The Strong Romanian Earthquakes of 10.11.1940 and 4.03.1977. Lessons Learned and Forgotten?

Andrei Bala and Dragos Toma-Danila

Abstract Bucharest is among the European capitals most vulnerable to earthquakes. Although located at a relatively large epicentral distance (about 140–160 km) from Vrancea area, Bucharest has suffered much destruction and loss of life during great Vrancea earthquakes. In the last century, November 10th, 1940 earthquake (Mw = 7.7) caused the completely collapse of Carlton building located in the central city area, killing over 300 people, and many other high buildings were affected in capital city as in other cities closer to the epicenter. More than 1000 people were killed in a matter of minutes in all Romania during the earthquake, while city of Panciu was destroyed in 90–95 % proportion. This was the moment when the first alarm signal regarding the introducing of mandatory regulations in the seismic design of buildings came out. However, the recommendations made by the specialists were largely ignored by the authorities of the time, so that the next major earthquake of March 4, 1977 (Mw = 7.4) caused the biggest recorded disaster in the history of Bucharest The earthquake of 1977 caused only in Bucharest the collapse of 32 buildings, 8–12 floors high, while about 150 old buildings, with 4–6 floors were badly damaged. Most of the collapsed buildings were built between the 1920 and 1940, they did not benefit of the anti-seismic design. In the case of Bucharest the buildings have been previously damaged in the 1940 earthquake and during the bombardments in the World War II. Over 1500 people died and about 7500 were wounded, most of them in Bucharest City. The total cost of the damage amounted to more than 2 billion dollars, two thirds being related to the capital city only. The aim of the paper is to present aspects related to the consequences of the Vrancea 1940 and 1977 earthquakes, highlighting the differences between the two catastrophic events and their consequences. Therefore everything learned from the past should not be forgotten in order to insure that the next catastrophic event will find a better prepared society.

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R. Vacareanu and C. Ionescu (eds.), *The 1940 Vrancea Earthquake. Issues, Insights and Lessons Learnt*, Springer Natural Hazards,
DOI 10.1007/978-3-319-29844-3_2

Keywords Strong Vrancea earthquakes · Destroyed cities · Damaged and collapsed buildings · The most seismically endangered capital city in Europe

1 Introduction

Studies and observations made after the occurrence of strong earthquakes in the Vrancea area have shown that in Bucharest higher buildings are the most exposed to destruction comparatively with the small buildings, and the destruction effects are much attenuated when moment magnitude of the Vrancea earthquake is less than 7. These two features make Bucharest a unique city in order to study the influence of local conditions upon the ground movement during an earthquake. To explain the damage caused by the strong Vrancea earthquakes ($M_W > 7$), Raileanu et al. (2007), and Bala et al. (2007), Grecu et al. (2011) consider that two factors are particularly important, namely: local conditions (thickness of sedimentary layers and physical and dynamic parameters of the sedimentary package), as well as the seismic source radiation.

In a recent paper, Bala et al. (2015) show that the earthquake mechanism and depth of the event, as well as the seismic path, which is controlled by the depth of occurrence, are responsible to the same extent as the local site effects for the intensity of the ground movement induced by a moderate Vrancea earthquake. According to the single recording of the 1977 earthquake available in Bucharest (*INCERC* station), a spectral amplification with a predominant period of 1.6–1.7 s was derived and assumed to be the key element causing major damage to high tall buildings, higher than 10 floors (Enescu et al. 1982). It was also considered as potential characteristic period for future $M_W > 7$ events. However in 1986, after an event of $M_W = 7.1$, spectral amplification peaks at periods of 0.5, 0.75 and 1.4 s were found on recordings at *INCERC* station, east of Bucharest (NS component; Aldea et al. 2004), proving that strong Vrancea earthquakes might have a larger domain of characteristic periods and by consequence, some other buildings might be at risk.

Bala et al. (2015) conclude that local PGA recorded in Bucharest during strong Vrancea earthquakes is depending not only by seismic site effects and magnitude of the seismic event, but is controlled by all characteristics of a certain event, like fault mechanism, depth of occurrence and distance.

In particular when the fundamental period of sedimentary package lies in the 0.5–2 s, which seems to be the situation in the case of Bucharest, and coincides with the predominant spectral characteristics of the major seismic event, then disaster strikes. Therefore, knowledge of the distribution of resonance period of the ground is most important for local hazard study, and in particular in Bucharest city which is considered the most endangered capital city in Europe by a strong earthquake.

2 The Great Earthquake of November 10th, 1940

Year 1940 was one with a high seismic activity in Vrancea, due not only to the earthquake on November 10th and its aftershocks, but in fact, along this year, several earthquakes have occurred with a significant magnitude from the very beginning of year (Fig. 1). These earthquakes, with moment magnitude greater than 4.5, occurred at depths of 125–160 km (ROMPLUS). They have occurred before the November strong event and after as numerous aftershocks. By contrary, in 1977 only one event precedes the strong event and after that, only one aftershock greater than magnitude 4 was recorded in the next 3 months.

On October 22nd 1940 a strong earthquake, occurred in Vrancea, at 150 km depth (Demetrescu 1941); this earthquake was strongly felt especially in Muntenia and Moldova (with intensities which on an extended area were of VII on Mercalli scale).

