Engineering and architectural solutions for sustainable and multi-hazard management of urban seismic risk in Romania

E.-S. Georgescu
The National Research and Development Institute URBAN-INCERC, and European Center for Buildings Rehabilitation, ECBR, Bucharest, Romania

M. S. Georgescu
University of Architecture and Urbanism „Ion Mincu", Bucharest, Romania

SUMMARY:
The sustainable management of risk is a component of sustainable development and the existing buildings and urban fabrics vulnerability, including infrastructures, are the most visible risk determinants. In order to evaluate the threshold between the vulnerability and resilience of a city, the multihazard approach (to arthquake, landslides, floods, extreme winds, gas explosions and terrorist actions), presumes engineering methods, while architectural and sustainability criteria are expressed in other terms. In Romania, the Vrancea intermediate earthquakes that may affect with high intensities ca. 50% of the territory and more than 40 densely populated towns. The paper will evaluate the likelihood of urban disasters and multihazard solutions, function of strengths and weaknesses of each generation of buildings, with a case study of Bucharest City, where neoclassical low-rise houses and high-rise buildings, made of masonry and/or concrete, are challenged by the new financial-banking or commercial centers using steel and curtain walls.

Keywords: *multi-hazard, urban vulnerability, sustainable risk management, Vrancea diasasters, Romania*

1. INTRODUCTION

In order to evaluate the threshold between the vulnerability and resilience of a city, the available tools are different. The multihazard approach (referring to earthquake, landslides, floods, extreme winds, gas explosions and terrorist actions), presumes engineering methods, while sustainability criteria are expressed in other terms. Engineering criteria of the „4R" approach are in many cases applied only to structures, because technical issues are divergent of those from architecture and much more of those in urbanism, where the system is spread in a territory (Bruneau, 2007, Ettouney et al 2007).

This approach is challenged by the most ambitious goals of the „Total Disaster Risk Management Approach" or a holistic approach (Guzman, 2001, Nishikawa, 2003). In this context, it is of fundamental importance to make hazard mapping, risk and vulnerability assessments. This is not an easy task. Since the urban risks are related to an apparently static fabric but with historical roots and evolution, with living functions, the question which is valid for any approach is how to make preventive interventions without hampering the current activity. The complexity of urban infrastructure must be evaluated with due care in this respect, and affordable solutions may depend also on the socio-economic level of development. However, recent earthquake disasters have proven that impacts are not directly related to the size of motions and technical development level and suprises may occur:

- Kobe, Japan (1995) - disaster was dominated by extensive fires, in a country with a cult of fire prevention; damage to concrete structures was extensive in a country with tight quality control;
- L'Aquila, Italy (2009) - urban evacuation of a city with some 70,000 people was largely caused by mass falling down of ceramic blocks of external nonstructural walls, in a country with historically advanced engineering and architecture;

- Christchurch, New Zealand (2010 and 2011) – a city was evacuated because of numerous damages to old masonry houses, but the death toll was caused mainly by the collapse of 2 structures of the 1960's, in a country which is champion in earthquake engineering and codes enforcement;
- The Chile, Maule (2010) - damage of some recently built high-rise structures was caused by architectural configurations that have jeopardized the very detailed engineering design of shear-walls, no matter if the school of engineering is a long-term promoter of advanced approaches.

Earthquakes may have some patterns to go in line with other extreme actions but the society is not an easy partner to make changes. Thus, the need to consider some new types of hazards in urban landscape were considered as against the architectural freedom and only after 2001 the terrorist threats were accepted in urban planning, at least for a debate. On the other hand, the standard EUROCODE 1 requires that a structure be protected against a fires, blasts, impact or human errors just when cause-effect is „disproportionate". The code requirements of ductility and acceptable local damage are still under questioning for usual works or difficult to be applied for existing structures. EN 1991-1-7:2006, part of Eurocode 1, adopted in Romania too, refers to accidental actions but excludes external blasts, military actions and sabotage, natural hazards as tornadoes. (EN 1991-1-7:2006).

