MAJOR HISTORICAL EARTHQUAKES IN ROMANIA AND CONTEMPORARY SEISMIC RISK MANAGEMENT ACTIVITIES

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ABSTRACT

With more than 2 millions inhabitants, population mean density of about 11000 persons/km^2 and more than 110,000 buildings, Bucharest can be ranked as the megacity having the highest seismic risk in Europe. The paper focuses mainly on: (i) the effects on buildings of the 4 largest subcrustal Vrancea earthquakes in the last 200 years and (ii) the national strategy for seismic risk reduction.

INTRODUCTION

The Vrancea region, located where the Carpathians Mountains Arch bends, at about 130km epicentral distance from Bucharest, is a source of subcrustal seismic activity, which affects more than 2/3 of the territory of Romania and an important part of the territories of Republic of Moldova, Bulgaria and Ukraine. Bucharest is the capital city of Romania and the main administrative, economic and cultural center of the country.

Romanian earthquake catalogues (Radu, 1974, 1980, 1995), Constantinescu and Marza (1980, 1995) and INFP (2014) contain around 1000yr. of seismic effects evidence of the Vrancea subcrustal source (60 – 180km) in Romania.

However, the last 2 centuries are by far the best documented as well as the most severe in terms of buildings damage. The 4 largest subcrustal Vrancea earthquakes in the last 200 years are:

(i) In the 19th century: the 1802 (Mw = 7.9) and the 1838 (Mw = 7.6) event

(ii) In the 20th century: the 1940 (Mw = 7.7, h = 150km) and the 1977 (Mw = 7.5, h = 109km)

The 1802 is considered the largest Vrancea earthquake ever felt in Romania, and the 1977 is considered the most severe earthquake in terms of people lost and building damage (World Bank Report 16.P-2240-RO, 1978). Figure 1 present the locations of epicentres from 984 to 2003 earthquakes and seismic regions.

MAJOR HISTORICAL VRANCEA EARTHQUAKES

1802 EARTHQUAKE

The 26 Oct 1802 earthquake (M_w = 7.9) is considered to be the strongest Vrancea subcrustal event; there is no precise information on causalities but some information on damages.

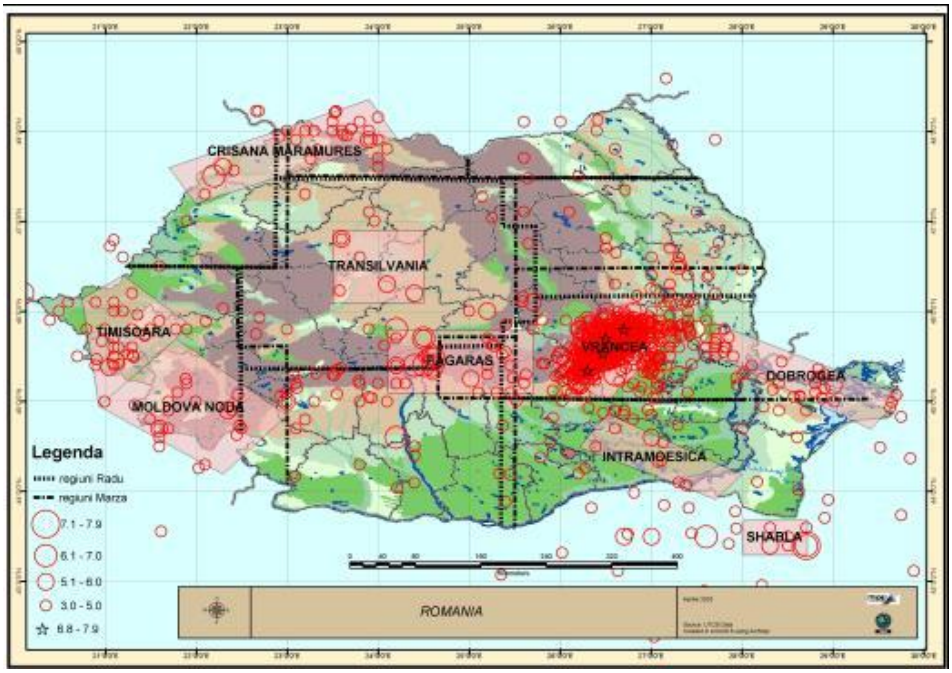

Figure 1. Romania. Location of the epicenters from 984 to 2003 and seismic regions

