ENGINEERING, STATE & INSURANCE EFFORTS FOR REDUCTION OF SEISMIC RISK IN ROMANIA

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SUMMARY

The paper describes procedures and actions adopted for assessment and reduction of seismic risk in Romania. The study is based on following information: (i) Design provisions for earthquake resistance of structures during 6 generations of seismic codes (1941 - 1998); (ii) Probabilistic hazard assessment in the influence area of subcrustal (60÷170 km) Vrancea source in Eastern Europe; (iii) Classification of model buildings of the Romanian building stock (iv) Vulnerability curves for typical RC and masonry model buildings and (vi) Expertise reports for the most damaged by earthquakes buildings in Bucharest. Using FEMA/HAZUS methodology (1997), the paper presents Guidelines for selection of the damage function for building structures in Romania, based on building age and seismic zonation map valid during construction of the building. Two Governmental countermeasures documents aiming at providing safety to strong earthquakes for the building stock of Romania are presented: Order No.6173/NN/1997 of the Minister of Public Works and Land Planning and Governmental Ordinance HG 597/1998 providing, from state funds, about 20 Millions US $ per year for retrofitting the most damaged buildings in Bucharest.

1. INTRODUCTION

Within the last 60 years, Romania was threatened by 4 strong Vrancea events: Nov.10, 1940 (Gutenberg-Richter magnitude M=7.4, focal depth h=150 km), March 4, 1977 (M=7.2, h=109 km), Aug. 30, 1986 (M=7.0, h=133 km) and May 30/31, 1990 (M=6.7/6.1 h=91/79 km). In the epicentral area, acceleration of 0.3g was recorded at Focsani during the 1986 event. In the soft soil condition of Bucharest, at 105 km from the epicentre, a peak acceleration of 0.2g and a 1.6 s long predominant period of soil vibration were observed during the 1977 event.
The estimation of losses after the 1977 earthquake indicates 2.05 Billion US $. 2/3 of the total losses were in the capital city, Bucharest, where more than 1400 people died and 32 RC tall buildings collapsed. The 1977 direct losses and indirect consequences mark probably the starting point of economical decay of Romania during the last decades. The losses explain the present interest and concern of civil engineering community, Romanian Government and international insurance industry for assessment and reduction of seismic risk in Romania.

2. SEISMIC HAZARD ZONATION FOR VRANCEA SOURCE IN ROMANIA

The Gutenberg-Richter relationship for Vrancea large ($M \geq 6.0$) magnitude recurrence [Lungu *et al*., 1995]:

$$\log n(\geq M) = 3.49 - 0.72\, M \qquad (1)$$

was modified to take into account the source maximum credible magnitude using Hwang & Huo (1994) model. The average number per year of events with magnitude greater than or equal to M is [Elnashai, Lungu, 1995]:

$$n(\geq M) = e^{8.036 - 1.658\, M}\, \frac{1 - e^{-1.658(M_{\max} - M)}}{1 - e^{-1.658(M_{\max} - M_0)}} \qquad (2)$$

where M_{max} is the maximum credible magnitude of the source and M_0 = 6.0 is the threshold lower magnitude.

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The values of surface rupture area (*SRA*) and surface rupture length (*SRL*) from Wells and Coppersmith (1994) equations were used to estimate maximum credible Vrancea magnitude as M_{max}= 7.8 [Lungu *et al*., 1997c]. Consequently, from Equation (2) the magnitudes having mean recurrence interval $\overline{T}$ = 50, 100 and 475 yr are $M \cong$ 7.1, 7.3 and 7.7. The damage intensity of strong Vrancea subcrustal earthquakes is the combined result of both magnitude and location of the focus inside the earth. The relationship between the magnitude of a destructive Vrancea earthquake $(M \geq 6.0)$ and its corresponding focal depth, h (in km) was found as:

