are cases in which these are the only available type of records, thus providing extremely valuable information. Several stations, located all across the country, have been found to be candidates for the study. Moreover, the information in some stations that were included previously in the analysis needs to be re-evaluated, taking into account recent seismic station classification and conclusions from recent research in the field.

The paper presents the first results of an ongoing research concerning the usability of the strong-motion records available from seismic stations located in densely urbanized areas in Romania, similar to the SMBRS-DU category in the COSMOS classification. The research aims, in the subsequent phases, to re-evaluate existing information (ground motion records, information on buildings where instruments were located, including modal frequencies, structure and foundation type, site soil characteristics etc.) in order to extract additional data that would serve to an improved assessment of the spatial variation of ground motion parameters during the strong Vrancea earthquakes of the past three decades. This could contribute to a better substantiation of the analyses concerning seismic hazard originating from the Vrancea subcrustal source, which is affecting about two thirds of the Romanian territory.

PREREQUISITES OF THE STUDY

The use of ground motions recorded at foundation level in instrumented buildings could represent a valuable source of information for various studies, among which those concerning empirical evaluation of attenuation relationships. However, this requires either detailed knowledge on building and site characteristics or, at least, the existence of a minimal data set, which would form the input for various methods available in the literature for the assessment of the influence of soil-structure interaction on recorded ground motions. Besides the foundation-level record, records obtained at the upper stories of the building (or at least at the top level) are also needed for modal characteristics identification, as well as a reference free-field record in a nearby location. A list of the requirements that the instrumentation of a building ("Structural Response Station") should satisfy can be found in the USGS-ANSS technical guidelines (ANSS, 2002). Criteria for the optimal distance between the free-field station and the building are reviewed in (Stewart, 2000).

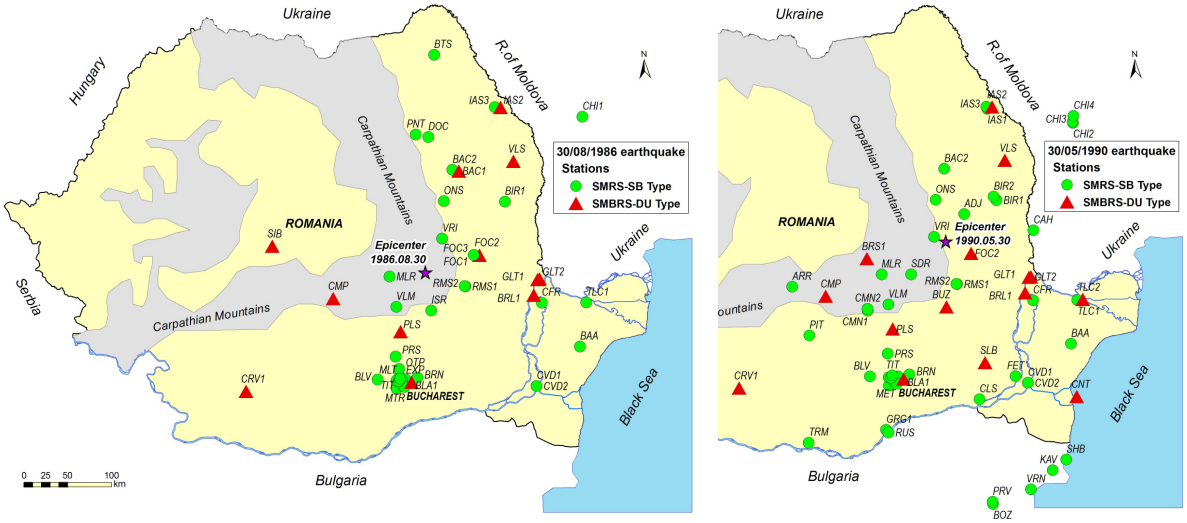
The issue of the effect of buildings on ground motions recorded in their basement or in their vicinity has been addressed by several authors. The parameters that influence soil-structure interaction (SSI) phenomena have been found to provide valuable information also for assessing variations between foundation and free-field spectral acceleration. Detailed reference on various approaches that have been used during the past decades to investigate SSI effects on ground motion is given in (Stewart et al., 1998). More recently, experimental and analytical research was conducted, in the shown context, to calibrate the significant parameters that determine the inertial and kinematical effects due to SSI (Kim and Stewart, 2003, Rayhani and El Naggar, 2008, Pandey et al., 2012, Mason et al., 2013 etc.). Revised provisions to allow for the modification of the seismic input level at building base due to SSI effects were implemented in the ASCE/SEI 41-13 standard, as an improvement of the previous edition (ASCE/SEI, 2007). Other approaches concern site-city interaction (Semblat et al., 2008), as well as the effects of the seismic vibrations of buildings on the "free-field" motions recorded nearby (Guéguen et al., 2000, Ditommaso et al., 2010 etc.).