The great earthquake measuring M_{GR} = 7.4 (Mw = 7.7) and maximum intensity I_0 = IX − X occurred at 150 km depth (Demetrescu 1941), on 10th of November 1940, at 3:39 AM (local time). The most severe consequences were noticed in south and center of Moldova (Moldavian Platform), but also in the north-east of Muntenia (Moesian Platform). The town of *Panciu* was destroyed in a proportion of 90–95 %. Towns like *Focșani*, *Galați*, *Marașesti*, *Tecuci* and *Iași* have suffered great damage. The main damage in Bucharest was the collapse of Carlton block, although other buildings were significantly damaged. The earthquake on November 10th 1940 had many aftershocks, from the very first moments, among which, 6 measured more than M_{GR} = 5.0. The strongest aftershock was recorded in the morning of November 11th, 1940, with a maximum intensity of VI, focal depth: 150 km; this aftershock seemed to be weakly felt in Bucharest. The series of aftershocks continued towards the beginning of December 1940, and after that they gradually disappear (Fig. 1).

The macroseismic effects were felt on a surface of over 2,000,000 km^2 in Eastern Europe, being reported in the north up to *St. Petersburg* (Russia) at over 1300 km distance, where seismic intensities of IV-V (MCS degrees) were estimated, in the south, up to Greece, in the east, up to the *Harkov-Moscow* line, with estimated intensities of V-VI (MCS degrees), in the west, up to Belgrade (Serbia) and Budapest (Hungary) and in the north up to Warsaw (Poland). The distribution of the

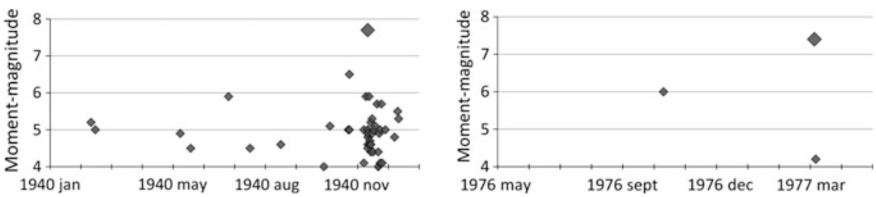

Fig. 1 Earthquakes over moment magnitude 4 produced in Romania around the major events of 1940 (*left*) and 1977 (*right*). *Source* ROMPLUS catalog (Oncescu et al. 1999)

macroseismic effects over such a large area is a measure of the significant energy released during the earthquake (Pantea and Constantin 2011).

The parameters of the earthquake of 10th of November 10th, 1940 could not be determined from the instrumental recordings in Romania, because the first impulse of the longitudinal wave destroyed inferior suspension of the only seismograph installed on the ground floor of the Romanian Observatory from Bucharest (Petrescu 1955). In order to determine the source parameters of the earthquake from the November 10th, 1940, the recordings from different worldwide stations operating that time were used (Demetrescu 1941). The number of the victims of the VRANCEA earthquake from the November 10th, 1940, could not be exactly established or published because of the censure imposed by the political situation and the state of war, which have begun in 1941. Some sources stated that the casualties surpassed 1000 deaths and 3000 wounded throughout Romania.

However Prof. Gh. Demetrescu tried to compute some coordinates for the earthquake in his paper (Demetrescu 1941), based on several recordings outside the country. He established a first set of coordinates at lat 45.8°N and longitude 26.6°E. All the arrival times at the seismic stations that have recorded the earthquake were put on a graphic and after some consideration the true epicentre was chosen. The depth was estimated at 100–200 km, with a great uncertainty. Demetrescu succeeded to perform a quite good location of epicentre close to the location in Romplus catalogue. It was also his merit to bring scientific arguments in favour of a Vrancea subcrustal event. Today the estimation of the coordinates from ROMPLUS catalog is almost the same: lat. 45.8°N; long. 26.7° and depth at 150 km. As for the magnitude, most of the scientists agreed that a value $M_{GR} = 7.4$ was a good approximation, which today corresponds to a moment magnitude $M_W = 7.7$ (ROMPLUS).

2.1 *The Destructive Effects of the Earthquake of November 10th, 1940*

Demetrescu published in 1937–1941 several seismological notes where he presented the problems of the seismic wave interpretation and the determination of the seismic foci coordinates. He studied the Vrancea earthquakes of November 1st, 1929, July 13th, 1938, October 22nd, 1940 as well as the earthquake of November 10th, 1940. Demetrescu evidenced first the deep seismic focus in the bending zone of the Carpathians (Vrancea zone), a persistent and isolated focus comparable with the foci of the Hindukush Mts. (Afghanistan) and Bucaramanga (Columbia, South America). The extension of the Romanian seismological network happened after the Vrancea major earthquake of November 10th, 1940 ($M_{GR} = 7.4$). Demetrescu reorganized the seismological activity by improving the instrumental endowing and setting up five new stations: *Focşani* (1942), *Bacău* (1942), *Câmpulung Muscel* (1943), *Iaşi* (1951) and *Vrâncioaia* (1952), all working till now (Radulescu 2009).