$$\ln h = -0.77 + 2.86 \ln M - 0.18\, P \qquad (3)$$

where: P=0 for mean relationship and P=1.0 for mean minus one standard deviation relationship. The curve for P=1.0 should be used in the seismic hazard assessment as a pessimistic correlation of magnitude with focus depth.
The research devoted to the attenuation of Vrancea ground motions started in 1994. The database used for the last (1998) analysis of the Vrancea ground motions attenuation comprises 78 triaxial or biaxial accelerograms recorded at 49 free-field stations from 3 Romanian seismic networks (INCERC, INFP and GEOTEC) and from Republic of Moldova and Bulgaria. The accelerograms are distributed as follows: 41 from 1990 event, 36 from 1986 event and 1 from 1977 event. The free field records were obtained at the ground floor or the basement of 1 - 2 storey buildings. The following model was selected for the analysis of attenuation [Lungu *et al*., 1995]:

$$\ln PGA = c_1 + c_2 M_w + c_3 \ln R + c_4 h + \varepsilon \qquad (4)$$

where: PGA is the peak ground acceleration at the site, M_w- the moment magnitude (for Vrancea subcrustal events $M_W \cong M$+0.3), R - the hypocentral distance to the site, h - the focal depth, c_1, c_2, c_3, c_4 - data dependent coefficients and ε - random variable with zero mean and standard deviation $\sigma_\varepsilon = \sigma_{\ln PGA}$. Taking into account the directionality of the seismic field produced by the Vrancea source, the attenuation analysis was performed on two orthogonal directions (the average direction of the rupture surface N45ºE and the normal to this direction E45ºS) and 3 circular sectors (of 90° each) centred on these directions:Bucharest, Moldova and Dobrogea, Table 1.

CONTOUR MAP FOR PGA (cm/s2) HAVING 10% PROBABILITY OF EXCEEDANCE IN 50yr

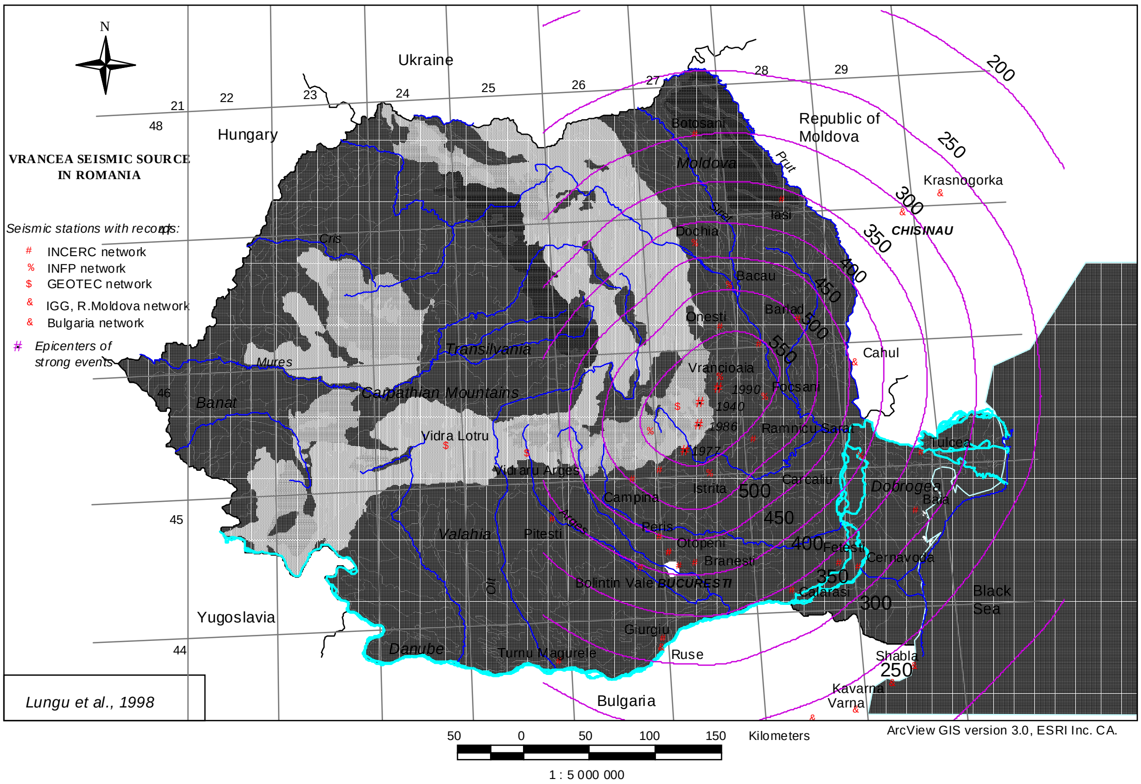

Figure 1: Predictive contour map for peak ground acceleration from subcrustal Vrancea source

