Building Damage vs. Territorial Casualty Patterns during the Vrancea (Romania) Earthquakes of 1940 and 1977

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SUMMARY
During the 20th century two large ($M_w \geq 7.4$) intermediate depth earthquakes occurred in 1940 and 1977 in the Vrancea region of Romania and caused heavy life and economic losses. The correlation of building damage, intensity and human casualties for each event is explored in this study. The intent is to present and correlate newly recovered and assembled data on building damage and associated casualties, attempting to explain the number and patterns, ratios and social impacts that were apparently so unusually or even randomly distributed in the territories affected. In 1940, damage was heavier near the epicentral area largely to masonry buildings. For the 1977 earthquake, unpublished data from government archives allowed us to derive the spatial distribution of damage and human casualties.

Keywords: earthquake damage, human casualties, building collapse, Vrancea

1. INTRODUCTION

Recent earthquake disasters in the World keep reminding us that progress in construction techniques, earthquake resistant design, planning and preparedness is the path to reduce losses and casualties, arising due to the effects of strong ground motion and induced hazards such as giant tsunami waves, extensive landslides, liquefaction and the risk of conflagration. In Romania, large magnitude ($M_w \geq 7.2$) intermediate depth earthquakes ($h \geq 60$km) occurring in the Vrancea seismogenic source, are a tremendous threat. Such Vrancea earthquakes may affect simultaneously with intensities of VII to IX, circa 50% of the country's territory, over 50% of its population, about 35% of the population, i.e. more than 66% of the urban population, is exposed to Vrancea earthquakes in urban settlements.

In the past few years we have been studying the consequences of the two most important Vrancea earthquakes of the XXth century that occurred in 1940 and 1977. Our incentive was and remains to present new information related to the effects of these events particularly on damage, human casualties and economic losses that has not been previously reported (Georgescu and Pomonis, 2007, 2008, 2010, and 2011). It is important to note that both earthquakes occurred during periods that were unfavorable to the free flow of information, but through patient gathering of information from many different sources we can still gain an understanding that is more in line with present-time standards of information about the effects of destructive earthquakes. We consider this task quite important as often the lack of detailed knowledge and understanding leads to wrong assumptions and even unnecessary misinformation in society propagated through the media (e.g. fear of excessive number of building collapses and casualties in future earthquakes).

At the start we would like to set the record straight in what relates to the human casualties caused in Romania during XXth century Vrancea earthquakes. The figures presented in Table 1 are to the best of our knowledge the most authoritative. They are based on our research and compilation of data from many sources that will be discussed in this paper. Moment magnitude and focal depth are those used in URBAN-INCERC Institute's database and may differ somewhat from those by other authors.

Table 1. Human casualties in Romania due to significant earthquakes in Vrancea (various sources)

				Total Casualties		of which in Bucharest	
Event	Occur. Time (Local)	M_w	Depth (km)	Deaths	Injuries	Deaths	Injuries
1990.05.30	12:40	7.0-7.1	91	9	296	2	unknown
1986.08.31	00:28	7.1-7.3	133	8	317	0	some
1977.03.04	21:22	7.5	109	1,578	11,321	1,424	7,598
1940.11.10	03:39	7.6-7.7	150	593	1,271	140	300

2. HUMAN CASUALTIES DUE TO HISTORIC EARTHQUAKES IN VRANCEA

Prior to the XXth century there have been two major events in Vrancea in the XIXth century that have been better documented relative to events that took place in the XVI-XVIII centuries. These two events occurred on October 26, 1802 and January 23, 1838. Their consequences are discussed by Georgescu (2004), Constantin et al. (2010). Reported loss of life and damage from these two earthquakes in Romania is very low compared to the relatively high magnitudes attributed to these two events and the losses that occurred in 1940 and 1977.

We consider that this behaviour, can be regarded as a proof of a „local seismic culture" (Georgescu, 2004), since the people that lived for thousands of years in areas exposed to Vrancea motions reached a satisfactory level of protection, at least in what concerns life safety. The explanation thus for the limited casualties prior to the XXth century may be partly due to the rural-type of the majority of houses along the centuries. The use of wood in combination with earth / clay could explain the protective behavior of vernacular low-rise and compact houses with light roofs. Thus, even in Bucharest, the stone and/or brick masonry was used only for some palaces, manors and churches, as local building materials for usual houses were wood / wattle and earth / adobe / daub, with roofs of wooden logs and wooden tiles or reed. Brick masonry became more common only in the XVIIIth century, especially for merchants vaults, and only in the second half of the XIXth century its use became more common for urban housing. French architecture was influential, mainly in urban context, thus, some patterns of the local seismic culture were challenged or even replaced by the new materials and techniques. Reinforced concrete started to be used in the XXth century, with high-rise structures appearing in Bucharest from the early 1920's.