AVAILABLE DATA

Fig. 1 displays the seismic stations that provided records from the August 30, 1986 and May 30, 1990 Vrancea earthquakes (Borcia et al., 2014). Circles and triangles indicate SMRS-SB-type and SMBRS-DU-type stations, respectively. Note that, due to the development of seismic networks, on

one part, and to the malfunction of some instruments, on the other part, the sets of stations are different for each of the considered earthquakes.

From Fig. 1, it can be observed that, for several locations in the country, the SMRSB-DU-type stations represent the only source of seismic information. Moreover, due to the large distances between stations, these additional points would be important for a better assessment of the spatial variation of ground motion parameters. Overall, the inclusion of the SMRSB -DU-type stations would add 13 stations for the 1986 earthquake and 16 stations for the 1990 earthquake.



a) August 30, 1986 earthquake b) May 30, 1990 earthquake

Figure 1. Stations that recorded the analyzed Vrancea earthquakes

The eighteen SMBRS-DU-type stations are located in buildings with four to eleven stories, located in densely urbanized areas of county administrative centres (county seats) and in the capital city, Bucharest. Of these, eight are multi-apartment residential buildings; five were, at the time of the considered earthquakes, premises of the county building design institutes, while the rest were public or state-owned buildings as, for instance, county prefectures. All buildings are of reinforced concrete, with moment-resisting frames or shear wall structures, newly built at the time of station installation. This means that all buildings were designed according to the earlier editions of the Romanian seismic code. In most cases, the buildings have continuous foundations (spread footings), with three known exceptions, two in the city of Galati (stations GLT1 and GLT2), where mat foundations were used, due to the local loess deposits, and one in the city of Braila (station BRL1) where, due to poor soil conditions, pile foundations were used. The embedment depth is about one story height in current cases.

The buildings were divided in two groups, A and B, according to their instrumentation. Buildings in group A have basement and top story instruments, while buildings in group B have only basement or ground floor instruments. Some characteristics of the buildings are shown in Tables 1 and 2, based on information in the SM-ROM-GL database (Borcia et al., 2014) and on modal identification analyses performed for buildings in group A by Demetriu and Borcia (2001) and Demetriu (2002). Additional data was available, for some of the buildings in the first group, from measurements and analyses performed before and after the 1986 and 1990 earthquakes, and also from the assessment of the state of these buildings after major seismic events.

It can be noticed, from Figure 1, that there are cities in which both SB- and DU-type stations have recorded the seismic motion, such as Iasi (IAS stations), Focsani (FOC stations), Bacau (BAC stations), Tulcea (TLC stations) and Bucharest. The usability of motions recorded by SB-type stations by their potential assimilation with reference “free-field” stations should be further assessed for these cities, based on the criteria in the literature.

From the above, it can be observed that information available on the analyzed stations is rather lacunary. Additional information is planned to be collected in the future stages of the research, to allow the computation of parameters required to assess, on an individual basis, the effect of the

buildings on recorded ground motions. The investigation will focus especially on buildings in group A, for which fewer characteristics are lacking. In the following, an analysis based on existing data is presented.

