SEISMIC VULNERABILITY ASSESSMENT OF THE EDUCATIONAL SYSTEM OF BUCHAREST

M.A. Ferreira[1] **and J.M. Proença**[2]

[1] *PhD Student, Dept. of Civil Engineering, Instituto Superior Técnico, TU Lisbon. Portugal*
[2] *Professor, Dept. of Civil Engineering, Instituto Superior Técnico, TU Lisbon. Portugal*
Email: monicaf@civil.ist.utl.pt, jmiguel@civil.ist.utl.pt

ABSTRACT :

Considering that Bucharest has been rated as the 10th capital city worldwide in the terms of higher seismic risk, altogether with the general functional inadequacy and lack of building conservation in educational buildings, EIB - European Investment Bank – has requested an integrated school building survey, whose seismic risk assessment stages are presented herein. This study was intended to support a School Rehabilitation Strategy to all pre-university public educational buildings in the municipality of Bucharest. The importance of the study can be stressed by the fact that a non-negligible number of educational facilities was built prior to 1940, with no earthquake-resistance regulatory codes, and that these schools have to be upgraded to minimum EU standards.
The study focuses in a group of 470 schools of the following types: Kindergarten (up to 6 years old); Primary, I-IV (6 to 10 years old); Gymnasium, V-VIII (11 to 14 years old); College, IX – XII (15 to 18 years old) and Professional, IX-XIII. In the 2006/07 school year the corresponding school population was of nearly 180,000 students.
To know the existing schools in Bucharest, where they are located, their general features, type of structure and number of students and other relevant information, a survey was launched in the project internet site. A detached section of the survey – technical form - was prepared for specialized answer by local university team technicians for assessing structural conditions and seismic vulnerability of the existing school buildings. This technical form comprised general information on the building structure, with explicit recognition of aggravating factors, pre-existing damage and non-structural hazards. This information allowed the assessment of building vulnerability which was implemented in GIS environment creating damage scenarios. The knowledge of soil properties as the definition of the intensity was necessary to derive the expected damage of structures (MDG), as defined in EMS-98.

KEYWORDS: Educational buildings, Bucharest, Seismic Risk, Assessment, EMS-98, GIS

1. INTRODUCTION

Bucharest, a populous city with 1,927,559 inhabitants (July 1, 2004, Institutul National de Statistica – Romania), presents a diverse building stock in which many of these educational buildings are in ruin or present high level of deterioration. There was no former program to reconstruct and improve the infrastructures following the World War II. The historical center was built between 1875 and 1940. The 19th century buildings are built over basements dating from the 18th century (Armas, 2006). Bucharest is highly exposed to seismic hazard from the sub-crustal Vrancea source in the Carpathians. During the last 60 years, Bucharest has been threatened by four strong Vrancea events: 10 November 1940 (Mw=7.7), 4 March 1977 (Mw=7.5), 30 August 1986 (Mw=7.2) and 30 May 1990 (Mw=7.0). The statistics of casualties and property damage compiled reveal that the 1977 earthquake killed 1,424 persons in Bucharest; injured 7,598 and about 35,000 buildings were damaged. The total damage was estimated at more than two billion dollars.
In 2006 the European Investment Bank jointly with the Municipality of Bucharest launched a short term consultancy to support the Municipality of Bucharest in a preparatory work for a School Rehabilitation Strategy. The objective was to assist the Municipality in the production of a school map and write the Terms of Reference for a subsequent consultancy assignment to develop an investment prioritisation and decision support framework. The Bucharest School Map Report (Freire da Silva, J., 2007) resulting from the first phase of the consultant work, illustrates the results of a specialized research that has been made on the city about geographic and urban conditions, seismic risk, population, Romanian education system and a Survey on the schools in Bucharest to know how many they are, the existing school building regulations, what kind of education they offer, what are their dimensions and use, location, their general and specific conditions and what is their users' opinion about spaces and furniture as to quality and suitability. This paper will focus on the seismic risk assessment developed to Bucharest School Map from a total of 470 schools.