In Table 1 the casualties for the 1940 event are those reported by Sima (1982). By contrast in the internationally accepted earthquake catalogues the fatalities of the 1940 event are given as 1,000 and those injured as thousands (Utsu, 2002; USGS Earthquakes with 1,000 or More Deaths since 1900 at http://earthquake.usgs.gov/regional/world/world_deaths.php). In addition the 1940 event killed approximately 78 people and caused an unknown number of injuries in Moldova Republic (mostly in the city of Chisinau-Kishinev; Alcaz, 2006) as well as 15 injuries in Bulgaria (Tillotson, 1940).

The data for the 1977 event's casualties in Romania are complete and almost identical in all the international sources; Table 1 gives data of BSSA (1978), checked as being most reliable and consistent both with local data and a World Bank Report (1978). In addition the 1977 event killed 120 people (Tzenov and Botev, 2009) and injured around 165 in Bulgaria (in the town of Svishtov on the southern shores of the Danube River), most of them caused by the collapse 4 buildings (Georgescu and Pomonis, 2010). It also caused some injuries in Yugoslavia. It is noticeable that the 1986 and 1990 events caused limited casualties, due to smaller magnitude (1990), deeper focus (1986) or other reasons.

According to Steiner and Manastireanu (1996), the 1986 event caused 8 deaths and 317 injured in Romania, while damage of intensity VIII was reported in the Focsani-Birlad area of Romania, including the collapse of a church (BSSA, 1987). In addition, 2 deaths and 558 injuries, 55,000

damaged homes and 12,500 homeless in the Kishinev-Kagul region were reported from the Moldova Republic (BSSA, 1987). Grecianîi *et al.* (2007) reported for the World Bank a new assessment of 1986 Moldova casualties, with 261 affected, out of which 45 hospitalized.

The 1990 earthquake caused 9 deaths in Romania of which 2 in Bucharest in the district of Colentina, when the heavy plasterboard of a large 11-storey apartment block collapsed along the expansion joint, due to pounding between the two sections; these two people were trying to evacuate a ground floor shop. Adevarul Newspaper, (May 31, 1990) reported 8 deaths, 75 seriously injured and 221 lightly injured for Romania (Pomonis *et al.*, EEFIT, 1990), consistent with Steiner and Manastireanu (1996) giving 9 deaths and 296 injured. BSSA reported 9 deaths and more than 700 injured in Romania as well as 4 people killed, many injured and many buildings damaged in Moldova Republic as well as one loss of life due to heart attack and extensive damage in northern Bulgaria (BSSA, 1991).

3. HUMAN CASUALTIES IN THE 1940 AND 1977 EARTHQUAKES

3.1 The November 10, 1940 earthquake

This is the greatest earthquake since 1802 in the Vrancea region. Another earthquake struck on October 22, 1940 (M_{G-R} = 6.1). Seismological data are rather different, depending on authors and epoch, as follows:

- magnitude M_{G-R} = 7.4 (converted at present as M_w = 7.6-7.7); epicenter coordinates were determined by triangulation at 45.8 N; 26.6 E, in Vrancea area, using 7 international stations by Demetrescu (1941);
- the focal depth was assessed as 140-150 km, a value which is until now under debate and re-evaluation; Demetrescu (1941) gave 100–200 km;

Damage was heavier in counties and towns near the epicentral area, such as: Panciu, Focsani, Galați, Barlad, Brăila, Buzau, Valeni, with buildings made of masonry, adobe, wattle and daub and timber. The earthquake affected seriously the Moldova and Bessarabia regions which presently lie within Romania and Moldova Republic. It caused significant damage in Bucharest, where the 12-storey Carlton block, an emblematic building of the 1930's, collapsed entirely. Many other buildings had structural damage in Bucharest but there is no report of any other building collapsing.

Initial dispatches, reported casualties that were based on sketchy evidence, however on the second day official reports gave 267 killed and 476 injured all over the country until the evening of November 10 (Universul Newspaper, Nov 12). After the emergency response phase, Tillotson (1940) gave many details of the effects of the earthquake around the country and said that due to telecommunications still interrupted a conservative estimate would place the casualties at 400 killed and 800 severely injured in Romania, with more than 150 killed in Bucharest where 30 or more were still trapped under the debris of Carlton and more than one thousand badly damaged houses had to be evacuated. Time Magazine (1940) said that about 98 bodies were extricated from under Carlton debris, while there were 357 killed and thousands injured in all the country.

