# TOWARDS EARTHQUAKE SCENARIOS UNDER THE CONDITIONS OF ROMANIA

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## SUMMARY

The paper represents an attempt to explore the specific features of the natural conditions, of the various categories of elements and systems at risk and of the complementary data required for a suitable development of earthquake scenarios in Romania. The Vrancea (subduction) seismogenic zone is a peculiar intermediate depth source that strongly affects over 50% of the territory of Romania in case of each high magnitude earthquake. For these areas, the suitable scenario earthquakes should correspond to return periods ranging from some 50 to 200 years, as far as severe or extreme magnitudes are considered. There are some assessments for other seismogenic zones of rather local importance, with longer return periods for relatively high magnitudes. A system of earthquake scenarios is necessary at large scale (national, local/urban, level of some national networks, level of some sectors of the national economic activities etc.) for which some legal duties of disaster prevention exist. Some data concerning alternative possible condensed scenarios are presented. The implications and needs of developing databases and integrated methodological developments are dealt with too.

## CONCEPTUAL ASPECTS AND EXPERIENCE TO DATE

The earthquake scenarios are required first of all by the seismic setting of Romania, which is dominated from the seismological viewpoint by the Vrancea intermediate depth earthquakes (as a rule, depths between 80 and 160 km) that affect with high intensities extensive parts of the territory. The 1940, November 10, earthquake ($M$ = 7.4) and the 1977, March 4, earthquake ($M$ = 7.2) (where $M$ represents Gutenberg-Richter magnitudes) produced considerable losses, reaching in this century disaster levels [Sandi, 1999, Georgescu and Kuribayashi, 1992]. The crustal seismogenic zones are characterised by less intense activity and by reduced focal depths, such that their importance is rather local, but, nevertheless, some of them can generate locally very high intensities. The level of seismic risk is definitely high, since the seismic areas cover 65% of the territory, including almost 75% of population (over 60% in strong seismic zones), in 38 counties the reference intensities are VII - IX and only in 3 counties the reference intensity is VI.

The impact of a major Vrancea intermediate depth earthquake, affecting simultaneously ca. 50% of the territory, may produce strong direct damage, as well as indirect losses in other areas of the country, thus leading to a national disaster. The specific pattern of seismic hazard, represented by the two main categories of earthquakes as well as the differences between the distribution and vulnerability of elements at risk in different zones, requires alternative scenarios. Therefore, there is a need of different scenarios, from national ones to scenarios on zones/localities, as well as scenarios for socio-economic sectors and lifelines/systems.

The forecasts in probabilistic terms concerning the likelihood of strong intermediate and shallow earthquakes during the next decade [Constantinescu and Enescu, 1985, Sandi and Marza, 1996] and the situation of vulnerability and risk urge a faster development and use of alternative earthquake scenarios, to be used as a tool for tailoring disaster prevention strategies [Georgescu, Popescu, Sandi and Stancu, 1999]. The paper presents some background issues and preliminary case studies for creating a system of earthquake scenarios for Romania. The previous preparatory studies for a specific scenario for Bucharest are convergent with this study [Georgescu and Sandi, 1998].

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The paper relies on a system of basic concepts to be used for developing earthquake scenarios and risk analysis, presented elsewhere [Sandi, 1986; Georgescu and Sandi, 1998, Sandi, 1999]. The basic entities to be considered are: *elements at risk*, *seismic action* and *seismic hazard, damage and loss*, *vulnerability of elements at risk*, including reference to the *exposure* of elements at risk, *seismic risk.* An intended outcome of analyses is an *earthquake scenario* with some forecast of expected potential losses. The most advanced earthquake disaster scenarios in the world rely on the studies from few countries. In USA, [Steinbrugge and Algermissen, 1990] different loss estimations are available for California, Utah etc. and ATC-13/1985 presented model loss evaluation methodologies used in USA by FEMA [ATC, 1985]. The RMS's IRAS Expert System was used in USA for earthquake scenarios for the San Francisco Bay, the Los Angeles Area, the Tokyo zone [RMS, 1995]. In Portugal, Mendes-Victor and Oliveira (1984, 1994) developed comprehensive earthquake scenarios for Lisbon, while in Italy, South America and New Zealand other earthquake scenarios were developed. In Japan, the scenario earthquakes are chosen usually similar with the historical ones (Nobi, 1891, Kanto, 1923); advanced econometric loss evaluation was introduced in scenarios by Kuribayashi, Ueda & Tazaki (1985).