During the 1802 earthquake many bell towers and towers of churches felt down and several churches were destroyed included St. Spiridon Church and Cotroceni monastery in Bucharest and the Monastery in Valeni, Figure 2 (left). Half of Coltea tower in Bucharest collapsed and the remaining part was seriously damaged; most of wealthy residences were heavily damaged and part of them collapsed. At Brasov, many chimneys felt down and houses and churches were damaged. The earthquake was felt in Transylvania (Sibiu, Sighisoara) and Banat (Timisoara). The earthquake was felt in Poland, Bulgaria, Turkey and Russia. In Cernauti some houses were damaged. In Lvov, Armenian Church was cracked and the bells ring alone.

Figure 2. Chronicle of Monastery Valeni, Southern Carpathians

1838 EARTHQUAKE

The following description of the effects of 1838 earthquake effects in Bucharest is given in the book "Voyage dans la Russie Méridionale et la Crimée par la Hongrie, la Valachie et la Moldavie"-Figure 3, par M. A. de Démidoff, Illustré par Raffet, E. Bourdin, éditeur Paris. 1841 & 1854, page 144: “Chaque année, le sol de la Valachie est ébranlé par deux ou trois secousses de tremblement de terre plus ou moins sensibles; mais, malheureusement, on a à noter, tous les huit ou dix ans, quelque atteinte réellement désastreuse de ce fléau. On conserve encore le souvenir du tremblement de terre de 1802, qui renversa la tour du monastère de Koltza; de celui de 1829, qui ébranla fortement la plupart des édifices de Bukharest. Depuis que ces lignes sont écrites, une secousse plus violente que toutes celles dont le souvenir attriste encore le pays, a pensé engloutir Bukharest. Tout à coup, le 11-23 janvier 1838, c'était le soir, la ville s'ébranle; les plus solides monuments chancellent; plusieurs maisons s'écroulent; toutes son endommagées, et, dans tout ces ravages, plusieurs hommes perdent la vie.”

Figure 3. M. Anatole de Démidoff, “Voyage dans la Russie Méridionale et la Crimée par la Hongrie, la Valachie et la Moldavie”. Illustré par Raffet. Ernest Bourdin éditeur, Paris, 1841

In Bucharest, the Police report mentioned: 8 deaths, 14 injured and 36 collapsed buildings. Many other buildings (especially the larger ones among which was the Royal Palace) were heavily damaged.

The engineer Gustav Schuller, counsellor of the Great Duque of Saxa, who was in Romania at that time, was asked by Romanian Government to make an investigation in the epicentral area. He indicates a maximum intensity IX in the area of Vrancea Mountains, Focsani and Ramnicu Sarat where many villages were completed destroyed. Schuller concludes: ”all the stone masonry buildings were heavily damaged and some of them especially the churches and other large buildings become unusable”.

The earthquake was felt on an extended area in Europe: Ukraine, Poland, and Bulgaria, up to Constantinople and to North East of Italy.

1940 EARTHQUAKE

“In five minutes more damage was caused than the Luftwaffe has accomplished in London since the war began” relate Time Magazine journalists in number 21, Vol. XXXVI from November 18, 1940.

“The November 10, 1940 earthquake (Mw = 7.7) put damages all around Romania and throw the people in mourning”, Comptes Rendus des Séances de l’Académie des Sciences de Roumanie, 1941. In Bucharest the most significant loss was the complete collapse of RC framed Carlton building, the highest RC building (47m, 12 storeys) in Romania at that moment. Until Nov 24, 136 people were found dead in the rubble of that building. Several high-rise RC buildings in Bucharest were very severely damaged: Belvedere, Wilson, Lengyel, Pherekide, Brosteni, Galasescu. Other important heritage buildings in Bucharest suffered important damage: Palace of Justice, Romanian Atheneum, CEC Bank Palace, and Postal Palace.