In 1982, the published memoirs of the vice-premier of Romania at the time of the event, indicated 593 killed and 1,271 injured in all the country, and in Bucharest 140 killed from the 226 occupants of Carlton block, with another 300 injured in the city (Sima, 1982). The rest of the country's casualties were mostly in masonry buildings. Near the epicenter, the city of Focsani and the town of Panciu were heavily damaged and many lives were lost. The cities of Galați and Ploiesti were seriously affected, as was the region of Muntenia.

In order to correlate these data and check casualty figures, we used all available information for some 35 towns and locations and a calibration based on the casualty map and data of Radulescu (1941b). Some more research was done for locations were significant casualties were reported (Carlton block, Panciu Town, Doftana Prison).

In the case of the collapse of Carlton block we collected photos and assessed that the loss of volume loss ratio was very high (>0.70) (Fig. 1). This collapse was the first urban search and rescue case in the history of Romania, with time-consuming operations and technical difficulties caused by heavy rain and fire during the operations. The lethality of the Carlton collapse is assessed as 62% based on figures by Sima (1982).

Figure 1. Carlton Block before collapse (left) and immediately after collapse (right)
(Photo: postcard and Ministry of Propaganda files, 1940)

In Doftana prison most sources talk of 100 deaths, but our research has shown that only 21 were killed, 38 seriously injured and 40 lightly injured, i.e. 99 casualties (Rudenco, 1945 and Buhoiu, 1977). For the rural town of Panciu in the epicentral area, apparently only a handful of buildings remained standing among a total of 371 (Wikipedia article about Panciu in Romanian language), but the number of casualties is uncertain (22 to 62 deaths, 54 to 300 injured). Based on our research so far we lean towards the higher figures, as of Radulescu (1941a). A similar remark was written by Radulescu (1941a) about Odobesti, which was reported as razed, but actually damage there was not so serious.

The new image of the spatial distribution of casualties in Romania due to the November 10, 1940 Vrancea earthquake is presented in Table 2. Thus, it appears that Bucharest shared 23.6% of the dead and injured relative to the total, mainly due to the collapse of the highest reinforced concrete structure, in the city.

British and US press agencies in 1940 reported that many buildings were destroyed or heavily damaged in the Prahova River Valley and at Ploiesti, partly due to fires that broke out in the oil refineries. Fires did break out in the Ploiesti refineries, but housing was not so near as to have been directly affected by the fires. Damage was indeed extensive in the Prahova River Valley as the evidence of loss of life from numerous localities suggests.

In the internationally accepted fatal earthquake catalogues (Utsu, 2002; USGS Earthquakes with 1,000 or More Deaths since 1900 at http://earthquake.usgs.gov/regional/world/world_deaths.php) the 1940 earthquake is listed to have caused 1,000 fatalities. Our research to date suggests that 593 people were killed in Romania and 78 in Moldova Republic. Therefore we consider that a more accurate representation would be a figure of around 700 fatalities, as it is entirely possible that some additional cases in rural areas may have not been reported.

Table 2. Spatial distribution of casualties in Romania due to the November 10, 1940 Vrancea earthquake