Based on EUROCODE 8 and UBC-1997 codes requirements, predictive GIS mapping of *PGA* produced by Vrancea earthquakes is herein illustrated for 10% probability of exceedance in 50 yr (i.e. mean recurrence interval $\overline{T}$= 475 yr), Figure 1. The values on the map represent $(m+1.5\sigma)$ attenuated values. That gives for Bucharest PGA_{475yr}=0.42g. The map containing $(m+1.0\sigma)$ values changes to PGA_{475yr}=0.32g for Bucharest.

Table 1: Regression coefficients inferred for Equation 4 [Lungu *et al*., 1998a]

	c_1	c_2	c_3	c_4	σ_{lnPGA}
Bucharest sector	0.500	0.999	-0.471	-0.004	0.405
Complete set of data	3.598	0.971	-1.022	-0.005	0.473

2. CHARACTERISTICS OF EXISTING BUILDING STOCK IN ROMANIA

2.1 Building stock of Bucharest

The classification of the existing building stock in Bucharest was based on the 1992 Census data, Table 2. The data was processed at the Technical University of Civil Engineering, Bucharest, in the framework of the Grants 155a/1996 and 156/1997 provided by the Municipality of Bucharest. According to our criterion of classification, the periods of buildings construction were classified according to the period of validity of Romanian seismic codes: before 1945, 1945-1963, 1964-1970, 1971-1977, 1978-1990, after 1990. This criterion of classification of buildings was later adopted by the Ministry of Public Works and Urban Planning (Governmental Order Nr.6173/NN/26.09.1997). Existing housing units (apartments) in Bucharest (780000) were also classified according to the above criterion for the Understanding Urban Risk Around The World UN RADIUS related Project.

Table 2: Classification of buildings in Bucharest, according to their period of construction

Number of storeys	Number of buildings	Period of construction / *Code for earthquake resistance of structures*							
		until 1900	1901-1929	1930-1945	1946-1963	1964-1970	1971-1977	1978-1990	1990-1995
		-	-	*P.I. - 1941*	*I. - 1945*	*P13 - 63*	*P13 - 70*	*P100 - 81*	*P100 - 90*
1-2	95484	5562	16205	27275	30524	8413	4391	2893	221
3-7	7514	315	1255	2146	979	804	782	1214	19
>8	5283	41	95	164	378	645	1072	2854	34
Total	108281	5918	17555	29585	31881	9862	6245	6961	274

2.2 New building structures in Romania

The construction of the new buildings in Romania was based on standard projects. In Bucharest, the apartments built using standard projects represented more than 80% of the total number of apartments built in 1987. Based on Institute Project-Bucharest data (1987) and on the State Committee for Municipal Councils data (1986-1989), the distribution of types of new building structures in Bucharest versus the rest of Romania is given in Table 3. One can note the very different architecture of the two relative frequency histograms.

Table 3: Frequency of the new structure types in Romania [Lungu *et al*., 1998c]

Structure fundamental period T, s	Type of structure	Number of storeys	Relative frequency, % of the buildings in:	
			Bucharest, 1987	Romania without Bucharest, 1986-1989
≤ 0.15	Shear walls	5	14	41
0.15 - 0.3	Shear walls	5	3.5	23
0.3 - 0.45	Shear walls	9	47.5	14
0.45 - 0.6	Shear walls	9-11	23	9
0.6 - 0.75	Shear walls	11	4	8
0.75 - 0.9	Frames	10	1	2
0.9 - 1.05	Frames	10; 11	5	-
1.02 - 1.2	Frames	> 11	2	-

2.3 Identification of building period

The fundamental period of 82 RC buildings and 36 masonry buildings built before the World War II was measured in Bucharest by the Building Research Institute (INCERC) in the years after the great 1977 earthquake. Regression results for those periods are recently computed [Lungu *et al*., 1999] and are given in Figure 2.