Regarding the strong shock of November 10th, 1940 (M_{GR} = 7.4), he elaborated the map of the macro-seismic intensities for the Romania and Bulgaria (Demetrescu 1941). A large zone of intensities VIII + IX appear just near the epicentral area. In a later version of the map some local maxima (of X degree) were cited in different points, superimposed on the central zone (Petrescu 1955; Atanasiu 1961). He mentioned some localities in which the intensity was at least of Xth degree: *Panciu*, *Targu Bujor*, *Focsani*, *Lopatari*, *Neculele*. For Bucharest an intensity of IX was appreciated. Macro-seismic intensities of V–VI degree appeared in Moscow area (at 1300 km distance) and V in southwestern Bulgaria (at 600 km). All the intensities cited here are given in Mercalli-Cancani-Sieberg scale (MCS).

The macroseismic scale MCS is the scale of Mercalli, improved by Cancani to 12° and revised by the German seismologist August Sieberg. The 12° scale was the idea of the Italian physicist Adolf Cancani who suggested to make "total destruction —degree 12" and then there was room for a better grading of levels of damage at intensities 9, 10 and 11. August Sieberg in 1912 write the description of damage at these different degrees (Musson 2012).

The destructive effects of the earthquake of 10.11.1940 in Bucharest were presented the best by Beleș (1941), who was a civil engineer, Professor at Politechnic University in Bucharest (1938–1948) and at Institute of Civil Engineering Bucharest (1963–1976). In recognition of his merits he was appointed correspondent member from 1955 and full member from 1963 of the Romanian Academy (Fig. 2).

In 1941 he presented an extended study, *The earthquake and constructions*, in Romanian. Beleș presented several different buildings damaged in Bucharest, as a result of November 10th, 1940 earthquake, with photos and comments, beginning with the Carlton building, which suffered a total collapse just in the beginning of the seismic movement. In Fig. 3 the distribution of these buildings on a present Bucharest map is given.

In his study, Beleș (1941) begins by presenting the earthquake characteristics and the intensity scale of Mercalli-Cancani-Sieberg of 12 grades, which is presented thoroughly. For each grade he presented not only the description of the effects upon constructions, but also the values of the horizontal acceleration of the ground motion. For a IX grade, a horizontal acceleration of 50–100 cm/s^2 might occur, as it was appreciated in his study the intensity of November 10th event in Bucharest.

After presenting the different damages the author insisted on the necessity of repairing all the parts and most of all the concrete frame of the buildings affected by the earthquake. Actually, in some cases which Beleș (1941) presented, this repairing process was poorly executed and by consequence appear the premises to further increase the damage in the next great earthquake.

The author mentioned that the well-known seismologist A. Sieberg, co-author of the Mercalli-Cancani-Sieberg intensity scale, have visited Romania in 1941, where he sustained a couple of conferences about the earthquake. In his conferences *Sieberg* "***draws attention seriously upon the lack of professionalism in which the repairs of the damaged buildings are made, preparing in this way for the next***

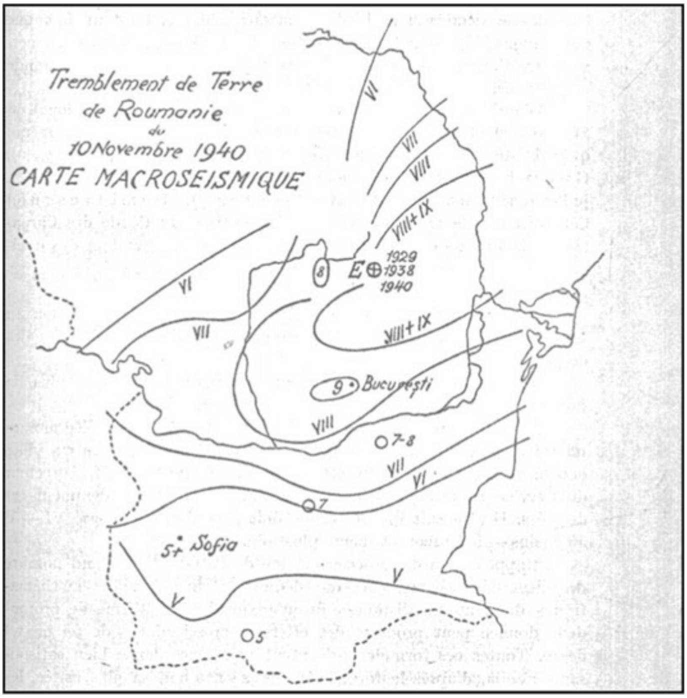

Fig. 2 The isoseismal map of the 10.11.1940 event based on macroseismic effect on MCS scale (Demetrescu 1941)

earthquake, a disaster of a greater amplitude compared with the one from the past" (Beleş 1941).

Beleş presented in his study a set of observations upon the damages suffered by buildings with reinforced concrete frame structure and he also made some recommendations for the future. The largest part of the study deals with the total collapse of the Carlton building, right in the centre of Bucharest, at the corner of Regala str. with Bratianu Blvd.

Two main flaws in design were found, discussed and blamed for the collapse: (1) A set of "non-rational" concrete columns in front of the building, having an *L* shape with non-usual dimensions of the section 20–24 cm by 120–170 cm; (2) Many discontinuities of the columns in the vertical direction. Beginning with the III-rd floor a series of concrete columns were suppressed and they were replaced by other columns placed on the beams for the next 5–6 floors. Another failure in design was placing beams with a large section on rather thin concrete columns.