Location	County (1940 names & boundaries)	Dead (Sima, 1982)	Injured	Remarks
Carlton Building	Bucharest city	140	86	assuming 226 occupants
various locations	Bucharest city	some?	300	
Panciu	Putna	44	Many (70?; 190?)	Radulescu (62 dead & 300 injured); Adevarul Newspaper (1 Apr 2006) 42 dead & 70 injured; Ziarul Iasi (3 Jan 2005) 42 dead & 76 injured; Nature (23 dead & 71 serious injuries)
Focşani	Putna	12	~115	Radulescu's map (deaths & injuries); Nature (70% of buildings destroyed)
Galaţi	Covurlui	34	40-130	Radulescu's map (deaths & injuries); Nature (36 dead; 130 injured)
various locations	Covurlui	107	not known	
Bârlad	Tutova	12	~20	Radulescu's map (deaths & injuries)
Huşi	Fălciu	few	~20	Radulescu's map (deaths & injuries)
Vaslui	Vaslui	few	few	Radulescu's map (deaths & injuries)
Tirgul Bereşti	Covurlui	few	0	Radulescu's map (deaths)
Tecuci	Tecuci	19	~20	Radulescu's map (deaths & injuries)
Buzău	Buzău	20	not known	Radulescu's map (deaths)
Rimnicul Sărat	Rimnicul Sărat	0	~5	Radulescu's map (injuries)
Pătârlagele	Buzău	few	not known	Radulescu's map (deaths)
Iaşi	Iasi	8	~5	Radulescu's map (deaths & injuries)
Câmpina	Prahova	6	not known	Nestor (2010)
Doftana Prison	Prahova	~20	78	40 seriously injured
Ploiesti	Prahova	7	not known	Nestor (2010)
Margineni Prison	Prahova	4	not known	Nestor (2010)
Valea Boului	Prahova	4	not known	Nestor (2010)
Boldesti	Prahova	3	not known	Nestor (2010)
Apostolache	Prahova	3	not known	Nestor (2010)
Scaieni	Prahova	2	not known	Nestor (2010)
Malaesti	Prahova	2	not known	Nestor (2010)
various locations	Prahova	~14	~270	Nestor (2010): in Bertea, Romanesti, Banesti, Mislea, Cotofenesti, Teisani, Alunis etc. (1 death per location); ~110 seriously and ~160 lightly injured (excl. Doftana Prison)
Mizil	Buzău	few	few	Radulescu's map (deaths & injuries)
Târgovişte	Dâmboviţa	few	not known	Radulescu's map (deaths)
Craiova	Dolj	5	few	Radulescu's map (deaths & injuries)
Turnu Măgurele	Teleorman	0	few	Radulescu's map (injuries)
Tulcea	Tulcea	few	few	Radulescu's map (deaths & injuries)
Constanţa	Constanţa	0	few	Radulescu's map (injuries)
elsewhere in Rom.	Misc.	~94	~360	
TOTAL		**593**	**1,271**	**Romania borders (Autumn 1940)**

3.2. The March 4, 1977 earthquake

The main seismological data are as follows (Balan et al, 1982):

- magnitude $M_{G-R} = 7.2$; depth 109 km; coordinates of the main shock: 45.34 North; 26.30 East;
- epicentral intensity was assessed at $I_0 =$ VIII MSK for a reduced area at Carpathian Mt. curvature, surrounded by large areas of intensity VII MSK towards S-E and N-E; Bucharest, Iasi and Zimnicea were islands of intensities VIII.

Casualties were reported in 1977, in rounded figures, as 1,570 deaths, 11,300 injured. The casualties were concentrated in Bucharest, with 90.2% of the killed and 67.1% of the injured, resulting mainly due to the collapse of 19 high-rise apartment buildings (of 7 to 14 storeys) that were constructed in the inter-war period as reinforced concrete frames designed only for gravity loads. There was also the collapse of 3 public buildings (Ministry of Metallurgy, Faculty of Chemistry and Computer Centre) but due to the time of occurrence were not heavily occupied. In addition 2 low-code high-rise reinforced concrete shear wall structure apartment block buildings collapsed partially (Block 30 and Block OD16). These had 10 and 11 storeys and were built in 1962 and 1974 respectively. The collapse of these two blocks affected 77 dwelling units. In total in Bucharest 28 buildings collapsed, pancake collapse pattern was common for the pre-1940 structures, while shear-wall failure and soft-storey were causes for the collapse of four low-code buildings that had lower levels of volume loss. Loss of volume ratio was in the range of 0.15 to 0.85. Search and rescue needs were extensive as 23 of these buildings were heavily occupied residential structures with 15 to 89 apartments and extrication of the trapped was very difficult. Fire occurred after collapse in several cases. For the high-rise building collapses, causes of deaths and injuries were the crushing under concrete or under members or parts of buildings and falling of non-structural members (Fig. 2). Details about each of the buildings that collapsed in Bucharest are given in Georgescu and Pomonis (2011).

Figure 2. Full collapse and extreme loss of volume in 1977 in case of pre-1940 RC structure, Al. Sahia No. 1-3, (left) and collapse of pre-1977 OD 16 Block shear-wall section (right).

Prahova County, like in 1940, was next in terms of concentration of casualties, where an extremely lethal collapse occurred in Plopeni when a Worker's Dormitory made of masonry totally collapsed killing 30 to 60 workers and injuring many. The weakness of mid-rise masonry buildings with some reinforced concrete members, as in Ploiesti is reported by Balan et al. (1982). Damage to these buildings was serious but collapses were very few, thus preventing heavy life loss. The next important case of casualties was in Craiova in Southern part of Romania, where the heavy damage to old masonry buildings' structural and non-structural members was a major cause of life loss, with many wounded. Some data were recovered about small towns as Rosiorii de Vede, Turnu Magurele and Alexandria, where gable walls of old masonry houses were a source of casualties (Vlad, 2011).