Regression results for computed fixed-base (transverse & longitudinal) fundamental period of the most frequent new RC buildings designed by IPB (Institute Proiect-Bucharest) and IPCT (Institute for Design of Typified Buildings) during the period 1987-1990 are also presented in Figure 2. The data (transverse & longitudinal period data) was collected from 23 shear wall buildings and 17 framed buildings [Lungu *et al.*, 1998c]. We also represented in Figure 2 the period formula for framed structures recommended by the EUROCODE 8:

$T=0.075(H)^{3/4}=0.075(2.9\text{m}\cdot N)^{3/4}$; H - building height;   2.9m - usual story height in Romania   (5)

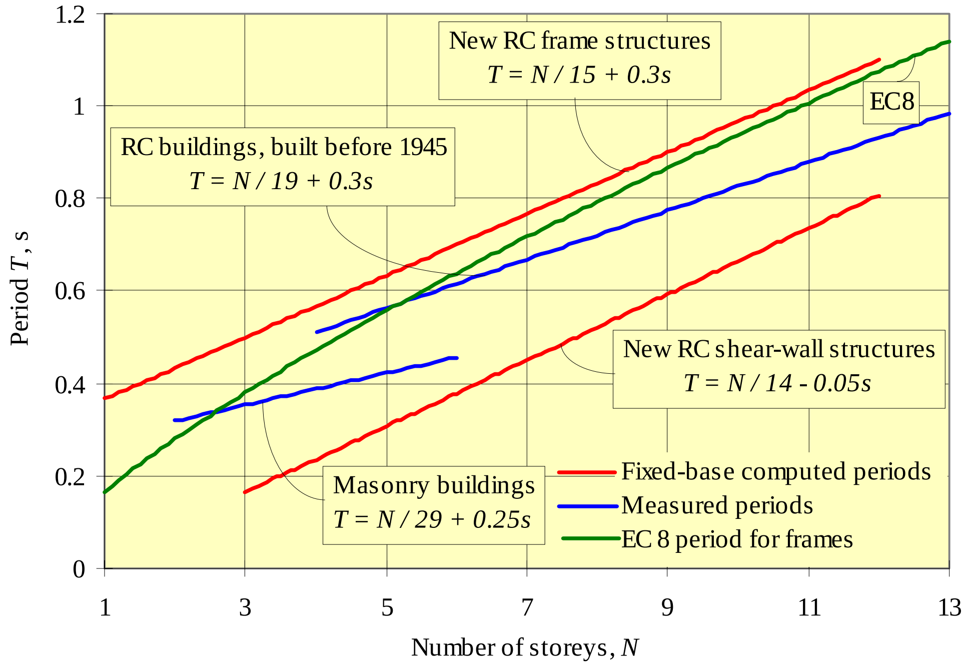

Figure 2: 84 % percentile values for fundamental period of existing buildings in Romania

The increase of the period of tall RC buildings in Bucharest after the 1977 earthquake can be described by the ratio of the periods measured before and after that earthquake. The mean and the mean plus one standard deviation values of the period ratio were determined as being 1.25 and 1.45, respectively. The statistical study is based on a sample of 46 new *RC* buildings (23 buildings of 8 & 9 storeys and 23 buildings of 10 to 18 storeys).

3. VULNERABILITY ANALYSIS FOR ROMANIA USING HAZUS/FEMA METHODOLOGY

The results which follow yielded from the application to seismic condition and building stock of Romania of the HAZUS Loss Estimation Methodology, prepared by the National Institute of Building Sciences for the Federal Emergency Management Agency (FEMA), Washington, US, 1997. The application was developed for AON Risk Consultants London, UK, a member of AON Group Worldwide Resources.

The most frequent types of existing reinforced concrete and masonry structures in contemporary Romania can be classified according to the FEMA/HAZUS methodology as in Table 4.