The international experience at hand recommends that a reasonable choice of scenario earthquakes shall take into account historical earthquakes as well as seismic hazard analysis. Several scenario earthquakes can be selected, as they shall be different in what concerns source location (possibly a random position of epicenters), magnitude, intensity, return period/exceedance or nonexceedance probability, directionality, local characteristics of motions etc.; thus, the scenario events may represent different combinations of parameters.

Even without adopting a sophisticated approach, it is suitable to keep in view, for an earthquake prone area, several scenario earthquakes, coresponding to different severities (and return periods). It was considered appropriate for this purpose to refer to three levels of severity:

-a *moderate* earthquake, to which it would be possible to react basically using just own resources of towns, cities etc. affected;

-a *severe* earthquake, to which it would be possible to react mobilising most of the domestic resources;

-an *extreme* earthquake, to which it would be no longer possible to react using only domestic resources and which would involve the need of massive international aid.

The three levels referred to will differ (if they exist) as a function of the features of activity of the different seismogenic zones.

Some suggested relationship to alternative return periods, are discussed further on, taking into account, besides seismological aspects, also aspects related to the potential impact of these earthquakes.

At this place one might state just that scenarios related to moderate earthquakes should be of interest primarily for local authorities (as far as, within their area of responsibility there are no high risk sources which could turn secondary hazards into disasters), while severe and extreme earthquakes should be a concern for authorities at all levels.

The technological disasters in combination or addition with earthquake effects or other natural hazards (Na-Tech Disasters) shall be considered in a specific way in scenarios. A set of scenarios, expressed in terms of different outcomes (earthquake engineering and engineering seismology, social and economic impacts) will answer to different needs of users. Each of these approaches was calibrated abroad on the basis of local data, therefore only the overall structure can be used as an example; the hazard and attenuation laws, vulnerability etc. shall be considered for the unique situation of Romania. There is a number of Romanian research studies and published papers in this field [Georgescu, 1986, Sandi and Georgescu, 1988, Georgescu, Popescu, Sandi, Stancu, 1999, Sandi, 1999 ].

Presently, the characteristics of the earthquake scenario represent in case of Vrancea earthquakes perhaps the most certain component of basic data, given the work of [Sandi and Stancu, 1995, Sandi and Floricel, 1995].

## SCENARIO EARTHQUAKES FOR ROMANIA

### Seismic Sources and Intensity Distribution Patterns

According to well established knowledge, the intermediate earthquakes generated in the Vrancea seismogenic zone are by far the most important among the earthquakes affecting Romania. According to data at hand [Balan et al, 1982] more than 95% of the energy released in the average per century in the territory of Romania is related to these earthquakes.

The seismogenic zone of intermediate Vrancea earthquakes has specific patterns as well as some regularity features of occurrence (macroseismic field, seismic activity after the main shock, cyclicity etc.), that are useful for confidently deriving isoseismal maps for scenarios:

- at surface level, the epicentral area of intermediate and normal depth earthquake can be bordered within two oblique rectangles, slightly shifted, sized at 60/40 km for the magnitudes over $M$ = 4.0 , for 1901-1979 [Radu, 1982, Balan, Cristescu and Cornea, 1982]; other data for 1900-1980 indicated an ellipse-like area of epicentres, with some irregular extensions towards NE, SW and SE;