In Romania, the seismic hazard is dominated by the Vrancea intermediate earthquakes that affect with high intensities ca. 50% of the territory and more than 40 densely populated towns are in seismic zones. The crustal (shallow) seismogenic zones affect reduced areas. (Balan et al, 1982, Georgescu et al, 1999). At a first glance, the threats of concentrated impacts, possibly associated with some other extreme hazards (i. e. terrorism or industrial explosions), seems to be significant for large cities. However, the cases of gas explosions in relatively small towns increased and must be addressed; this issue is critical especially for high-rise buildings, business centers and malls. Climatic actions are considered a threat for small settlements, since their capacity to react is reduced, fact proved by the winter season 2012. But all these assumptions were not yet evaluated to a due extent and with analytical tools.

Presently in Romania is enforced a National Program for seismic risk reduction (O. G. 20 /1994), correlated with Eurocode 8 provisions, regional and European needs, and a National Program for thermal and energy rehabilitation of buildings, but they are conditioned only in order to intervene on buildings that are not at seismic risk. A mutual feedback could be analysed. The paper is based on a Research Project coordinated by INCD URBAN-INCERC, INCERC Bucharest Branch (Contract 31031/2007). A conceptual and applicative approach dedicated to a part of issues was presented in several researches and papers (Georgescu et al, 2008, 2010).

2. MULTI-HAZARD APPROACHES AGAINST URBAN DISASTERS

2.1. Engineering aspects of multi-hazard approach

In the USA, there are multi-hazard engineering concepts (Bruneau, 2007, Ettouney et al 2007), as well as approaches and methods of calculation to prevent progressive collapse, testing at cladding impact, etc promoted by codes and standards. Thus, the main issues for engineering aspects of multi-hazard approach in case of structures are:

- identification of extreme actions characteristics and vulnerable systems/typical damage;
- methods of rehabilitation, remodeling, strengthening, repair;
- correlation with seismic design code limit states and other requirements;
- designing the new buildings to robustness, redundancy, ductility, drift limitation, progressive collapse, mitigation on the existing ones;
- design of protection barrier for the columns and strengthening the beams that transfers the loads to the columns of a soft storey;
- design to strong impacts, repeated impacts on envelope elements;

- solutions for masonry – in plane and normal to the plane associated with prevention of structural elements fragmentation

In Romania there are several codes and guidelines for repair and strengthening, but only few of these aspects are included in them (Code P100-1/2006; Code P100-3/2008; GP 100/2004). Some less addressed issues must be developed for extreme actions on adjacent exterior infrastructure elements:
- galleries / canopies, pedestrian bridges, stairs – interactions with the structure;
- tunnels/ galleries, underground utilities, underground parking, train stations, above ground and underground subways.

2.2 Architectural and urbanistic aspects of multi-hazard approach

The main architectural issues covered by USA standards, guidelines (FEMA, ASTM) and practices are related to:
- configuration solutions for plane and volume;
- design of frequently used access zones, buffer zones, secure zones/shelters, stand-off distances, bollard areas;
- risk evaluation of certain components:
    - atrium (fire propagation, gas explosions)
    - terraces (gravel, equipments)
    - roofs structures
- solutions for envelope to be:
    - resistant to penetration, impact, from non-brittle materials, walls resisting to aggression
    - design of doors/windows to be impact resistant
    - design of waterproof curtain walls, laminated glass/skin, special fitting, steel or aluminium frames, sunscreens made of waterproof fabrics and protected against UV radiations
- urbanistic solutions related to:
    - geopolitics of the zone, natural hazard vs. terrorism
    - concentrating the functions vs. descentralising, target buildings
    - criteria/concepts/approaches regarding anti-disaster urbanism
    - the zone adjacent to the building, stand-off distance, barriers.