The main cause for the collapse was the shear forces induced by the earthquake that far exceeded the capacity in shear of the columns at the first ground floor. These columns failed in shear and they perforated the bellow floor to the first and

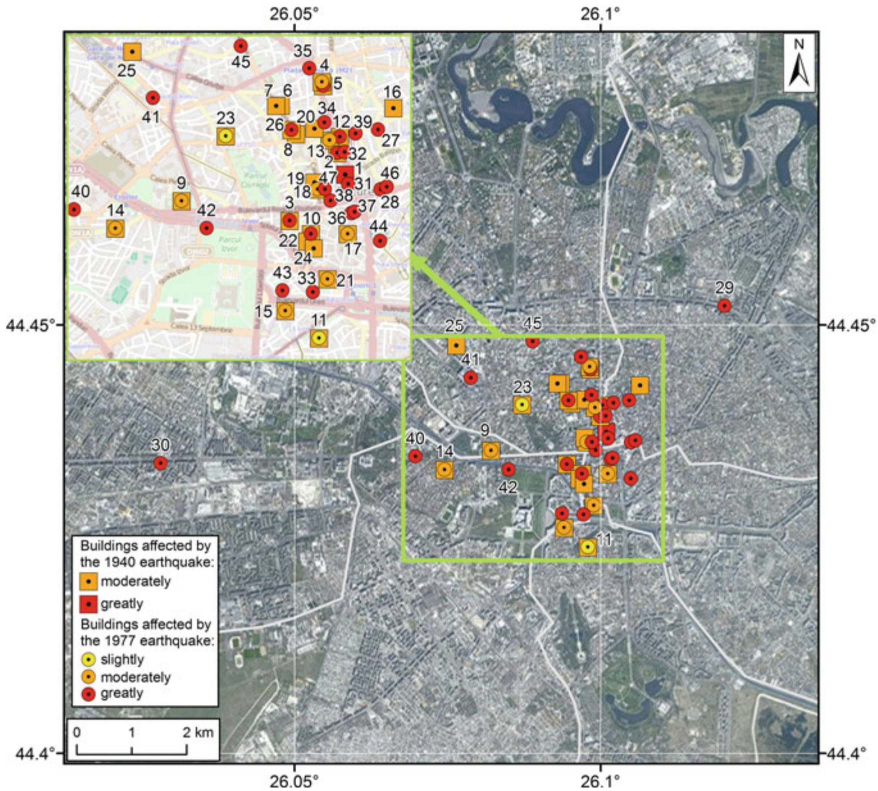

Fig. 3 Position of the buildings greatly affected by the earthquakes in 1940 and 1977 in the centre of Bucharest City. With *squares*—buildings damaged in 1940 event (data from Beleș 1941); with *circles*—buildings damaged in 1977 earthquake (data after Lupan 1982)

second underground levels. The reinforced mainframe begun to collapse at the III-rd and IV-th floors, where the columns were placed on beams. This scenario is in complete agreement with the eyewitnesses that stated: "The building looks that begin to sink, then begin to bulge in the middle, and finally suffered a complete collapse" (Beleș 1941).

At that time the buildings, even the tall ones, with reinforced concrete frames, were not designed in generally to support the shear forces that occurred during an earthquake. Most of them were built following the German regulations that do not include, at that time, the necessity to withstand the horizontal forces generated by an earthquake.

All the studies and reports following the earthquake led to the conclusions that in order to support an earthquake with controlled damage a construction should stand horizontal forces that are equal to the mass of the building multiplied by the maximum acceleration given by the strong ground motion.

Other important recommendations were made by Beleș (1941):

1. *The necessity of placing the building on a solid ground, which do not amplify the effect of the earthquakes*. The weak soils of heterogeneous structure, like recent filling, the young silts along the rivers must be avoided. This recommendation prefigures and recognizes the importance of seismic site effects that might introduce important amplification of the ground during a strong earthquake. The author recognizes that in Bucharest this problem appear along the Dambovita river, where young sediments are in place. He considers that the foundation of the building must be continuous and as deep as possible, but without touching the phreatic level, which might "amplify the seismic movements".
2. *The necessity to reduce the building heights.* This appears only for mechanical reasons, and the link with a possible resonance with the seismic waves was not yet introduced. That recommendation was almost completely ignored by the authorities in the new constructions erected in Bucharest in the following years.
3. *The horizontal layout of the building must be rectangular in shape*, *close to a square in order to resist to the earthquakes.* That idea was in generally followed for the new blocks erected in communist era, but some buildings that did not respect that were badly damaged at the earthquake in 1977.
4. *The floors must have the center of mass as close as possible to the center of stiffness*. That recommendation was usually followed, but in some cases some heavy weights were put in the building after construction, also like in the case of the building of Institute for Geology.

All these important recommendations, which were made in 1941 were reintroduced when Beleș and Ifrim (1962) published the book "Elements of seismology engineering" (in Romanian), in which the bases of this important discipline are set up. Beleș treated all the important feature of the earthquake in 1940 in a manner that belongs equally to seismology and to civil engineering. He treated also the damages of the earthquake with a thorough attention, speaking of the great damages suffered by the concrete frame of important buildings in central part of Bucharest, with more than 9 floors: *Belvedere*, *Wilson*, *Lengyel*, *Pherekide*, *Broșteni*, *Galașescu.* Beleș insisted that if they will be not-strengthened in a professional manner, these important buildings could be destroyed in the next great earthquake. Unfortunately, this grim prediction come true in the earthquake of 4.03.1977 for at least 4 of the cited buildings. The others have also suffered important damage even to collapse.