- the area presenting maximum epicentral intensities is mapped as an obliquely placed and deformed ellipse; isoseismal areas, which tend to follow the bow of Carpathians) are strongly stretched towards NE-SW (N45$^o$E-N225$^o$E) for some earthquakes (1940, 1977) but there are also other historical data on isoseismal ellipses slightly “turned” anti-clockwise (the "great earthquake" of 1802) or even placed perpendicularly against the usual directions;
- the focal depth at over 100 km for strong earthquakes; the increase of magnitude appears to be positively correlated with the increase of depth [Lungu, Cornea and Nedelcu, 1999];mailto:ad@ncimii;
- the rupture process in a multishock event (3 main shocks in 1977), the rupture plane (reverse fault) being oriented N 40$^o$ E and dipped 70$^o$ to NW, under the Carpathians;
- the territory of Romania is affected in case of every intermediate depth earthquake with $M \geq 7{,}0$ by intensities of $I \geq$ VII *MSK* on more than 50% of its area (ca. 100,000 km$^2$); such earthquakes are felt at very large distances (Moscow, St. Petersburg, Istanbul); sometimes, local culminations of intensities can be recorded at epicentral distances of 200-300 km.

In all other epicentral zones of Romania the occurrence of earthquakes (normal earthquakes) can be related only to intracrustal fractures, with a strong tendency of concentration in several zones. The superficial and crustal earthquakes can be:

- polykinetical earthquakes (with numerous aftershocks) in Fagaras, Banat, Dobrogea, Somes;
- monokinetical earthquakes (a single shock) in the center of Transilvania, Mures and Tarnave Rivers area, and Pre-Balkan earthquakes (foci in Bulgaria that affect some areas in the North of Danube);

These earthquakes are moderate and generally have a low-energy content, but the energy concentration can be locally quite high. The recurrence intervals for significant earthquakes tend to exceed 100 years, so return periods are higher than for strong Vrancea earthquakes and swarms of earthquakes occur in the periods of increased activity.

- the depths are of 5-30 km and the magnitudes are close to 6.0 for Banat earthquakes (Banloc 12.07.1991, $M$ = 5.7, Herculane 18.07.1991, $M$ = 5.6, Voiteg 2.12.1991, $M$ = 5.6 etc.), while intensities are of $I$ = VII-VIII *MSK;* magnitudes may be $M > 7$ for Dobrogea earthquakes: 31.03.1901, $M$ = 7.2, with intensities $I_0$= X *MSK*, $I$ = VII-IX *MSK* in South Dobrogea; maximum magnitudes are $M_s$ = 6.5 ($I_o$ = VIII) in the Fagaras Mountains (1916); a moderate seismic activity (generally $I_o$ = VII and $I$ = V-VII) affects the rest of territory;
- the intensities of VII-VIII *MSK* can affect areas of some tens up to hundreds of square kilometers, with local peaks of damages.

**Recent Hazard Assessments and Earthquake Forecasts**

*Vrancea earthquakes***.** The remarkable stability of the activity of the Vrancea seismogenic zone over one millennium made it possible to determine with a fair credibility a recurrence law (corresponding to the Poissonian model) considering the Gutenberg-Richter magnitudes observed on an instrumental basis in this century. Estimates on local hazard were conducted for various localities using Cornell’s approach, with a full convolution between the magnitude recurrence law and the (random) attenuation law [Sandi and Stancu, 1995]. The recurrence laws presented elsewhere [Sandi, 1999] allowed to derive the return periods of some magnitudes as in Table 1.

**Table 1. Return periods of Vrancea magnitudes**

| $M$ | 6. | 6.5 | 7. | 7.2 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 |
|---|---|---|---|---|---|---|---|---|---|
| $T_{ret.}$(yrs) | 6. | 14 | 32 | 46 | 82 | 126 | 234 | 650 | 4600 |

For the same high magnitudes, other authors [Lungu, Cornea and Nedelcu, 1999] have obtained different values, which are in general more conservative (shorter return periods).
The outcome corresponding to the City of Bucharest leads (on the basis of probabilistic hazard assessment referred to) to the intensity recurrence presented in Table 2.

**Table 2. Intensity recurrence for Bucharest**

| *MSK* intensities | VII | VIII | IX |
|---|---|---|---|
| $T_{ret.}$(yrs) | 20 | 50 | 200 |

There are convergent opinions that a new major earthquake, perhaps destructive, should occur during the next decade. Its magnitude could be easily somewhere between 7.0 and 7.5 [Sandi and Marza, 1996]. This does in no way exclude the occurrence of important earthquakes in other zones.