Masonry buildings located in Chisinau, Republic of Moldova have been very severely damaged, according to the photographic information provided by the Seismologcikii Institut Academii Nauk, CCCR, Moskow 15.02.1941.

Two zones of maximum seismic intensity were identified according to the actual structural damage: one was the epicentral area of Focsani and the second one was located at the North of Bucharest. In those areas the seismic intensity was over VIII, close to IX, on Mercalli-Sieberg scale. In Panciu, near Focsani no building was standing after the earthquake (Timpul newspaper of 12 Nov. 1940). Since the earthquake was a deep event (about 140km depth) it has been felt on about 2 millions square kilometers i.e. to the East: in Odessa, Cracovia, Moscow; to the North: up to Saint Petersburg; to the West: up to Tissa river and to the South: up to Istanbul.

1977 EARTHQUAKE

The March 4, 1977 (Mw=7.5, depth h= 94km) was the most destructive earthquake in the history of Romania, epicentral distance to Bucharest of the main shock was about 100km. This earthquake (Fattal, Simiu, Culver, 1977):

- killed 1,578 people including 1,424 in Bucharest;
- injured 11,221 people including 7,598 in Bucharest and 3,723 in the rest of the country;
- destroyed or seriously damaged 33,000 housing units in high-rise apartment flats and conventional type dwellings (35,000 families, more than 200,000 persons homeless);
- caused lesser damage to 182,000 other dwellings;
- destroyed 374 kindergartens, nurseries, and schools and badly damaged 1,992 others;
- destroyed 6 university buildings and damaged 60 others;
- destroyed 11 hospitals and damaged 2,288 others hospitals and 220 polyclinics;
- damaged almost 400 cultural institutions (theatre, museums, etc.);
- damaged 763 factories;
- directly affected over 200,000 people.

Famous international experts dispatched in Romania in the aftermath of the earthquake reported as follows: “The unusual nature of the ground motion and the extent and distribution of the structural damage have important bearing on earthquake engineering efforts in the United States” Jennings & Blume, NRC&EERI, Washington. “It was felt on an area of 1.3 million squared kilometers and caused damage over an area of about 80000 km2 within which the most frequently occurring intensity did not exceed VII (MM). Much of the damage was caused to old multi-storey reinforced concrete buildings of 6-12 storeys. These structures have a fundamental period of the order of 0.7-1.6 s, which places them on the ascending branch of the Bucharest response acceleration spectrum. Progressive damage during the earthquake should have caused a lengthening of their period and an increase in the lateral forces acting on them. In contrast, rigid structures of large panel or frame construction with shear wall, of the same height, as well as 1-3 storey masonry dwellings, suffered little damage” (Ambraseys, 1977).

The earthquake has been recorded in Bucharest by a SMAC-B Japanese instrument and further digitized and processed by the Observational Committee of Strong Motion Earthquake of the Building Research Institute, Ministry of Construction of Japan, January, 1978 (254 pages Report).

Figure 4. Total and partial collapse of the Bucharest RC tall buildings in 1977 earthquake

In Table 1 are presented the most notable buildings collapsed by the 1977 earthquake. The lack of structure horizontal-regularity, lack of mass vertical-symmetry, accumulated damage during the 1940 earthquake, low strength concrete (mean of compressive strength less than 200 daN/cm2), soft ground floor due to commercial use of the floor (no infilled masonry walls) and dynamic characteristics clearly explain the collapse of buildings in the centre of Bucharest.

Figure 5 presents the location of all the buildings collapsed during March 4, 1977 Vrancea earthquake. Most of them of are concentrated in the central part of Bucharest due to the 1935 issued Plan of Urban Development of the city of Bucharest which recommends the city centre for the tallest buildings within the city.