Such issues are relatively recent (Department of Defense, 2003, 2004);

3. CASE STUDY OF BUCHAREST

3.1 Vulnerability of building types

A preliminary analysis of the built stock gives the following families of buildings, in their historical evolution:
- heritage buildings of churches, manors, palaces of XVII-XIX centuries;
- buildings of traditional masonry 1890...1930; buildings of contemporary masonry;
- low-rise buildings of low-cost type, in masonry and some concrete members, of 1930's;
- medium to high-rise buildings of masonry with some concrete members 1920-1940; and contemporary buildings;
- high-rise buildings of reinforced concrete skeleton (not moment resisting frames) 1930-1940, with cladding of masonry;
- high-rise buildings of moment resisting reinforced concrete frames and/or shear-walls, 1950-1990, with cladding of of masonry;

- large panel buildings, shear-wall structures, made after standard catalogs in IPCT and tested in INCERC (1960-1990); series of 5 and 9 stories structures have certainly the best qualities of prevention of progressive collapse;
- office buildings of moment resisting reinforced concrete frames and curtain-wall, with envelope made of aluminium panels and glass, after 1990;
- malls - commercial buildings of steel / reinforced concrete frames and glazed envelopes, mainly in periurban areas, after 1990;
- financial and banking buildings in clusters or in the urban fabric, using curtain walls, after 1990; many structural members are sight exposed, have hinged mechanical structural systems with tyrants, and they have reduced redundancy and are vulnerable to extreme actions. For Vrancea seismic motions, it is known the larger drift requirement, which may cause damage to glazing.

Presently, the central area of Bucharest has an agglomeration of less vulnerable neoclassical low-rise houses and of vulnerable high-rise reinforced concrete pre-1940 buildings, while in other districts exist mostly buildings designed to resist earthquakes. In Bucharest, the tall buildings erected before the 1940 Vrancea earthquake (M_{G-R}=7.4; Mw=7.6…7.7) are at highest risk. The next event, March 4, 1977, an earthquake of magnitude (M_{G-R}=7.2; Mw=7.5) occurred also in Vrancea area; most of the damage was concentrated in Bucharest. Out of the US $ 2 billion losses, about US $ 1,42 billion were in construction field (buildings, water supply system), while Bucharest City cumulated 70% of losses (Georgescu and Pomonis, 2007, 2008).

During the WW2 bombing and many fires and gas explosions affected Bucharest and other cities. A part of the existing buildings, including envelopes, proved to be vulnerable to other extreme actions, as interior gas explosions or storm/tornado.

3.2 **Vulnerability of building envelopes to extreme actions**

The dominant material of envelopes is masonry. The ratio of glazed area of a facade was used as a proxy tool in addressing the vulnerability to extreme actions. According to engineering criteria, this ratio enters in two contradictory assessments:
- for actions from interior – gas explosions, the favorable patterns are:
    - a greater area of openings or glazing, doors or windows to open outside, to provide venting;
    - envelope materials that do not fail before venting and to not harm the bearing structure.
- for actions from exterior – wind, tornado, terrorism, the favorable patterns are:
    - a smaller area of openings or glazing, doors or windows, to be under a better control;
    - envelope materials that do not constitute misiles of fragments to inside occupants;
    - envelope to be resistant to penetration from wind borne missiles or alien instrusions:

The envelopes of buildings were designed function of light requirements, therefore the large series developments have an average ratio of 20...25% of glazing on facade; thus, vulnerability is reduced or moderate. Newly developed envelopes have large glazing areas, and may have a risk to impact or of chain propagation of fire and / or destructive effects for large agglomerations of persons.