*Crustal earthquakes.* For the Fagaras zone, the seismic input was considered from two seismogenic sources (crustal and intermediate) considering various alternative assumptions on the contribution of local active faults and circular azimuthal radiation, neglecting local geological conditions. Some outcomes useful for developing earthquake scenarios are presented in the Table 3.

**Table 3. Return periods of Fagaras magnitudes**

| $M$ | 6.25 | 6.5 | 6.75 | 7.0 | 7.25 |
|---|---|---|---|---|---|
| $T_{ret.}$(yrs) for 100% contribution of the local fault | 108 | 153 | 230 | 500 | >2,500 |
| $T_{ret.}$(yrs) for Vrancea source | 10.8 | 15.3 | 21.6 | 30.6 | 46 |

As far as other faults were considered, the return periods of hiogher magnitudes are considerable higher.

For the Banat zone, four potential seismogenic source zones were considered. Some estimated outcome, useful for earthquake scenarios, is presented in Tables 4 and 5.

**Table 4. Return periods of Banat magnitudes**

| $M$ | 5.0 | 5.5 | 5.75 | 6.0 | 6.25 |
|---|---|---|---|---|---|
| $T_{ret.}$(yrs) | 10 | 25 | 44 | 112 | 1320 |

**Table 5. The recurrence of maximum intensities for two cities of Banat**

| City | Intensities, with return periods (yrs) | | | |
|---|---|---|---|---|
| | 20 | 50 | 100 | 200 |
| Arad | 5.6 | 6.4 | 7.0 | 7.5 |
| Timisoara | 6.0 | 6.7 | 7.2 | 7.7 |

One can remark that for return periods of 100 years, the maximum values of intensities exceed the intensities given by the zoning map in force for Timisoara, and for Timisoara and Arad in case of return period of 200 years, respectively.

**Scenario Earthquake Patterns**

Based on the previous data, one can consider adequate that the hypotheses for the seismic input should include:

- the scenario earthquake produced by a local source able to affect the analyzed zone;
- the scenario earthquake produced by an intermediate source of Vrancea zone.

The scenario events having different return periods are to be selected using historical, engineering or social significance criteria. The alternative assumptions on seismic input can be related to: alternative magnitudes, radiation patterns, predominant frequencies of seismic motion etc. The randomness of hazard and vulnerability characteristics will be reflected also in the output of performance of elements at risk.

*For the Vrancea seismogenic zone***,** one can suitably consider alternative scenario events corresponding to the (Gutenberg-Richter) magnitude range from 7.2 (severe earthquakes) to 7.6 (extreme earthquakes), i.e. to return periods in the range of 50 to 200 years. Even if one considers only two magnitudes, the system of scenarios may become quite sophisticated in case one considers alternative radiation patterns, as put to evidence by historical and instrumental experience.

*For crustal seismogenic zones*, the similitude with historical earthquakes can be put into value primarily for the Banat zone, for which there exist rather rich catalogues of earthquakes for the most recent centuries. The magnitudes could range from 5.6 to 6.0, in case one intends to cover the same domain of return periods as that referred to above.

The international design practice is using, as known, a somehow standardised return period of 475 years in earthquake engineering analyses. The harmornisation with such a requirement implies some comments: according to information at hand, the difference between magnitudes with return periods of 200 and of 500 years respectively is small and , also, uncertain, given the unmcertainties raised in the range of highest magnitudes. So, a higher limit in the range of 200 years appears to be perhaps more suitable. The same is not true for intensities, in case scenarios are to be developed at the level of some sites or localities, since for intensities the differences from 200 to 500 years, derived as e.g. in [Sandi and Stancu, 1995] appeared to be relevant.

Taking into account the aim of the earthquake scenarios as well as the higher level of uncertainty of other categories of data, the use of return periods between 200 and 500…600 years are equivalent in fact to the choice of an earthquake as the one of 1802 with M=7.6-7.7.