Table 4: Building structure types for Romania

HAZUS code		Structure type	HAZUS height range	
			Name	stories
17 18	*C1M* *C1H*	Reinforced concrete moment frames	Mid-rise High-rise	4 - 7 8+
20 21	*C2M* *C2H*	Reinforced concrete shear walls	Mid-rise High-rise	4 - 7 8+
23 24	*C3M* *C3H*	Reinforced concrete frames with unreinforced masonry infill walls	Mid-rise High-rise	4 - 7 8+
34 35	*URML* *URMM*	Unreinforced masonry bearing walls	Low-rise Mid-rise	1 - 2 3+

According to FEMA/HAZUS methodology there are four building damage states or ranges of damage: *Slight, Moderate*, *Extensive* and *Complete*. The quality of seismic design incorporated into existing building stock is modelled by four categories of buildings (levels of seismic design): *Pre-code, Low-code, Moderate-code* and *High-code.* Table 5 provides expert guidance for classifying the vulnerability of buildings in Romania based on building age and seismic zonation map valid during construction of building.
For the most frequent new building structures in Romania, the vulnerability curves were computed using the log-normal model with mean and standard deviation from FEMA/HAZUS Technical Manual. An example is presented in terms of *equivalent PGA* in Figure 3.

Table 5: Guidelines for selection of the damage function for buildings in Romania

MSK intensity, from seismic zonation map	Period of construction of building				
	before 1940	1941 - 1963	1964 - 1977	1978 - 1990	after 1990
VI	*Pre-code*	*Pre-code*	*Pre-code*	*Pre-code*	*Pre-code*
VII	*Pre-code*	*Pre-code*	*Low-code*	*Low-code*	*Low-code*
VIII	*Pre-code*	*Pre-code*	*Low-code*	*Moderate-code*	*High-code*
IX	*Pre-code*	*Pre-code*	*Low-code*	*Moderate-code*	*High-code*

The following two levels of seismic ground acceleration are settled for building design in Bucharest :
(i) Most probable seismic scenario: $\overline{T}$ =50 yr *PGA*=0.2g,
(ii) Worst case seismic scenario: $\overline{T}$ =475 yr *PGA*=0.4g.
The percent of damaged buildings being in between various ranges of damage for the most probable seismic scenario were computed as in Table 6. The mean of the ratio of percent of buildings damaged by 0.4g to percent of buildings damaged by 0.2g is computed from Table 6 and indicated in Table 7.

Table 6: Percent of buildings in between various ranges of damage for *PGA*=0.2g and 0.4g (examples)

HAZUS code		Type of damage	% of buildings in between various ranges of damage for *PGA*=0.2g			% of buildings in between various ranges of damage for *PGA*=0.4g		
			Pre-code	*Low-code*	*Moderate-code*	*Pre-code*	*Low-code*	*Moderate-code*
18	*C1H*	Damage ≤ *Slight*		14	18		2	2
		Slight ≤ Damage < *Moderate*		19	25		4	9
		Moderate ≤ Damage < *Extensive*		35	44		21	41
		Extensive ≤ Damage < *Complete*		21	11		29	31
		Damage ≥ *Complete*		11	2		44	17
20	*C2 M*	Damage ≤ *Slight*		21	33		3	6
		Slight ≤ Damage < *Moderate*		26	33		9	19
		Moderate ≤ Damage < *Extensive*		37	28		35	44
		Extensive ≤ Damage < *Complete*		12	5.5		29	24
		Damage ≥ *Complete*		4	0.5		24	7
21	*H*	Damage ≤ *Slight*		18 *	22		2 *	3
		Slight ≤ Damage < *Moderate*		29	37		10	16
		Moderate ≤ Damage < *Extensive*		37	36		35	52
		Extensive ≤ Damage < *Complete*		13	4.6		31	23
		Damage ≥ *Complete*		3	0.4		22	6
34	*URM L*	Damage ≤ *Slight*	25	19	Not permitted by HAZUS	4	5	Not permitted by HAZUS
		Slight ≤ Damage < *Moderate*	15	21		5	9	
		Moderate ≤ Damage < *Extensive*	26	27		16	22	
		Extensive ≤ Damage < *Complete*	17	13		20	23	
		Damage ≥ *Complete*	17	10		55	41	