Table 1. Characteristics of buildings with SMRSB-DU-type stations. Group A: buildings with base and top instruments

Group A Buildings						
No.	**Station**	**Station Code**	**No. of Stories***	**Instrument Position**	**Structure Type**	**Estimated $\tilde{T}$ (s)**
1	Bacau Cornisa	BAC1	B+GF+10S	B & TS*	RC Shear Walls	0.48; 0.76
2	Braila	BRL1	B+GF+11S		RC frames w. Masonry Infill	0.87…1.04; 0.92…0.95
3	Bucharest – Balta Alba	BLA1	B+GF+10S		RC Shear Walls	0.66; 0.73
4	Craiova	CRV1	B+GF+7S		RC frames w. Masonry Infill	0.75; 0.99
5	Galati IPJ	GLT2	B+GF+9S		RC frames w. Masonry Infill	1; 1.06
6	Galati Tiglina I1	GLT1	B+GF+10S		RC Shear Walls	0.69; 0.74
7	Ploiesti-Vest	PLS	B+GF+10S		RC Shear Walls	0.61…0.72; 0.81…1.02

* B = basement, GF = ground floor, S = story, TS = top story

Table 2. Characteristics of buildings with SMRSB-DU-type stations. Group B: buildings with base instruments only

Group B Buildings				
No.	**Station**	**Station Code**	**No. of Stories***	**Instrument Position**
1	Iasi City Centre	IAS2	B+GF+4S	B or GF**
2	Brasov	BRS1	B+GF+8S	
3	Bucharest - Carlton	CRL	2B+GF+6S	
4	Buzau	BUZ	B+GF+10S	
5	Campulung Muscel	CMP	B+GF+6S	
6	Constanta	CNT	B+GF+7S	
7	Focsani IPJ	FOC2	B+GF+3S	
8	Sibiu	SIB	B+GF+6S	
9	Slobozia	SLB**	B+GF+4S	
10	Tulcea – City Hall	TLC2	B+GF+4S	
11	Vaslui	VLS**	B+GF+4S	

* B = basement, GF = ground floor, S = story, TS = top story

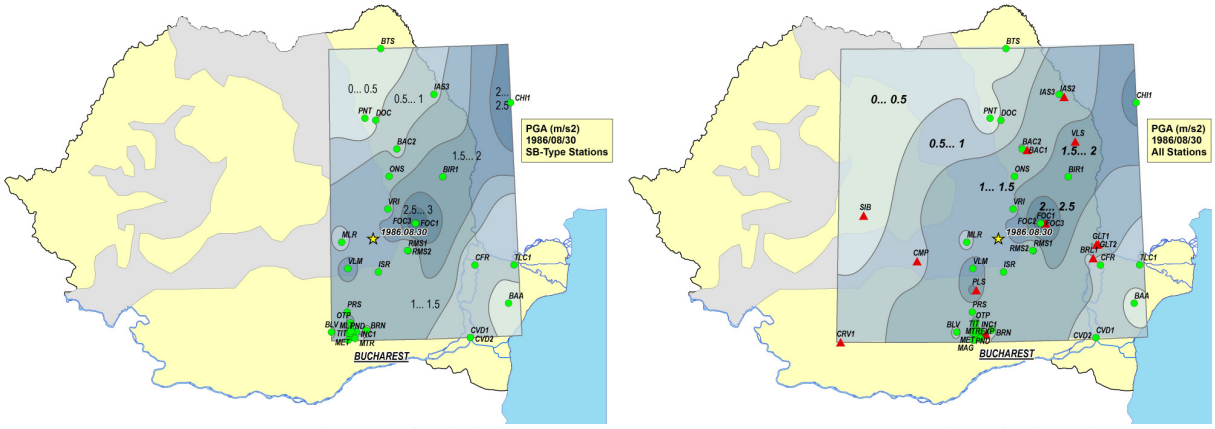
PRELIMINARY USABILITY ASSESSMENTS

Several studies on the spatial distribution of ground motion parameters for strong earthquakes generated by the Vrancea source have been conducted during the past decades (Dubina and Lungu, 2003, Lungu and Craifaleanu, 2008, Craifaleanu, 2010, Craifaleanu and Borcia, 2012 etc.). As mentioned, these studies have used exclusively ground motion data from free-field (similar to SMRS-OG stations in the COSMOS, 2001 classification) and SMRS-SB stations, available from various seismic networks in Romania and neighbouring countries. In the following, a discussion is made on the influence of including SMBRS-DU-type stations in the assessments. Given that, at this stage, analyses have not been yet performed to separate the effect of buildings on ground motion records, the discussion is based on values actually recorded at the considered stations.