## VULNERABILITY AND EXPOSURE OF ELEMENTS AT RISK

### Buildings, Localities, Population, Social and Economic Facilities

In Romania, a share of 60-75% of fixed assets is located in seismic zones producing an industrial and agricultural output of 70-80% of the country economic achievements. Bucharest concentrates 12.9% of the country's fixed assets and provides 11.3% of national industrial output. Out of the country's total number of employees of 6.5 million, a ratio of 75% is in seismic zones. Over 45% of the electric power plants, the main high-tension transmission lines, the main railroads, national highways and main roads, strategic bridges, gas pipes, water supply and sewage ducts are located or are passing through seismic zones of VII-IX MSK intensities.

Earthquake resistant design codes were put in force in 1942 (provisional rules), 1963, 1970, 1978 and 1981, 1991/1992. A parametric analysis performed in INCERC for Bucharest [Sandi and Floricel, 1994] showed that the collapse probabilities for various exposure periods affecting the pre-1940 categories of buildings are by far intolerable. Other building categories, infrastructures and lifelines may present also disaster potentials. During the 1992 census, a number of 4,478,655 buildings with 7,659,003 apartments were recorded, out of which 1,160,946 buildings (25.9 %) were built before 1944. The category which presents an obvious interest for earthquake scenarios is that of tall buildings, out of which 6,864 buildings (8.5%) were built before 1944, 42,689 buildings were built between 1945 and 1980 and 38.6% were built between 1981 and January 1992. Although the share of pre-1940 (1944) high-rise buildings seems to be not a matter of concern, the large number of exposed inhabitants, representing potential victims in case of collapse, makes them a major factor of risk, especially in Bucharest. The next in range should be considered other tall buildings erected until 1977, according to some repetitive designs; their weaknesses concerning the lack of ductility and excessive lateral drift.

According data at hand, the structural systems are represented by reinforced concrete frames and shear walls (27.64%), masonry with concrete floors (14.52%), masonry with wooden floors (21.82%), wood (10.33%), adobe and paddle work (25.68%). The reinforced concrete high-rise structures have been used mostly in urban centers, while masonry, wood and earthen buildings are still dominant in old districts of towns and in villages.

### Vulnerability of Elements at Risk and Population Exposure in Urban and Rural Localities

*Elements at risk*. In Romania, there are 260 towns (out of which 57 cities) with 12,411,174 inhabitants and 2,686 rural communities with 10,196,446 inhabitants (July 1,1996); a share of 71% of urban population lives in towns having over 50,000 inhabitants, out of which 26,1% live in towns with 200,000 to 1 million inhabitants; Bucharest has 16.4% of the total urban population (or 9% of the country's population).

Thus, the urban population represents 54.9% and the rural population represents 45.1%. More than 40 densely populated towns are located in highly seismic zones (intensity over VII). The overall density of living is higher in counties exposed to the Vrancea seismogenic zone: City of Bucharest- 8935.4 inh./km$^2$, Prahova- 184.1 inh./ km$^2$, Ilfov- 174.2 inh./ km$^2$, Galati- 143.7 inh./ km$^2$, Brasov- 118.9 inh./ km$^2$, while the average country density is 94.8 inh./ km$^2$.

*The vulnerability of localities* can be analysed as related to the following main categories: rural, recently urbanised, urbanised during the last 50 years and historically grown towns whose built stock is urban, including pre-1940 high-rise buildings.

One can assume that the urban population is exposed to higher risks arising due to the presence of buildings and industry. About 71% of the total population is at risk due to natural and technological hazards, including earthquakes.

*Urban localities* expose to the seismic hazard of the Vrancea zone ca. 35% of the total population or 66% of the whole urban population.

In other areas, that are prone to superficial and crustal earthquakes, over 10% of the country's population can be considered at risk, in two important zones: mainly Banat and the Tarnave Plateau in Transilvania. A number of 2,872,162 inh. representing 12.7% of the total population or 23.1% of urban population lives in zones considered exposed at intensity VI.

*Vulnerability of buildings.* The data available are related mainly to the earthquake of 1977 March 4 and represent histograms of damage degree and vulnerability functions for few categories and classes of buildings in Bucharest and Jassy. [Sandi, 1986]; the cumulative effect of subsequent earthquakes of 1986 and 1990 as well as other new patterns of selected scenario motions should also be considered in damage scenarios [Sandi 1998].