There were of course other buildings damaged by the earthquake in 1940, beside the important buildings having more than 9 floors, that were mentioned in the study of Beleș (1941). Important damages suffered some monumental buildings: Romanian Atheneum, National Theater, Opera House, Home Savings Bank (C.E.C.), the Post Palace (now National History Museum), Palace of Justice. Church *Popa Tatu* in Lipscani street collapsed and on Stirbei Voda str., the statue of General *Cernat* was toppled out of the statue pedestal.

3 The Strong Vrancea Earthquake of March 4th, 1977

In 4.03.1977 at the hour 19:21:56 (GMT) a destructive earthquake occured in the Vrancea seismogenic region, having destructive effects over a large area, extending from Vrancea area to the NE, towards Moscow, and to SW, into Bulgaria. The epicentre was established first at 45.8°N and 25.8°E and the depth at 95–100 km. Almost all the information and Romanian studies about this great earthquake are gathered in the volume "The earthquake from Romania of March 4, 1977", published in Romanian language under the coordination of Bălan, Cristescu and Cornea (eds) (1982).

The most important feature of this earthquake was the multi-shock character that was stated even in 1977 on the basis of seismological observations of Muller (1977) and Peterschmitt (1977). This particular character was described also by Mueller et al. (1978), like in Fig. 4. If one checks the position of the hipocenters of principal shocks, the conclusion is that they are like bursts of a single rupture process which affected a slab of at least 30 × 60 km. This rupture propagated with a velocity of up to 4.98 km/s and it have developed on a curve path, between 93–79 and 93–102 km depth. The direction of the shear displacement being from the NE towards SW, it appears that the slab was broken to a SW direction, from F and S1 towards S3 (Fig. 4).

The position of the principal shocks S1–S3, together with the mechanism of the initiating and propagating of the rupture are the principal factors of this directional effect recognized by Mueller et al. (1978), which explains why the maximum damage have been recorded to the SW, towards Bucharest. The magnitude of the earthquake of March 4, 1977 was adopted by many seismologists as $M_{GR} = 7.2$, as being the maximum magnitude attributed to the shock S3 (Enescu et al. 1982). Today moment magnitude is established at $M_W = 7.4$ in ROMPLUS.

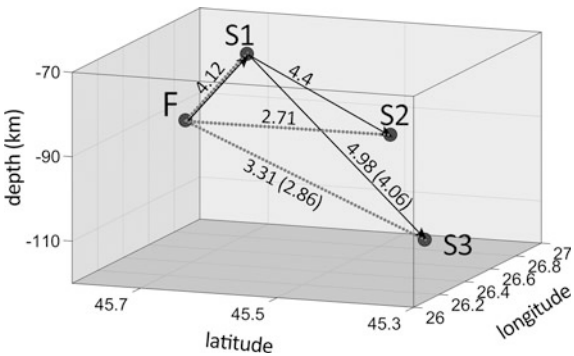

Fig. 4 Position of the foreshock and 3 principal shocks of the earthquake of. 4.03.1977. Coordinates after Muller et al. (1978). The numbers are propagation velocity in (km/s) for two scenarios

The focal mechanisms of the principal shocks of the 1977 earthquake were studied by several authors as there were different solutions for the number and characteristics of the principal shocks. A study of Enescu (1980), confirmed by other authors, established that the fault plane solutions were almost the same, indicating a fault mechanism oriented NE–SW which is sinking toward NW.

The hipocenter of the earthquake of 4.03.1977 is placed at least 40 km above the hypocentre of the earthquake of 1940. After Fuchs et al. (1979) the total surface of the rupture produced in 1977 must be at least 1800 km^2. The energy of the 1977 earthquake was lower than that of the earthquake from 1940, due to the relative reduced time, only 37 years, that passed between the two strong seismic events. By contrast, between the earthquake of 23 January 1838 (Ms = 7.3/Mw = 7.5, the previous great earthquake in Romania) and 1940, more than 100 years have passed. The energy of the 1977 earthquake focused towards SW, having important effects in *Cislau, Valenii de Munte, Bucuresti, Zimnicea in Romania and Svistov in Bulgaria.*

There is no direct information about the multi-shock character of other Romanian earthquakes in the past. There are studies of historic events, as Atanasiu (1961), which suggested that some events have had symmetrical effects in Moldova and in Muntenia (events from 30.07.1897; 16.10.1900; 1.07.1914). Other seismic events have had their important effects either in Muntenia (27.12.1895; 15.10.1905) or in Moldova (4.03.1894; 25.05.1912). We should assume that the latter events could have been multi-shock events with the main rupture towards SW, like the 1977 event, or towards NE.

3.1 The Destructive Effects of the Earthquake of 4.03.1977 in Bucharest

The earthquake of 1977 was analysed from its destructive effects in detail in Bălan, Cristescu and Cornea (1982). A map of the macroseismic effects of the earthquake that was realised on the basis of 12,000 of questionnaires which existed in Romania is presented in Fig. 5. The isoseismal lines were expressed in the MSK scale.