In the northeastern Romania, like in 1940, Iasi had few deaths but many injured, quite from the same causes (mostly due to damage to mid-rise masonry buildings). A specific case is the town of Zimnicea

in Teleorman county of Southern Romania, reported to have suffered destruction of 80% of its buildings. Moinfar (1978) and the AIJ Report (Architectural Institute of Japan, 1978) give 2,552 houses damaged and 2,332 homeless (out of a population of 15,000), but only 5 killed and 62 injured. One of victims died because of a chimney failure, another by heart attack. Tezcan (1977) mentioned 4 killed, 25 injured and 900 houses destroyed. The pictures and data have shown that vernacular houses were heavily damaged or collapsed but caused few casualties, a proof of "local seismic culture" (Georgescu, 1994).

The overall casualty figures for Romania and Bucharest are given in Table 1 (BSSA, 1978). The spatial distribution of the human casualties in 1977 is presented in the Table 3.

Table 3. The spatial distribution of human casualties of the March 4, 1977 Vrancea earthquake

COUNTRY	Romanian County	Town/Village	Killed	Injured	Hospitalized (among the injured)
ROMANIA			1,578	11,321	2,369
BULGARIA		Svishtov	120	165	not known
MOLDOVA			2	not known	not known
YUGOSLAVIA			0	some	0
	Dolj		41	315 to 562	n/a
	Teleorman		20	204	67
	Prahova		15 (or >50?)	not known	not known
	Vaslui		7	40	not known
	Iasi		4	270 to 440	not known
	Braila		3	5	not known
	Vrancea		2	23	5
	Buzau		0	55	not known
	Giurgiu		1	35	not known
	other county		61?	2359 to 2776	797
		Bucharest	1,424	7,598	1,500
		Plopeni Worker's Dormitory	30 to 60?	many	not known
		Craiova	30	500	not known
		Valenii de Munte	7?		not known
		Iasi	4	270 to 440	not known
		Zimnicea	5	62	not known
		Turnu Magurele	4	70	not known
		Rosiori de Vede	4	not known	not known
		Alexandria	3	not known	not known
		Braila	3	5	not known
		Giurgiu	1	35	not known
		Focsani	1	not known	not known
		Odobesti	1	not known	not known
		Naruja	0	1	1
EVENT TOTAL			**1,700**	**~11,500**	**~2,400**

The time history of the total number killed, injured and hospitalized was recovered, mostly from press sources, checked for final values with BSSA data, and given in Figure 3. These data are influenced by the number and patterns of Bucharest casualties, with victims under concrete debris and they are not necessarily simultaneously valid, per each day, as there was a continuous flow of admissions and exits from hospitals. The pattern of injuries was reported by Steiner and Manastireanu (1996) for 6,980 patients, and some 49.7% were treated for surgical and orthopedic wounds. In a certain measure, the

figures provide also an image about the speed of extrication as well as about the ratios between killed and injured.

Based on these figures, the distribution of the casualties of the 1977 earthquake for the sum of final numbers of fatalities, light injuries and hospitalized (a total of 12,899 casualties) would be: 12.2% fatalities, 18.4% hospitalizations and the remaining 69.4% light injuries. We propose a total for the event at 1,700 deaths and about 11,500 injured (incl. the casualties in Bulgaria and Moldova Republic).