*Secondary vulnerability (of inhabitants).* Some limited data on mortality and morbidity during Vrancea earthquakes are available. One can assume an overall correlation with the vulnerability of buildings, as follows:
-a quite reduced vulnerability for occupants of traditional low-rise, individual houses, especially in the areas exposed to Vrancea intermediate earthquakes (excepted some buildings, in epicentral areas);
-a very low vulnerability (as a matter of fact there were no reported casualties) for inhabitants in large panel buildings and a low vulnerability for occupants in some rigid structures designed according to the code after 1963, with major improvements after 1977;
-a higher vulnerability for the occupants of high-rise reinforced concrete buildings, erected before 1940, and a lower but significant vulnerability in structures designed between 1940 and 1977, with soft ground floor, slender frames etc.; excessive lateral drift may be a cause of casualties;
-a higher psychological resistance and a positive behaviour for inhabitants that were exposed during their life at Vrancea earthquakes as compared to those living in areas prone to shallow earthquakes.

## CATEGORIES OF EARTHQUAKE SCENARIOS

### A System of Earthquake Scenarios Suggested for Romanian Conditions

The system suggested includes three levels of analysis and three categories of scenarios, respectively (depending upo available data and their level of detailing). The system takes into consideration several seismological hypotheses based on several classes of possible seismic motions; they are different, depending upon seismogenic zone, depth of the source, spectral content and return periods as well as depending upon the specific features of elements at risk available in selected zones.
The earthquake scenarios for localities shall refer to:
-defining the type of scenario as a function of scale and of general urban or rural patterns;
-defining, identification and analysis of scenario earthquakes (including main and secondary hazards, other local conditions etc);
-identification and inventory of elements at risk (categories, number, specific vulnerability), critical and high risk facilities inside and outside the habitat area; establishing hypotheses on the topology and potential links in negative effects occurrence at community scale;
-scenario analysis under different hypotheses, including loss assessment;
-indicators for characterisation of losses as: limited or major disaster, as a function of ratios to the resources and capacities for reaction, relief and compensation;
-conclusions concerning the extent of preventive interventions in the respective community.
*The earthquake scenario for socio-economic sectors and networks/systems with geographically spread components (life-lines)* should refer to:
-defining the analyzed sector or network/system (components and their role in usual service);
-defining, identification and analysis of scenario earthquakes (including main and secondary hazards, other local conditions) in critical points of the sector, network or system;
-inventory of components and specific vulnerability for critical components (including topology analysis);
-scenario analysis for sector or network/system; assessment of relationship between direct damage and indirect losses, the potential for chain disasters, assessed losses and function disturbances;
-indicators for characterization of losses and impacts as limited or major disaster, depending upon ratios to the resources and capacities for reaction relief and compensation;
-analysis of the capacity of reaction and loss compensation (redundancy characteristics) inside and outside sectors or systems, in emergency and recovery period, respectively;
-conclusions concerning the extent of preventive interventions in sector or network/system.
*The earthquake scenarios at regional, national/macroseismic and macrosocial scale* should refer to:
-the chosen approach: summing-up, extrapolation, econometric methods;
-defining, identification and analysis of scenario earthquakes (including main and secondary hazards, other local conditions);
-inventory of significant macrosocial components, critical socio-economic units of some sectors at local, regional and national scale, data for input-output matrices;
-distribution or concentration of possible losses and their impact on different time spans;
-analysis of reaction capacity;
-indicators for characterization of losses and impacts as: limited or major disaster, or, in extreme situations “catastrophe”, requiring major international aid and assistance:
-strategic public reactions required for immediate, mid-term and long-term for prevention, intervention, recovery;
-conclusions concerning the necessary national strategy and public policies.

As far as specific data exist, the use of Monte-Carlo techniques combined with some parametric scenarios can provide a link with the risk assessments.

**Case studies: Condensed Scenarios**

A preliminary study (not published to date) was related to a very condensed scenario at national scale. The isoseismal scenario map was tailored starting from the present zoning maps in force, with some adjustments. The map can be regarded as a combination of 1940 and 1977 isoseismal maps, with a scenario return period of 100 years.