The parameter that will be discussed in the following is the peak ground acceleration (PGA). Figs. 2 and 3 show, comparatively, maps of the spatial distribution of this parameter for the August 30, 1986 and May, 30, 1990, obtained without and with the inclusion of the SMBRS-DU-type stations, respectively. Although various studies have shown that buildings could either amplify or deamplify

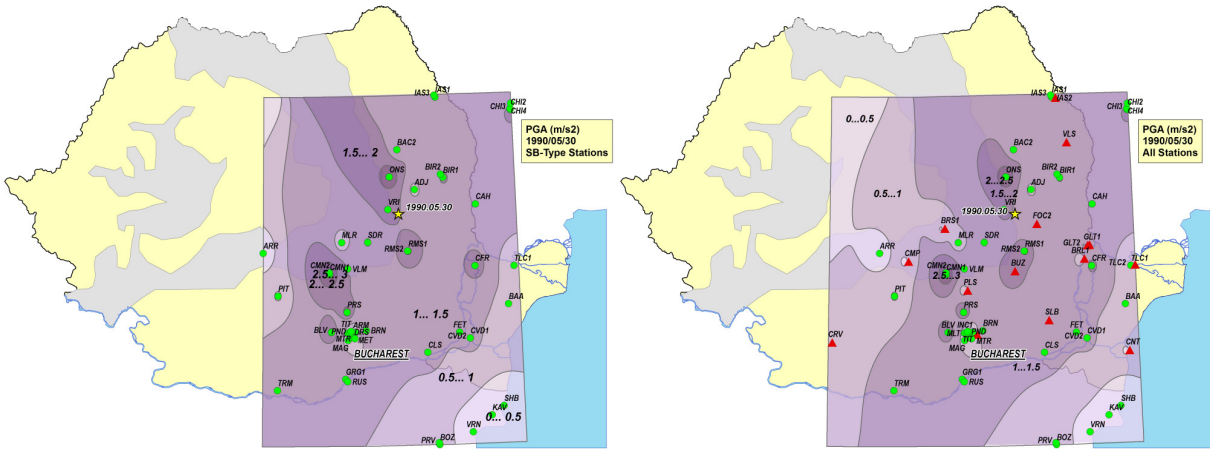
free-field ground motions (Stewart, 2000, Pandey, 2012) it was considered that the maps in Figs. 2 b and 3 b could provide a preliminary indication of the potential outcomes of including these stations.

Maps in Figs. 2 and 3 were obtained by using the Geostatistical Analyst extension of the ESRI ArcMap GIS software (ESRI, 2009). The largest value of the two horizontal components was used in each station. To obtain consistent results, a constant value of the power of the interpolation surface was used for all maps. By examining the spatial distribution of PGA values, it can be observed that the contours obtained by including the SMBRS-DU-type stations maintain the general pattern and the orientation determined in their absence. On the other hand, a "translation" of the contours, as well as local modifications can be observed. It is also obvious that, due to the non-uniform spatial distribution of the stations across the investigated area, the contour configuration has a high degree of approximation, especially in the north-western part, for the 1986 earthquake, and also in the south-western part, for the 1990 earthquake. The predominant placement of seismic stations in the extra-Carpathian area was justified, at the time of their installation, by the fact that, according to seismological observations, in this area the effects of Vrancea earthquakes were most strongly felt.



a) SMBRS-DU stations not included b) SMBRS-DU stations included

Figure 2. Spatial distribution of PGA values for the August 30, 1986 earthquake, obtained a) without and b) with the inclusion of SMBRS-DU stations



a) SMBRS-DU stations not included b) SMBRS-DU stations included

Figure 3. Spatial distribution of PGA values for the May 30, 1990 earthquake, obtained a) without and b) with the inclusion of SMBRS-DU stations

The effects of the inclusion of SMBRS-DU stations can be better observed, for the two considered earthquakes, on the maps in Figs. 4 and 5. The equal-PGA contours are drawn, respectively, with continuous lines for the surface obtained by the inclusion of all stations, and with dashed lines for the case where SMBRS-DU stations were omitted. The height of the rectangles symbolizing SMBRS-DU stations is proportional with the number of building stories. The fill on both maps is shown for the surfaces determined by including all stations. Contour values for the evaluation made by excluding SMBRS-DU stations are put in parentheses.