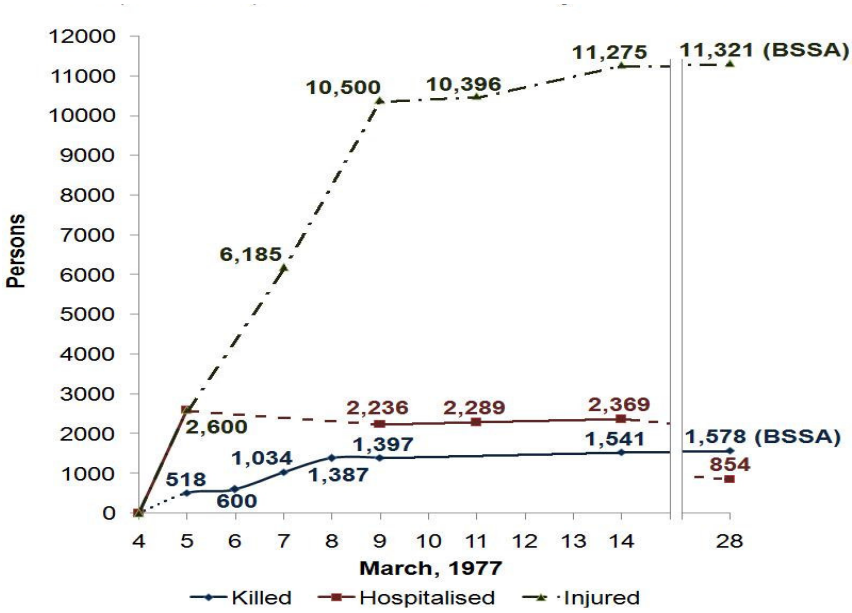

Figure 3. The number of killed, injured and hospitalized after March 4, 1977 Vrancea earthquake

4. CONCLUSIONS

The study recovered and interpreted data about the human casualties and their spatial distribution in 1940 and 1977 earthquakes, as well as about the potential of casualty during future Vrancea earthquakes, first of all related to the existing stock of pre-1940 high-rise buildings, especially in Bucharest. The spread and patterns of damage and casualties caused by vernacular houses in 1940 was documented in terms related to a greater extent to the statistical and photographic reality. Some data recovered from 1940 publications and reevaluated fit to engineering analysis done after 1977.

On the other hand, new data allowed a comparison about casualties caused by the collapse of pre-1940 multi-storey reinforced concrete structures designed for gravity loads only, both in 1940 and 1977. Many such buildings damaged in 1940, collapsed in 1977 causing heavy loss of life in Bucharest in 1977. As many buildings of this category remain in use until the present-time we consider their strengthening a matter of utmost priority and importance. In addition other 8 to 11-storey apartment buildings built in the period 1950-1976, with weaknesses and low-ductility are also a threat, as experienced by the collapse of Block OD16 and Block 30 buildings, in 1977 (Georgescu and Pomonis, 2011).

After the 1940 earthquake, there was a major gain in risk perception and building practices for masonry houses, mainly in using reinforced concrete foundations and collar beams, securing some gable walls and attics, using better bricks and mortars etc. The patterns of 1940 disaster was repeated in 1977 for old buildings and places where the lesson of 1940 was not at hand for a given community, or in cases when the repairs of 1940 were not technically competent or sufficient. The threshold between heavy damage and collapse of mid-rise masonry buildings, rather close to the Vrancea

seismogenic source, may be a factor of significant importance in the case of occurrence of an event stronger than 1977 in the future.

The number of casualties increased in 1977 vs. 1940 because of existing pre-1940 high-rise and pre-1977 high-rise low-ductility reinforced concrete buildings. Ratios of injured to killed in overall casualties was close to 2 in 1940 and over 7 in 1977, but for 1940 more research is needed to ascertain the number of injured. Since a new earthquake code was introduced in 1978 and subsequently upgraded in 1992 and 2006, post-1977 buildings are expected to present a significantly reduced probability of collapse.

The earthquakes of 1986 and 1990 caused very limited casualties, mostly due to non-structural damage (fall of plasterboards), but for future events of this magnitude, that occur more often, some structural alterations and aging of pre-war and socialist era apartment blocks and public buildings is an additional concern. Some towns and counties located at large distances from the Vrancea source zone suffered heavy damage and casualties in both 1940 and 1977, but in 1977 the cumulative damage effects, especially in pre-war high-rise structures, explains the concentration of damage and casualties in Bucharest. Trans-boundary damage and casualties happened in all four earthquakes, in Moldova and Bulgaria.

The correct reporting of human casualties following destructive earthquakes is always a tremendous challenge. We have strived through repeated publications to thoroughly investigate the consequences of the 1940 and 1977 Vrancea earthquakes. So far we have been able to complete many pieces of the puzzle. In this paper we report on the spatial distribution of the casualties of these two important earthquakes. We intend to provide such data to the Global Earthquake Model's Earthquake Consequences Database (http://www.globalquakemodel.org/risk-global-components/consequence-database) that will act as a repository of openly accessible data on earthquake consequences around the World. By geocoding each location and making assessments of the contemporaneous populations, casualty rates can be obtained and plotted against the ShakeMap of the events in question. The 1977 earthquake will be studied first, as there is already a good quality ShakeMap developed by the USGS for this event. In this way casualty rates can be estimated in relation to a suite of commonly used ground motion descriptors incl. spectral acceleration at different natural periods.

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