* see Figure 3

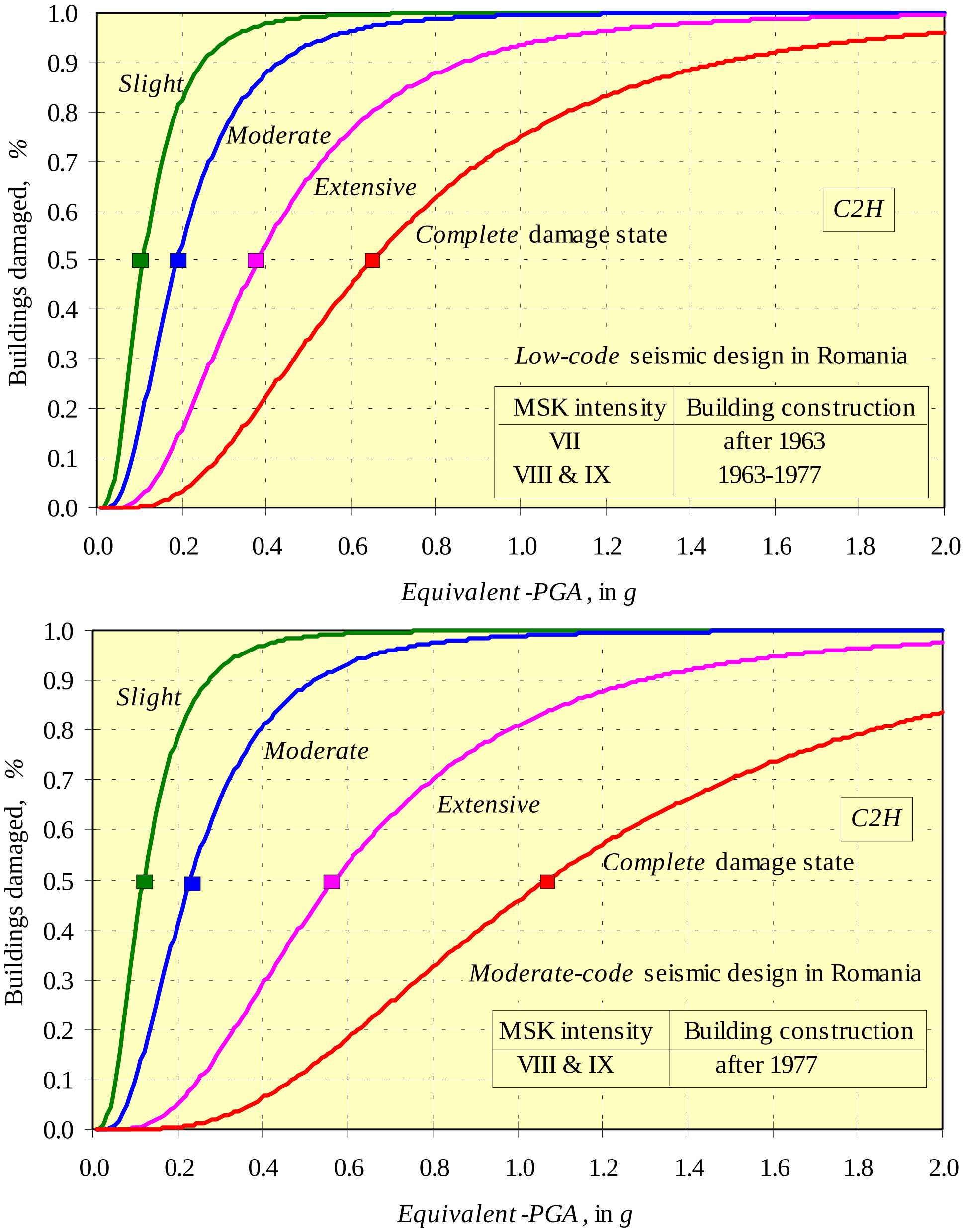

Figure 3: Vulnerability functions for high-rise RC shear walls, based on FEMA/HAZUS methodology

Table 7: Ratio of % of buildings damaged by *PGA*=0.4g to % of buildings damaged by *PGA*=0.2g

Type of damage	Level of seismic design		
	Pre-code	*Low-code*	*Moderate-code*
Extensive ≤ Damage< *Complete*	1.2	1.9	4.1
Damage ≥ *Complete*	3.2	5.2	12.5