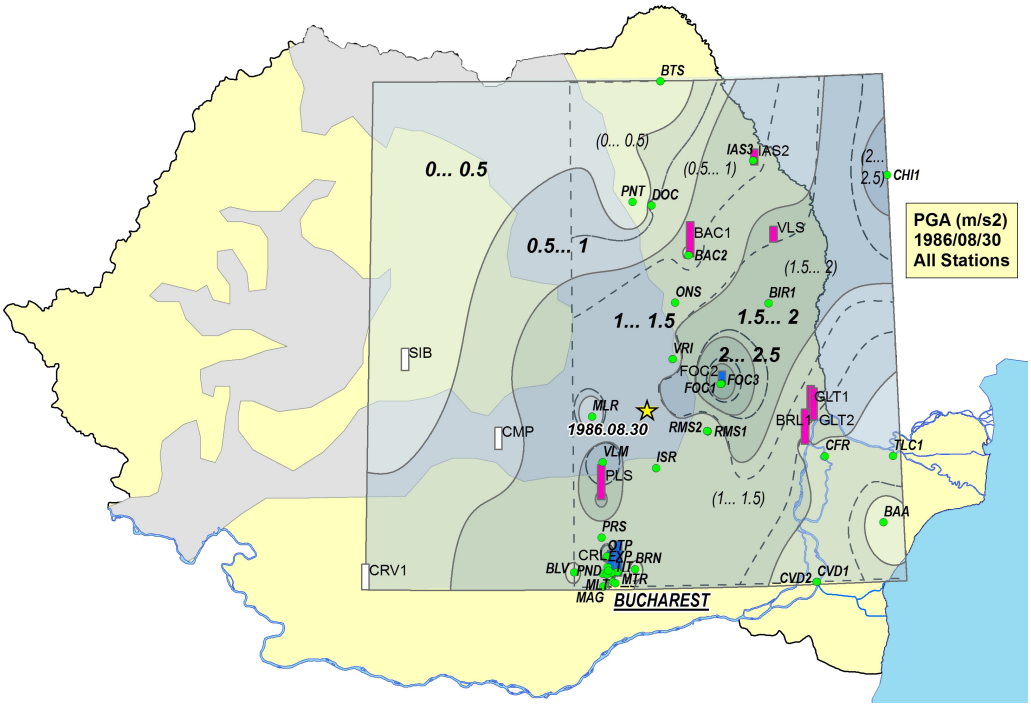


Figure 4. Comparative representations of PGA contours obtained for the August 30, 1986 earthquake: without (dotted line) and with (continuous line) the inclusion of SMBRS-DU stations. Rectangle heights in SMBRS-DU stations are proportional with the number of stories of instrumented buildings