The **Medvedev–Sponheuer–Karnik scale**, also known as the **MSK** or *MSK-64*, is a macroseismic intensity scale used to evaluate the severity of ground shaking on the basis of observed effects in an area of the earthquake occurrence. The Medvedev–Sponheuer–Karnik scale is somewhat similar to the Modified Mercalli (MM) scale used in the United States. The MSK scale has also 12 intensity degrees expressed in Roman numerals.

Although it is generally accepted that the event of 1977 had a lower energy (Mw = 7.4) in comparison with the earthquake of November 10th 1940 (Mw = 7.7), the former have inflicted more damages throughout Romania and especially in Bucharest City. This general observation is a combination of several particular characters of the 4.03.1977 event that might be:

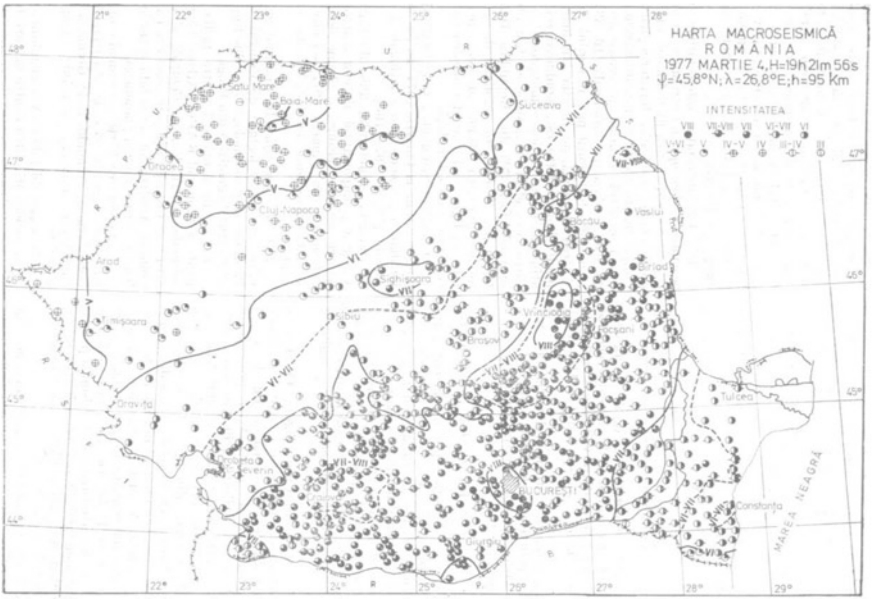

Fig. 5 Macroseismic map of the earthquake of March 4, 1977. Equal intensity lines are in MSK scale. After Radu and Polonic (1982)

1. The multi-shock character of seismic event likely increased the effects because of the multiple interferences of the waves, along their path to surface. In some places along the path an additional effect developed as different seismic waves just arrived in the same moment, increasing in this way the destruction effect of the earthquake.
2. The damaging effect is visibly greater to the SW direction to Muntenia, and farther in the NW part of Bulgaria, due to the rupture developed from one shock to the other, with a general direction towards SW. It is interesting to note that in seismic measurements with controlled source it is a custom to increase the force of explosion toward a certain direction by grouping the explosions, which are fired in a certain manner. It looks like the multiple shocks of the 4.03.1977 event occurred in the same scenario, the observation being made first by Bălan, Cristescu and Cornea (1982).
3. The boom of construction in Bucharest took place in the period 1960–1977, but following a weak standardized seismic hazard map from 1952 (STAS 2923-52). After this year the following codes and associated maps were adopted, which provide seismic hazard values that were inferior to the values within the original macroseismic map of Demetrescu (1941).

4. The main recommendations made by Beleș (1941) were largely ignored by the authorities of the time and because of the war. After that seismic regulations were introduced, but they were not respecting all the observations made in 1941. His predictions about the endangered old blocks with reinforced concrete frames were gradually forgotten, but they come to reality during the 1977 earthquake, with a deadly precision.

Some observations should be made on the macroseismic maps made by the specialists as a consequence of the earthquake of 10.11.1940. The map presented by Demetrescu (1941) with intensities on MCS scale, can be seen in Fig. 2.

The first official seismic zoning of the country was approved by Ministry of Public Constructions at 30.12.1941, published in 19.01.1942 (Georgescu 2003). It contains a map of seismic zonation based on the Demetrescu map, 1941, but very schematic and with a VIII degree in the area in front of Carpathians (Bălan, Cristescu and Cornea 1982; Georgescu 2003). The seismic zonation that followed in 1952 (STAS 2923-52) have also taken the Demetrescu map as a base, but it was reduced with two degrees in the epicentral area and with one degree in the area which surrounded Vrancea.

However, the macroseismic map of Atanasiu (1961) presented the known area in Muntenia and Moldova with a mosaic of zones with local amplifications with degrees 8, 9 and even 10 on MCS scale, based on studies made until 1949 (Georgescu 2003).

Previous seismic design norms prior to the earthquake of 1977 are P13-63 and P13-70 and associated seismic map of STAS 2923-63, which replaced the similar map from STAS 2923-52, introducing major reductions seismic intensity design in several areas. After the map adopted in 1963 a large number of localities were placed in the intensity grade 6 MSK, on the macroseismic map. In spite of the warnings of some of the Romanian seismologists, the intensity was gradually decreased in these maps as the time passed from the 1940 earthquake (Georgescu 2003).