4. RETROFITTING OF THE SEVERELY DAMAGED BUILDINGS IN BUCHAREST

A reference source for earthquake losses in Romania is the World Bank Report No.P-2240-RO, 1978 estimation of losses after the March 4, 1977 Vrancea earthquake: 2.05 Billion *$* (i.e. 1.4 Billion *$* general building stock, 0.4 Billion $ indirect economic loss, etc.). In that earthquake Romania lost more than 1570 persons, 11300 persons were injured, 35000 families lost their houses, 763 industrial units suffered extensive damage and 32 high rise RC buildings completely collapsed in Bucharest. According to the Government of Romania Order of July 11, 1977, the repairing works done immediately after the 1977 event were intended to provide to the damaged buildings the same seismic resistance they had before the earthquake. That was, of course, a big mistake.

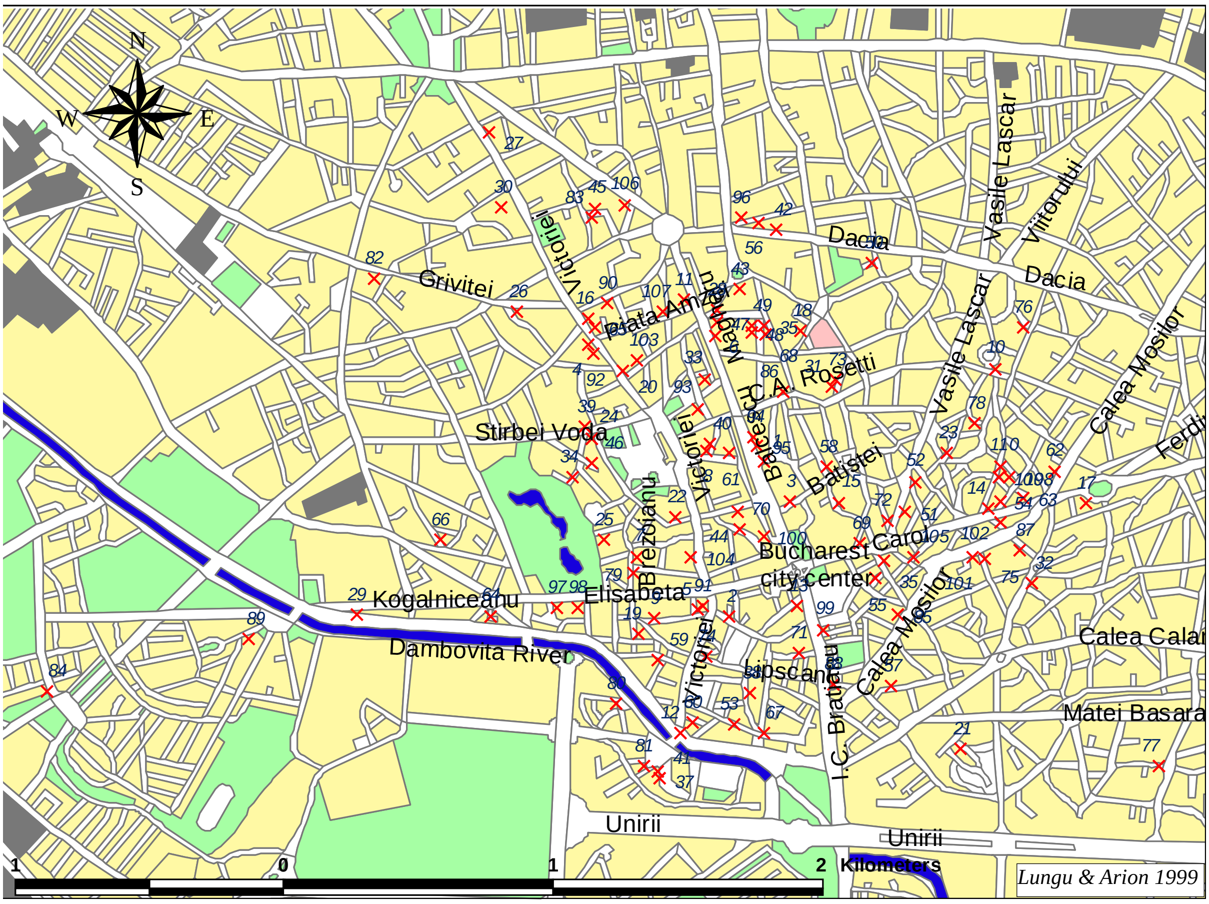

Figure 4: Bucharest central area. Tall RC buildings built prior to 1945 and expertised as having high risk of collapse in case of a strong earthquake ($M_W \geq 7.5$)