2. POPULATION FORECAST

To promote, evaluate and predict the necessary schooling offer, one important goal of this project was to forecast the scholar population, per scholar level, for Bucharest and for each of its sectors. Scholar levels are organized in 5 classes: *Prescolar, Primar si gimnazial, Liceal, Profesional si de ucenici, Postliceal si tehnic de maistri*. This study has a lot of data limitations and some (potentially important) correlations and factor impacts could not be considered. The available data shows the existence of three different temporal patterns: a pattern of negative population growth before 2001 followed by a steep decrease of Bucharest's population from 2001 to 2002 (emigration was possibly the major factor causing this behaviour) and a final, more constant pattern with a softly decreasing population after 2002. Population growth from 2005 to 2006 was positive, but, based on one year only; one cannot define whether this presents a real change in pattern or a single occurrence. Furthermore, population dynamics can be expected to suffer further serious changes due to, for instance, better life conditions or other consequences of Romania's recent EU membership.

3. SURVEY OF EXISTING EDUCATIONAL FACILITIES

To know the existing schools in Bucharest, where they are located, what their composition, epoch of construction, type, number of students, how they answer to educational needs, their functional and constructive conditions, and their compliance with regulatory standards and requirements was an ambitious task that was accomplished through a Survey launched in the internet site http://www.invatamantului.com. The Survey consisted on a Questionnaire with 9 sections with questions about the school facilities to be answered on-line by each Bucharest school during February 2007. The questionnaire is based on works developed at Portuguese educational and university institutions related to education and university research.

3.1. Technical survey

Form 4, a technical part of the questionnaire with specific questions about the building conditions, structure and damages, was prepared to be answered separately by specialized technicians to be appointed by the municipality, but facing the impossibility of their assistance in time, a decision was made, with the support of the EIB and the Technical department responsible, to complete a sample of 100 schools review with the help of the local University, with a team of a teacher and 6 students of engineering and architecture.

4. SEISMIC RISK ASSESSMENT

Seismic risk assessment was based on the contents of the technical part (form 4) of the survey form. Educational buildings existing in each campus were classified according to date of construction, structural typology, structural material, number of floors, and many other characteristics considered to affect structural vulnerability. The technical form was filled for a total of 100 campuses (221 buildings). Earthquake risk was expressed in terms of the MDG – Mean Damage Grade – (which can vary from 1 - slight damage to 5 - collapse). Results obtained in these 100 campuses were then extrapolated to other 201 campuses for which the number of storeys and construction date was provided. The survey suggests that around 60% of the school buildings have 1-2 floors and reinforced concrete is the predominant construction material (48%).

4.1. Seismic Action in the P100-1992 and P100-1-2006

Code P100-1992 was valid until December 31st, 2006. Code P100-1-2006 is valid from January 1st, 2007. For the seismic design, the territory of Romania is divided into seismic hazard zones with constant hazard level. Seismic hazard for design is described by the horizontal peak ground acceleration a_g determined for a reference mean recurrence interval (MRI) corresponding to the no-collapse performance requirements (Ultimate Limit State). Design Ground Acceleration, a_g, in Romania is shown in Figure 1 for seismic events having a magnitude mean recurrence interval MRI = 100 years (no collapse requirements).

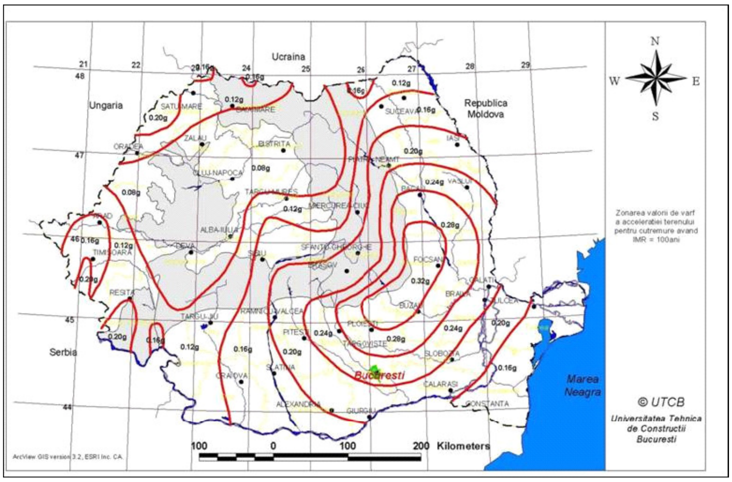

Figure 1 Zonation map of Romania in terms of design ground acceleration a_g for seismic events having the magnitude mean recurrence interval MRI = 100 years

Bucharest is included in the seismic zone with a_g=0.24 g, and only one value is considered for the entire city.