Table 1. Buildings collapsed in Bucharest on March 4, 1977 (excerpt)

No.	Building	Address	Construc-tion year	Storys	Occupancy	Housing units	Building structure	Type of collapse
Pre-WWII RC buildings								
1	*Belvedere*	7, Brezoianu	1938	GF+13S	housing	-	RC frame	total
2	*Continental*	3, Ion Ghica	1935	GF+10S	"	72	"	"
3	*Carpati*	5, Academiei	1936	GF+9S	offices	-	"	partial
New RC buildings								
4	*OD16*	7, Pacii	1974	GF+10S	housing	33	RC shear wall	partial
5	*Lizeanu*	33, St. cel Mare	1962	GF+9S	"	44	"	"
6	*MITc Comp. Center*	Garii de Nord	1968	GF+2S	offices	-	RC frame	total

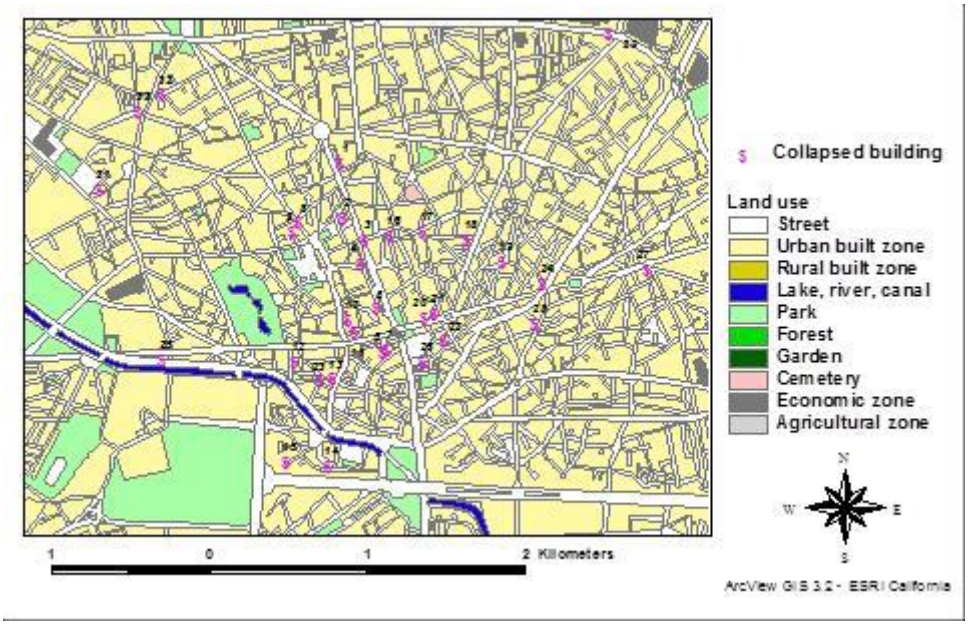

Figure 5. Collapsed buildings occurred in 1977 earthquake

On March 30, 1977 the national strategy for strengthening the buildings damaged by the 1977 earthquake was established by the Romanian Government in the letter to the Municipality of Bucharest of the General Inspector for Construction of Romania as follows: "The retrofitting of buildings must provide:

- For the old buildings - the same resistance they have before 1940 earthquake;
- For the new buildings - the same resistance they have when they were designed." The above Governmental Order was further explained in the letter to the Technical University of Civil Engineering, Bucharest from General Inspector for Construction of Romania and General Director of Central Institute for Research Design and Coordination for Construction, July 11, 1977, as follows: "Retrofitting of the buildings damaged by the 1977 earthquake will consist of strict local repairing of damaged elements. Additional measures for seismic protection are not allowed." The 1977 Romanian Government strategy for repairing damaged buildings has proved as a regrettable mistake.

In Table 2 are presented examples of the most severed damaged buildings and the existing damage score according to Gulkan et al. (1994) and also retrofitting work done after 1977 earthquake.