The list of 32 unfortunate buildings that collapsed in Bucharest in 1977 is presented by M. Lupan (1982) in (Bălan et al. 1982). Some of them suffered only a partial collapse, but have been demolished after that on the account that they were beyond repair. Their positions are very familiar as they were presented also by Beleș (1941), as being endangered buildings. Other damaged buildings were in the same category of old buildings constructed in the years 20s and 30s, in which no seismic rules or regulations have been in force and which have suffered the bombardments of the war and the previous earthquake in 1940. It is true that they are concentrated in the Bucharest center, but it seems that their collapse is due mainly to the fact that they belonged to the same category. The buildings made in 1960–1970 had a much better behavior. The collapse was rather exceptions, the cases are different, being a combination of factors, but most often they were mistakes of contractors.

4 Conclusions

Over time, some 2–3 devastating earthquakes per century occurred in Romania in the Vrancea zone at intermediate depth, and hit especially Muntenia and Moldova. In average, every 35–50 years Bucharest is heavily hit, as well as Iasi in Moldova and the epicentral region of Vrancea. With some variations, the earthquake looks the same, but the capital city is changing and developing every day and so is becoming more vulnerable. Vrancea region produce many earthquakes every year, most of them are recorded only by seismographs. The events exceeding 7° magnitude are responsible for considerable damage not only in the epicentral area, but also in other cities in Romania and abroad. Large earthquakes might produce considerable damaging effects especially on an axis NE–SW which crosses Vrancea area in front of Carpathians. Last disastrous event, the 1977 event, made 1,578 dead people and 11,321 injured, with 90 % of the fatalities being in the capital city Bucharest. The reported damages included 32,900 collapsed or heavily damaged dwelling units, 35,000 homeless families, thousands of damaged buildings, as well as many other damages and destructions in industry and infrastructure (Georgescu and Pomonis 2008).

According to World Bank estimates in 1978, the direct damage was over $2 billion USD, and amortization of long-term effects has absorbed almost as much. More detailed but until recently classified and largely ignored damage data contain information from 19 counties plus Bucharest, with the total damage value reaching Romanian Lei 3.7 billion (Georgescu and Pomonis 2008).

Today costs in case of an earthquake in Romania, similar to 1977 would amount to around 20 billion dollars, according to estimates, up from 2 billion as it was in 1977, this is an estimate of Munich Re group analysis. Damage estimates refer only to the capital, without regard to disasters in other areas because the missing information required to make a solid assessment (Munich Reinsurance Company 1998). The *World Map of Natural Hazards* prepared by the *Münich Re*, 1998 indicates for Bucharest: “Large city with Mexico-city effect”. The map focuses the dangerous phenomenon of long (1.6 s) predominant period of soil vibration in Bucharest during strong Vrancea earthquakes.

The occurring of great seismic events at about 35–50 years it means that it comes but rarely enough to forget it, and so society is unprepared at the next event; but often enough to be sure that people will try the disaster at least once in a lifetime. It is not a high enough frequency, so the phenomenon become an everyday experience, as in Japan, which knows how to live with the danger; but it come at an interval long enough to make from most of us an unexperienced potential victim. The main conclusions about the two great and destructive earthquakes that hit Romania in the XX century are:

1. The earthquake of 1940 had a greater magnitude, but its effects were directed mostly to the NE, having toward Moscow an intensity of V–VI. Bucharest was hit heavily, but the damages, as well as the number of victims were greater in Vrancea

area and to the NW, until Chisinau. The 1977 earthquake had a lower magnitude and a demonstrated multi-shock character. The foreshock and the succession of triggering of the principal shocks directed the energy towards SW and hit especially Bucharest, Zimnicea and NW Bulgaria. The number of victims and the damages increased considerably in Bucharest.

2. There were some preventive measures after the 1940 earthquake, but they were weakened soon and the principal recommendation made by specialists were forgotten as the time passed. Now almost all the seismologists and civil engineers agreed that Beleș (1941) was right and the absolute retrofitting priority in the case of Bucharest, after the experience of Vrancea earthquakes in 1940 and 1977, is for tall buildings before World War II, that do not have structural resources to withstand a major earthquake.

3. Only after 1940 some anti-seismic rules were adopted, there was a concern of legislators and civil engineers. Geologist Atanasiu (1962) has made a scientific study and sketched a seismic map of Romania, stressing that, although there are several seismogenic areas—Transylvania, Banat, Danubian zone, Fagaras Mts., Pontic zone—the most destructive earthquakes are the ones located in Vrancea area. Atanasiu's map alignments are figured two major seismic sensitivity in southeast Romania: first, Lehliu–Urziceni–Calarasi; second, Bucharest. Many years passed and many of the lessons of the 1940 earthquake have been forgotten. Deep cracks in buildings elements disappeared covered with plaster, walls were toppled down and even structural columns to make room on the ground floor premises. Even worse, the upper floors were sometimes overloaded. As a result 25 of the buildings damaged in 1940 earthquake, some of those on the list of Beleș (1941), collapsed totally or partially during the 1977 earthquake.

After 1977 a lot of studies have been made in the seismic hazard assessment and reduction of the seismic risk. Romania is now covered with a dense network of more than 100 real-time seismic stations. Seismologists and civil engineers were trying hard to link the destruction produced by earthquakes to their characteristics as magnitude, frequency, earthquake mechanism as well as the seismic site effects. As a result new Romanian standards appear (P 100–2013) which are successfully applied to the construction of new buildings.