Only the distribution of apartments at risk was approximated on assessed intensity zones from VI to IX and some monetary vulnerability functions, for different material and age categories have been considered. The casualties were differentiated for urban and rural buildings and calibrated with local data.

The loss assessment provided a damage pattern picture dominated by the economic loss in traditional masonry buildings, still dominant numerically in urban and rural localities. The economic loss was assessed using three alternative values for apartment prices, resulting a loss varying from 7.45 to 17.0 billions current US$.

For comparison, the 2 billions of US$ of loss assessed in the past for the 1977 earthquake (1 billion reported and 1 billion most probably neglected, especially for individual buildings) can be discounted to be presently equivalent to 3.3-3.5 billions for residential buildings only (the authors believe that the overall losses of US$ 2 bill. assessed for the 1977 event were considerably underestimated in case one takes into account the longer term follow-up of the earthquake).

The result related to the 100 yr. return period referred to can be also assigned to the chosen scenario earthquake map (more severe than in 1977) and to the market value assigned to all apartments, which is now different from the situation of 1977, under the former political regime.

The casualties assessment lead to a 2,855 dead and 5,858 injured in urban apartments, especially in reinforced concrete buildings, as well as to 350 dead and 2,000 injured in rural houses.

The second case study in course concerns the City of Bucharest and besides the published data [Georgescu and Sandi, 1998], one can remark that the exposure characteristics were obtained from general statistical data. The present approaches try to create some proxy vulnerability functions adequate for such data.

## CONCLUSIONS

The activity of the intermediate depth and crustal seismogenic source zones and the specific features of elements at risk require the use of alternative earthquake scenarios in Romania. This peculiar pattern has consequences to be reflected in an integrated approach in scenarios.

The *moderate scenario events* should correspond to a magnitude of 6.8 to 7.0 earthquake in case of intermediate depth earthquakes (return period of about 25 to 30 years) and to a magnitude 5.6 to 5.8 earthquake (about similar return period) for the Banat region.

The *severe scenario events* should correspond to a magnitude of 7.2 (like in 1977) or, perhaps, 7.4 (like in 1940) for Vrancea earthquakes. A magnitude 6.0 could be considered for the Banat region.

The *extreme scenario events* should correspond to a magnitude around 7.6 (like, probably, that of the" great earthquake of 1802") for Vrancea earthquakes.

The Fagaras area raises some special problems, since it is related to the secondary hazards due to the existence of the tallest arch dam in Romania (165 m height). According to data at hand, the ciclicity of Fagaras earthquakes is high: a clear-cut return period of 80 to 85 years for magnitudes 6.0 to 6.5 was observed during last centuries and the dam referred to is located in the epicentral zone of the most recent strong event ($M$ = 6.5) of 1916. The South Dobrogea area raises also special problems, due to the ocurrence of $M$ = 7.2 earthquake of 1901 and to the lack of a rich historical record, to be correlated with the history of the ancient Greek city of Callatis, whose Eastern half lies currently at the Black Sea bottom.

The integrated system of earthquake scenarios suggested for different levels and scales may contribute to the progress in losses forecasting at the country scale. For the time being, the scarcity of engineering data on elements at risk, on their resistance and evolutionary vulnerability, or exposure, impose the use of condensed scenarios at each level of legal authority. The insight on prerequisites of these alternative scenarios puts into evidence the availability of basic concepts, methodologies and data for seismic hazard and vulnerability analysis. Some general and specific natural and seismic conditions, recurrence laws for magnitudes and intensities obtained in INCERC can be used, as well as data on vulnerability and risk to serve this goal at the beginning of the next century.

There is a need of data and methodological developments on potential links between the vulnerability of individual items within the chains and trees of events, especially for natural-technological disasters and in case of lifelines and systems. The final forecasts of impact in socio-economic terms requires a transfer of knowledge between specialists concerned.

The national preliminary case study referred to has shown that the extent and value of damage and the related casualties can be much higher than in 1977. The ongoing research on the Bucharest scenario proves the potential of damage concentration due to higher exposure in pre-1940 buildings.
The use of earthquake scenarios may rise the public awareness and provide a sound basis for comprehensive strategies and policies in earthquake disaster management in Romania.

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