Table 2. Pre-1940 Buildings with more than 5 stories in central Bucharest, registered as having highest risk of collapse in case of strong (similar to '77) earthquake (excerpt)

No	Address	Year of building construction	Commercial occupancy of ground floor	Storeys	No. of apt.	Damages after the 1977 earthquake in structural elements	Repairing work after the 1977 earthquake	SD Damage score
1	Vasile Lascar 26-28	1937	*Yes*	7	28	Columns : *Extreme* Beams : *Extreme* Masonry : -	Masonry Repairs	86
2	Ion Campineanu 9	1915	*Yes*	7.5	25	Columns : - Beams : - Masonry : *Extreme*	Masonry Repairs Finishes	77
3	Dionisie Lupu 55	1936	*No*	6.5	13	Columns : *Extreme* Beams : *Extreme* Masonry : *Extreme*	Jacketing Masonry Repairs Epoxy resins injections	100
4	Calea Victoriei 112	1939	*Yes*	9	27	Columns : *Extreme* Beams : *Extreme* Masonry : *Extreme*	Jacketing of 4 columns Masonry Repairs Epoxy resins injections	100
5	Lahovari 5A	1935	*Yes*	8	18	Columns : *Extreme* Beams : *Extreme* Masonry : *Extreme*	Jacketing Masonry Repairs Epoxy resins injections Mortar injections	100

SEISMIC RISK REDUCTION STRATEGY

Many RC tall buildings built before WWII were randomly identified by authorities and structural engineers as “seismic risk class 1” buildings, i.e. buildings supposed to collapse or to be very severely damaged during the next earthquake similar or larger than 1977 one. The number of fragile high-rise RC buildings in the city centre of Bucharest is probably two times larger than the existing number of identified buildings having "seismic risk class 1" signalised with a „red spot”. Many of recognised most vulnerable buildings in the city centre are still not yet identified as being very vulnerable. In spite of the high cost of adequate retrofitting of the fragile RC high-rise buildings located in the centre of Bucharest, there are architectural and historical heritage constrains – after the Bucharest demolition large campaign of ’80 – suggesting that more demolition should be not allowed in the city center.

The distribution of the existing housing units and/or buildings located in seismically vulnerable central Bucharest is presented in Table 3.

Table 3. Bucharest housing units / buildings by seismic risk classes

	Seismic risk class 1* public danger	Rs 1*	Rs 2	Rs 3	Rs 4
Buildings	190	184	301	78	6
Housing units	5363	1276	11070	1781	86

* 31 buildings already retrofitted from which only 10 high rise buildings

The examination of the information made available for the buildings in Bucharest reveals the following conclusions:

1. The initial purpose of the technical and seismic assessment program of the buildings in Bucharest that were damaged during the earthquakes in 1940, 1977 and 1990, was to make a Priority List for consolidation and insurance of the inhabitants' security with respect to the buildings showing serious bearing structure damages.

2. Over the recent years, the list was updated with a very large number of low buildings, with only a few levels, generally having bearing or mixed structure (brick walls and concrete) and boards sometimes made of wood or metallic profiles and brick bolts. Such buildings could be included in the same seismic vulnerability class as the tall ones - those which collapsed in 1977 – but they cannot be definitively regarded as part of the same seismic risk class for the mere reason that, considering the seismic history of 1977, they can generate in case of a major earthquake similar to that from 1977, totally different human, economic and

structural consequences from those caused by the collapse of the multi-leveled concrete buildings collapsed on March, 4th, 1977.

3. Since more than 50% of the list of buildings in Bucharest falling under Class no. 1 of seismic risk are low buildings below GF + 4F (17 % are buildings of GF and GF + 1F), we can infer that the initial purpose of the priority list for seismic consolidation has been altered and deviated to other obscure intentions.