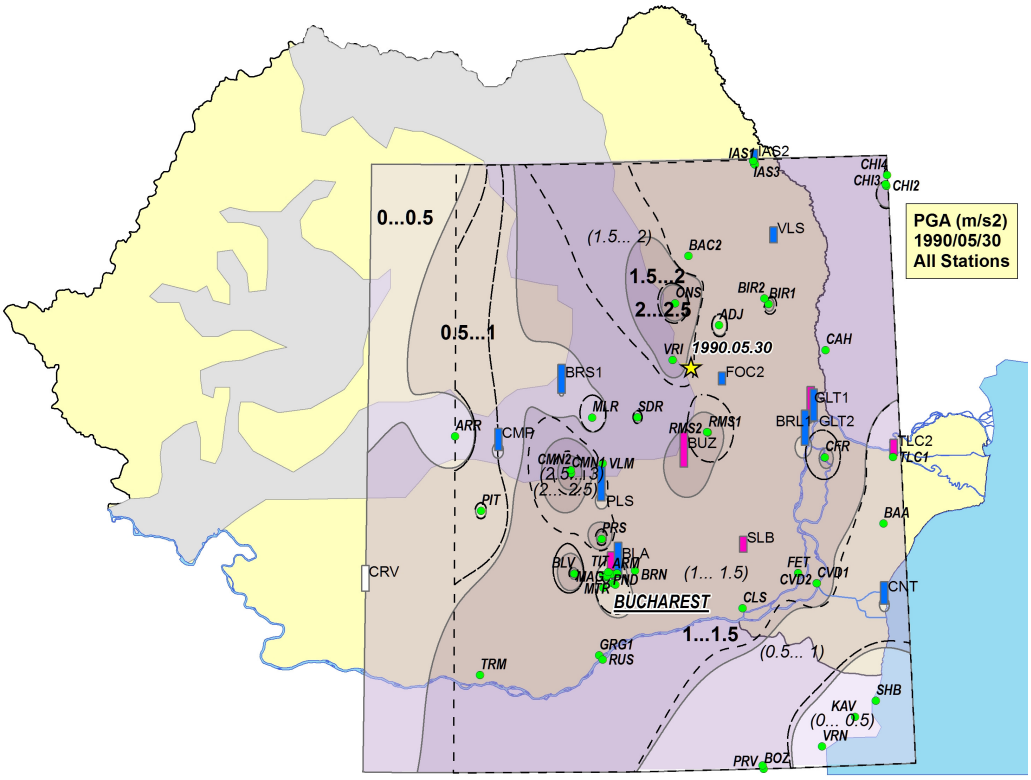
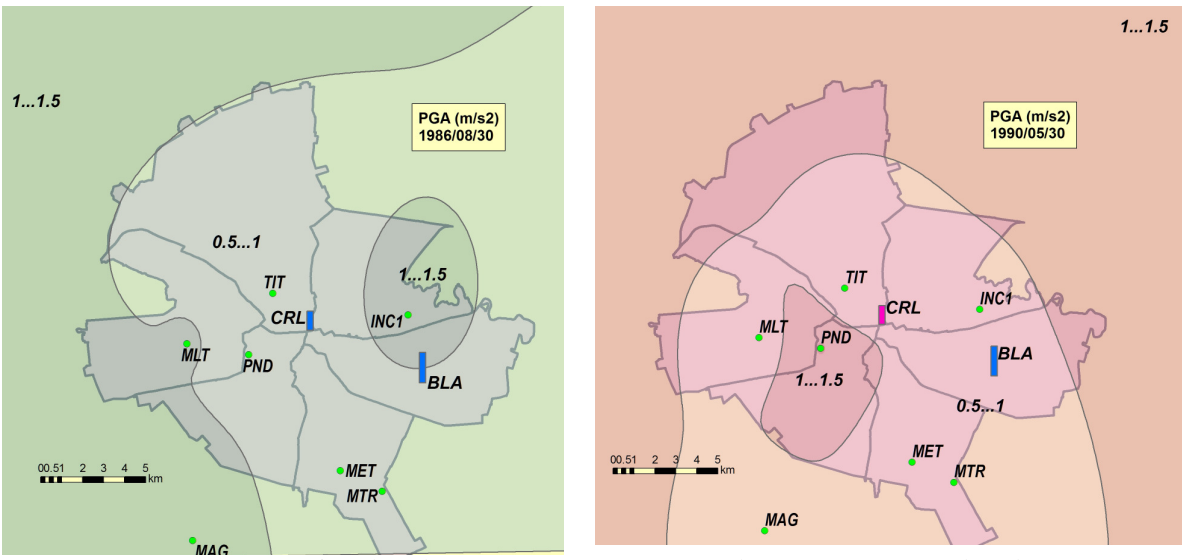


Figure 5. Comparative representations of PGA contours obtained for the May 30, 1990 earthquake: without (dotted line) and with (continuous line) the inclusion of SMBRS-DU stations. Rectangle heights in SMBRS-DU stations are proportional with the number of stories of instrumented buildings

To assess the effect of using the additional stations, PGA values of SMBRS-DU records were compared with the values predicted, at station locations, by the interpolation surface determined without including them. The stations for which the actually recorded value was larger that the predicted value are shown with magenta rectangles, while the stations where the actual value was smaller than the predicted one are shown with blue rectangles. Stations where no prediction was available are shown with white rectangles.