The list of the RC buildings collapsed in Bucharest during March 4, 1977 earthquake proved that all but 3 of the collapsed buildings (32) were built prior to the Second World War and generally located in the city centre.

One explanation for the location in the city centre of the collapsed buildings in Bucharest comes from the Plan of Urban Development of the city of Bucharest issued in 1935. It recommends the city center (red and brown zones on the city map) for the tallest buildings within the city, i.e. for buildings having: 6-7 full plus 2-3 setback storeys. Lack of mass vertical-symmetry, lack of structure horizontal-regularity, accumulated damage during the 1940 earthquake, low strength concrete (mean of compressive strength $\leq$200 daN/cm^2), soft ground floor (no masonry walls) due to commercial use of that floor), etc. explain the collapse of all those buildings in Bucharest.

Another explanation comes from the soft soil of Bucharest. In central area of the city (under the Magheru Av.) the 80% clayed soil deposits are located close to the surface and have a thickness of about 17-20 m. Both depth and location of those deposits can explain the collapse of the tallest RC building in Bucharest (Carlton) during the 1940 event and the collapse of 6 other buildings located on or near Magheru Av. during the 1977 event.

Presently, there are several important countermeasures documents aiming at providing safety to strong earthquakes for the general building stock of Romania. The Order No.6173/NN/1997 of the Minister of Public Works claims to the all Municipalities to prepare: (i) the classification of existing building stock with respect to period of construction, structure type, class of seismic risk (I-IV) and (ii) priorities for building expertise and retrofitting. Consequently, the Municipality of Bucharest selected more than 7000 buildings having significant cumulative structural damage and prepared more than 2500 detailed expertise reports.

In December 1999 there are already expertised as having high risk of collapse in case of a strong earthquake ($M_W \geq 7.5$) 110 RC buildings over 5 storeys in Bucharest, Figure 4. However, the total number of vulnerable mid-rise and high-rise RC buildings in Bucharest is as least 300. As an example, in the very central cross-shaped area of about 0.5 km^2 along Balcescu and Carol Av., there are 175 RC buildings with more than 7storeys built prior to 1945.

In August 1998, the Government of Romania adopted a Governmental Ordinance providing, from state funds, about 20 Mill. $ / year for retrofitting the most damaged buildings. The priority list for top of the buildings to be retrofitted is regularly approved by the Commission for Seismic Protection of the Ministry of Public Works. The first list (1999) containing 12 buildings with owners of apartments accepting the retrofitting works (i.e. the leaving the apartments during the retrofitting), was approved last June at the Ministry of Public Works The list contains 7-12 storeys RC buildings built between 1930-1940 having 398 apartments and 45317m^2 total floor area.

CONCLUSIONS

The assessment and reduction of seismic losses in case of earthquakes should be regarded as a collaborative work of state and local governments, insurance industry and engineers. The paper presents steps for the assessment of seismic risk in Romania: (i) probabilistic assessment of hazard, (ii) inventory of exposed building stock in Bucharest, (iii) vulnerability of model buildings and (iv) expertise reports for damaged buildings. The case study is the city of Bucharest since, according to 1977 actual earthquake scenario, the capital city of Romania concentrated about 2/3 of total losses, both due to vulnerability of the tall buildings built prior to 1945 and city's soft soil. That is why Governmental Ordinance HG 597/1998 provides, from state founds, about 20 Mill.US$/year for retrofitting the most damaged buildings in Bucharest. That is why consultance & guidance from international insurance industry is urgently needed. A priority list for the top 12 buildings to be urgently retrofitted, from 110 tall RC buildings expertised as having high risk of collapse in case of a strong earthquake, was established in July 1999.

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