4. **ENGINEERING AND ARCHITECTURAL SOLUTIONS FOR SUSTAINABLE AND MULTI-HAZARD MANAGEMENT OF RISKS**

The research identified engineering solutions solutions and materials already used with good results in USA, Europe and recently in Romania, as follows:
- polymeric geo-grids as reinforcement in masonry mortar layers or as a lateral jacketing, sprayed or plastered with lime-cement mortar, or insert of carbon fibre rods in external nuts in mortar joints, with epoxy resins;
- carbon fibre plates or of glass fibre fabrics or carbon fibre fabrics with epoxy resins, as jacketing or wraping;

- steel bands grills, steel strands woven with polymers, with special adhesives, as anchors or jacketing;
- protective films for facades glazing and finishing layers for fragments retention;n

The international experience was evaluated and several solutions for architectural and urbanistic design were considered as feasible for Romania, as follows:
- architectural design of verandas and of parapets for shielding of entrances against wind missiles, associated with a design of zig-zag access, a tornado shelter; limitation of glazing in some places of persons concentration, in areas exposed to such turbulences;
- architectural design of curtain wall envelope details as to fulfill safety needs for impact, penetration and deformation;
- stand-off distances and separation of functional spaces against terrorist threats.

5. CONCLUSIONS

The research proved that multi-hazard threats exist also in Romania and solutions must be of multidisciplinary type. Several engineering solutions have been selected for strengthening and some architectural and urbanistic approaches are available.

The building envelope is a very important part of a building and it is the interface with the environment, providing security and safety for people. The apparently contradictory criteria must be solved but earthquake engineering alone cannot solve all issues. The design belongs to architects and engineers, but the urban context must be considered too.

Present programs of thermal rehabilitation in Romanian could be associated with complex rehabilitation in multi-hazard concept. It is possible to achieve energy performance and also a gain in safety, if new windows or wall jacketing are multipurpose. Thus, the next step must be a „Guide for integrated design of building systems and subsystems". The multi-criterial or matrix analysis could be a tool.

There is a need of integrative approach, as well as of dissemination–outreach. The Institute URBAN-INCERC prepared a catalog with 9 solutions and framework for transfering the knowledge about new solutions. The University of Architecture and Urbanism „Ion Mincu" prepared curricula for a master Course in Sustainable Development on Architectural and urbanistic aspects of multi-hazard approach, while Technical University for Civil Engineering UTCB prepared a Master Course curricula for risk reduction at extreme actions. Basic knowledge will be posted on websites of URBAN-INCERC, UAUIM and UTCB, while professional associations will be partners.

ACKNOWLEDGEMENTS
This paper is based on a Research Project coordinated by INCD URBAN-INCERC, INCERC Bucharest Branch, under the contract 31031/2007 financed by the Romanian National Authority for Scientific Research-ANCS. The authors express their appreciation to Dr. Eng Emil Albota, Lecturer at Technical University for Civil Engineering UTCB. We appreciate the contributions of Dr. Eng. Claudiu Sorin Dragomir, Eng. Claudiu Matei, Eng. Constantin Praun, Eng. Vasilica Vasile and Dr. Eng. Daniela Dobre, team members from INCERC Branch. The contribution to testing of Mr. Savvas Antoniadis, General Director ISOMAT Romania SRL, of Wienerberger Sisteme de Caramizi SRL, Bucharest, of Mr. Eng. Lucian Mihai, Technical Manager, SIKA is acknowledged.

REFERENCES

Balan, St., Cristescu, V. and Cornea, I., (coordinators, 1982). *The Romania Earthquake of 4 March 1977* (in Romanian). Editura Academiei, Bucharest.

Bruneau, M. (2007): The Need for Integrated Multi-Hazard Engineering Design Solutions to Enhance Disaster Resilience; The 4 R's of Resilience and Multi-Hazard Engineering. *AEI/MCEER/ Steel Institute of NY. Symposium on Emerging Developments in Multi-hazards Engineering*, NY, 2007.

Cod P 100-1 (2006). Cod de proiectare seismică - Partea I - Prevederi de proiectare pentru clădiri", indicativ P 100-1/2006. MDRT-UTCB.

Cod P 100-3 (2008). Codul de evaluare şi proiectare a lucrărilor de consolidare la clădiri existente, vulnerabile seismic P100-3, vol. 2 – consolidare. MDRT-UTCB.

Contract 31031 (2007) Integrative structural and architectural technical solutions and advanced materials for risk reduction, increasing safety of buildings and life security at extreme actions (earthquake, impact – terrorism, blasts, tornadoes etc.). Contract 31031 INCERC-CNMP, 2007.