Currently, the „red spot" signifies an „invitation" to eliminate many buildings under Class no. 1 of seismic risk located in the central areas of the capital or residential neighbourhoods in the northern area of the city. Unfortunately, the various seismic risk class 1 low-rise buildings are systematically planned to be demolished –not to be retrofitted-. Such buildings have fragile brick bearing structure, easily to tear down and, thus, have become very „attractive" for real estate speculations intended to offer free lands for future investment in tall buildings, 3 to 8 levels above the general height of the area/neighbourhood.

The manifest of the present situation by the central and local authorities is presented in Table 4 divided by building age and number of storeys.

Table 4. Central Bucharest housing units categorised as "Public danger, Seismic risk class 1"

No. of storeys	Building age								
	<1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	>1960	Total
1 storey	21	-	-	-	-	-	-	-	21
2 storeys	86	8	1	11	-	-	-	-	106
3 storeys	89	3	2	23	5	-	-	-	122
4 storeys	143	43	-	12	128	-	-	-	326
5 storeys	34	-	-	239	296	31	-	-	600
6 storeys	39	67	33	40	632	-	-	-	811
7 storeys	-	-	25	142	681	30	-	-	878
8 storeys	-	-	-	105	538	134	-	-	777
9 storeys	-	-	-	54	369	52	437	339	1251
10 storeys	-	-	-	-	171	-	156	70	397
>10 storeys	-	-	-	-	74	-	-	-	74
Total	421	121	61	626	2894	247	593	409	5363

In Figure 6 is presented the distribution of seismic risk class 1 buildings housing units by the height of the building. One can notice that about 60% of the housing units are situated in buildings with more than 5 storeys.

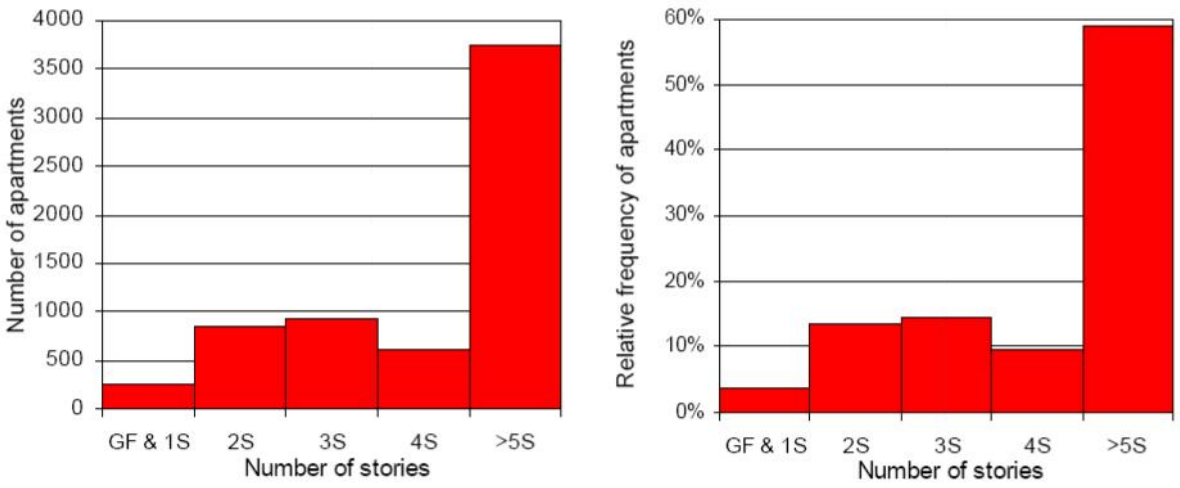

Figure 6. Housing units distribution for seismic risk class 1 buildings in Bucharest

CONCLUSIONS

In “Bucharest, Europe’s earthquake capital”, as The Guardian named Romania’s capital city, the retrofitting rate of “Public danger, Seismic risk class 1” buildings is slow (1 building per year) due to the ineffectiveness of legislation in constraining the owner of those buildings to retrofit them. Bucharest urgently needs the support of the population and, moreover, a new political strategy of central and local administrations to repair and strenghten the Seismic risk class 1 buildings in order to be prepare for the next majour seismic event.

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