As it results from Fig. 4, in the case of the 1986 earthquake, for most of the stations (7 of 10), the actually recorded values are larger than the estimations performed in the absence of SMBRS-DU stations. On the contrary, for the 1990 earthquake (Fig. 5), for 10 out of 15 stations, the recorded value was smaller than the estimation. Values of the ratios between recorded and predicted values ranged, generally, between 0.8 and 1.6 for the 1986 earthquake and between 0.5 and 1.4 for the 1986 earthquake. By examining these results with respect to the number of building stories, a very week correlation was found, with a slightly increasing trend for the 1986 earthquake, and a slightly decreasing trend for the 1990 earthquake.

The above assessments depend both on the several factors that influence the shape of the interpolation surfaces and on the individual building and site characteristics; thus their interpretation should be made cautiously. Despite this imprecision, it can be, however, noticed, that the inclusion of SMBRS-DU stations does not modify essentially the trends reflected by the contour patterns with, perhaps, some exceptions generated mainly by the lack of stations in certain areas. This could be due to the low amplification or deamplification of free-field motions due to building influence and/or to the relatively small number of stations situated in positions that would influence significantly the shape of the interpolation surface. Obviously, if a quantitative assessment is intended, as in the case of the empirical evaluation of attenuation relationships, thorough investigations are necessary, based on the evaluation of each station.



a) August 30, 1986 earthquake b) May 30, 1990 earthquake

Figure 6. Spatial distribution of PGA values for the city of Bucharest, obtained without the inclusion of SMBRS-DU stations and preserving the same set of stations for both the 1986 and 1990 earthquakes

It can be observed, from Figs. 4 and 5, that there are several buildings for which the ratio between the recorded and the estimated value is larger than unity for one earthquake and smaller than unity for the other. To eliminate the influence of the variation from one event to another of the stations considered in interpolation, a separate assessment was made for the city of Bucharest. Here, the relatively small distance between stations and the number of stations allowed that interpolation is done only for stations that recorded both earthquakes, again without SMBRS-DU stations. The examined stations were BLA1 (from group A) and CRL (from group B). The amplification/deamplification tendency obtained from the previous interpolation persisted (Fig. 6), even though the ratios between actual and estimated PGA values differed. Thus, for the BLA1 building, ratios smaller than unity were obtained for both earthquakes, while, for the CRL building, a ratio smaller than unity was obtained for

the 1986 earthquake and a ratio larger than unity was obtained for the 1990 earthquake. Assuming that the estimations given by the interpolation surfaces are acceptable approximations of the spatial variation of the free-field PGA, this would suggest that the change of the deamplification tendency observed for the CRL building would be due to the differences in the frequency content of the ground motions recorded in Bucharest during the two considered earthquakes. These differences were analyzed in (Sandi and Borcia, 2011).

CONCLUSIONS

The usability of ground motion records obtained, during the strong Vrancea earthquakes of 1986 and 1990, in the basement or at the ground floor of eighteen medium-rise instrumented buildings was assessed. The buildings match rather well the description of the SMBRS-DU stations in the COSMOS classification (COSMOS, 2001), being located in densely urbanized areas of county administrative centres in Romania. The records could be of significant importance for a better evaluation of the spatial distribution of various ground motion parameters during the considered seismic events, with applications including, among others, improved substantiation of the attenuation relationships for the Vrancea source. It was found that the partial information available, at present, regarding the characteristics of the buildings and the local soil conditions does not allow the application of advanced methods used in literature for separating the influence of the building on the ground motion. Further investigations are needed, in the future, to complete the information. Based on the use of actually recorded values, maps of the spatial distribution of peak ground acceleration for all stations were generated and compared with results obtained in the variant without the inclusion of the considered stations. It was shown that, by assuming, in the first instance, that the spatial distribution determined in the second variant represents a reasonable approximation of the free-field motion, various informations could be obtained both on the effects of including records obtained from SMBRS-DU stations and on the potential influence of buildings on the "free-field" ground motion.

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