However most of the damages may occur in Bucharest at a specific category of old buildings with reinforced concrete frames, with characteristics described by Beleș (1941). A list of buildings with technical expertise in terms of seismic risk that are endangered in the case of a strong Vrancea earthquake was published on the site of the Bucharest City Hall, most of them being assessed beginning with the years 90s (Fig. 6). The problem is that in the *Class I of seismic risk*, there are now listed 178 buildings which is dangerous for the population. Other more 182 buildings belong to the same list of *Class I of seismic risk.* Only some 57 buildings were retrofitted in the past 20 years (PMB 2015).

Further studies on seismology and seismic site effects will bring no news to the condition of these endangered buildings, but considered "danger to human lives", without a proper retrofitting. Their position on the map in Figs. 3 and 6 is due to the fact that the location was the best position (in the centre of Bucharest) at the time

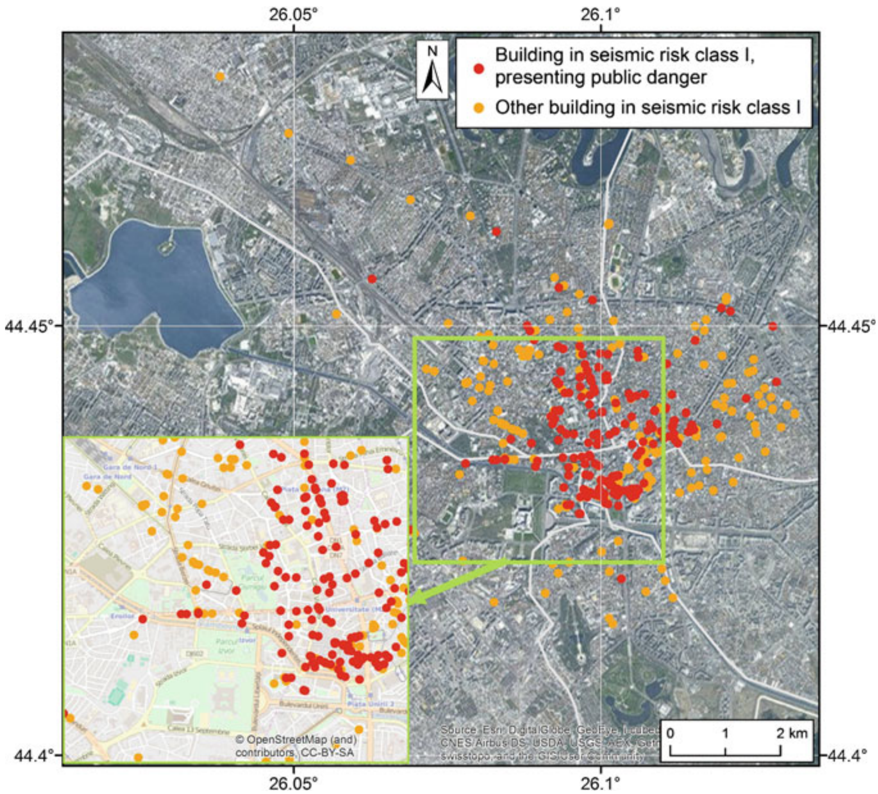

Fig. 6 Position of the buildings in seismic class I in the centre of Bucharest City. *Red dots*—buildings presenting public danger; *orange dots*—other buildings in seismic risk class I. Data from PMB (2015)

when they were built. Studies on local seismic hazard and site effects do not show a certain increase in the spectral amplification in the area occupied by these old buildings. But the position of the endangered buildings in Fig. 6, being almost superimposed on those from Fig. 3, strongly suggest that these buildings, suffering different damages in the past strong earthquakes of 1940 and 1977, will be further damaged in the next strong earthquake.

The risk computed in Bucharest for two Vrancea earthquakes scenarios (one typical for an observed major event, like in 1986, the other for a maximum expected event with Mw = 7.7) shows the critical impact of the event magnitude and the higher risk in the central part of the city (Bostenaru et al. 2014). Big quake is inevitable, it is not a question of if it occur, but when it will occur. It is part of the history of our collective experience.

> Beleș (1941): In our country the earthquake of 1940 put in front of our generation the problem of the buildings resilience to earthquake, showing the errors of the past and the current shortages. It demonstrated the role of extreme importance that played the

conscientiousness in design, in material choosing and in the execution of a building, in which both the civil engineer and the worker must be imbued. If we can gain the practice of these virtues in the aftermath of an earthquake, we can say that it must be a good thing in a disastrous one.

Acknowledgements This paper was sustained by UEFISCDI Programme Partnerships II, in the frame of the contract 90/2014 in which the author is partner from National Institute of RD for Earth Physics.

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http://www.springer.com/978-3-319-29843-6

The 1940 Vrancea Earthquake. Issues, Insights and Lessons Learnt
Proceedings of the Symposium Commemorating 75 Years from November 10, 1940 Vrancea Earthquake
Vacareanu, R.; Ionescu, C. (Eds.)
2016, XII, 521 p. 316 illus., 204 illus. in color., Hardcover
ISBN: 978-3-319-29843-6