Department of Defense (2003), Minimum Antiterrorism Standards for Buildings. *Unified Facilities Criteria (UFC) 4-010-01*, approved for public release.

Department of Defense, (2004), Design of Buildings to Resist Progressive Collapse, *Unified Facilities Criteria UFC 4-023-03*, approved for public release, distribution unlimited.

Ettouney, M.M. et al, (2007) Theory of multi-hazards: a quantification procedure to the process. *AEI/MCEER/ Steel Institute of NY. Symposium on Emerging Developments in Multi-hazards Engineering*, NY, 2007. Weidlinger Associates Inc., USA.

EUROCODE 8 – Design of structures for earthquake resistance. CEN. European Commision

FEMA (2000). Prestandard and Commentary for Seismic Rehabilitation of Buildings, *Report FEMA 356*, Washington, D.C., USA.

Georgescu, E.S., et al (1999). Towards a national earthquake protection program under the conditions of Romania, in F. Wenzel et al. (Eds), Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation, Kluwer Academic Publishers, Netherlands, pp. 241-250.

Georgescu, E.S., Georgescu, M.S., Albota, E. (2008): Structural and life safety alternatives in urban landscape under extreme actions in seismic zones of Romania. *The 14th World Conference on Earthquake Engineering,* Paper 09-01-0039, CDRom Proceedings, October 12-17, 2008, Beijing, China

Georgescu, E.S., Georgescu, M.S., Albota, E. (2010): Towards a Multi-Hazard Engineering and Architectural-Urbanistic Design in Seismic Zones of Romania. *The 14-th European Conference on Earthquake Engineering,* Paper 3-240, CDRom Proceedings, August 30 – September 03, 2010, Ohrid, Republic of Macedonia.

Georgescu, E.S. & Pomonis, A. (2007): The Romanian Earthquake of March 4, 1977: New Insights in Terms of Territorial, Economic and Social Impacts. *International Symposium on Strong Vrancea Earthquakes and Risk Mitigation",* October 4-6, 2007, International Conference Center of the Parliament of Romania, Bucharest. Symposium jointly organized by the UTCB Bucharest and the CRC 461 University of Karlsruhe, Germany.

Georgescu, E.S., Pomonis, A. (2008): The Romanian Earthquake of March 4, 1977 revisited: new insights into its territorial, economic and social impacts and their bearing on the preparedness for the future. *The 14th World Conference on Earthquake Engineering*, Paper 10-0013, CDRom Proceedings, October 12-17, 2008, Beijing, China.

Georgescu, E. S., Pomonis, A. (2011). Emergency management in Vrancea (Romania) earthquakes of 1940 and 1977: casualty patterns vs. search and rescue needs. *Proceedings of TIEMS – The International Emergency Management Society, 18th Annual Conference*, June 2011, Bucharest, Romania.

GP-100-04 (2004). Ghid privind proiectarea sistemelor de consolidare a pereților din zidărie prin cămăşuiri armate cu grile polimerice, indicativ GP-100-04. Publicat în Monitorul Oficial, Partea I nr. 780 bis din 25 august 2004.

Guzman, E. M. (2001). Towards Total Disaster Risk Management Approach. Asian Disaster Reduction Center and United Nations Office for the Coordination of Humanitarian Affairs-Asian Disaster Response Unit.

Nishikawa, S. (2003). Total Disaster Risk Management Approach – for sustainable development. DRA Workshop, 24 July 2003, ADRC.

O. G. 20 (1994). Ordinance of the Romanian Government No. 20/1994 on the mitigation of the seismic risk of the existing buildings. Official Gazette, 1994 (modified, republished)

Standard EN 1991-1-7:2006, on accidental actions. CEN. European Commision

Standard prCEN/TR 14383 (2008): Prevention of crime - Urban planning and building design, parts 2, 7, 8. European Committee for Standardization.

U.S. General Services Administration, (2003), Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects, June 2003.