4.2. Vulnerability modelling

The vulnerability assessment of school buildings was made using the concepts developed by Giovinazzi and Lagomarsino (2004), which can be implemented in a geographic information system (GIS) environment. The proposed method named macroseismic method derived from European Macroseismic Scale (Grunthal, 1998) and is useful when the seismic hazard is described in terms of macroseismic intensity.
Vulnerability is measured by a vulnerability index V_I evaluated taking into account the buildings typologies and constructive features. Structural and geometrical features (e.g. plan and vertical regularity, state of preservation,

floor and roof structures and existence of damages or retrofitting interventions) that contribute to change the seismic behaviour can further refine the vulnerability index. To this aim scores for the behaviour modifier proposed by Giovinazzi and Lagomarsino were used as other behaviours modifiers adapted from the Japan Building Disaster Prevention Association (2005) and introduced on this study, so the vulnerability index (V_I) can be increased or decreased on the basis of vulnerability factors recognized inside a certain building.
This method has allowed to group together structures that would be expected to behave similarly during a seismic event. Vulnerability index close to 1 means most vulnerable structures and values close to 0 comprise the low vulnerability structures or the high-code designed structures (Table 4.1).

Table 4.1 Mean vulnerability index (V_I), according to year of construction and number of floors

Year	**1-2 floors**	**3-5 floors**
< 1965	0.68	0.69
	1-3 floors	**4-7 floors**
1965-1979	0.62	0.66
1980-1994	0.47	0.49
> 1994	0.33	--

The following pictures – Figure 2 - illustrate some representative epochs of constructions in Romanian (Bucharest) educational buildings.

Pre code – prior to 1963


Low code – between 1963 and 1977

Moderate code – between 1977 and 1992


Moderate-advanced code – after 1992

Figure 2 Representative educational buildings from different epochs of constructions in Bucharest

4.3. Intensities

Bucharest has only one value of peak ground acceleration, ag=0.24g, that value was considered for all city. In Romania, buildings are classified in four classes according to their importance and class II includes "Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions, etc." and its importance factor is $\gamma_I = 1.2$.
The intensity to Bucharest was defined by the following equation:

$$I=0,4254 \log((Sa))^3 - 1,496 \log((Sa))^2 + 4,1869 \log((Sa)) - 0,3505 \quad (4.1)$$

where S_a is the spectral acceleration (cm/s2).

This equation obtain an intensity value of 9,5 (IX-X EMS-98).

4.4. Mean damage grade

Once fixed the values of intensity and vulnerability we are able to calculate the expected damage of structures, defined in EMS-98, according to the following equation:

$$\mu_D = 2,5.\ (1 + \tanh(I + 6.25.V_i - 13.1) / 2.3) \quad (4.2)$$

where μ_d means the mean damage grade (grade 1 = slight, grade 2 = moderate, grade 3 = heavy, grade 4 = very heavy and grade 5 = collapse), I is the intensity and V_I the vulnerability index.
The grouping of structures according to their period of construction and number of floors, used to compute the vulnerability index, was also adopted for the computation of the mean damage grade. An average value was chosen as being the representative of a structure and period of construction - maximum value (worst) of mean damage grade (Table 4.2).

Table 4.2 Mean damage grade according to year of construction and number of floors

Year	**1-2 floors**	**3-5 floors**
< 1965	3.2	3.3
	1-3 floors	**4-7 floors**
1965-1979	2.8	3.1
1980-1994	1.8	1.9
> 1994	1.0	--

5. RESULTS AND CONCLUSIONS

Final results, for the 301 campuses, showed that MDG of Bucharest schools ranged from 0.6 to 3.8 (slight to very heavy damages). In addition to building type, expected damage was shown also to be a function of building age and number of storeys. These figures refer to the average MDG in the campus (Figure 3). General results show that there is fact a very important seismic risk, particularly considering the human content and occupation of these buildings and the importance in post-earthquake emergency management scenarios. Existing risk is higher in buildings prior to 1979 and even more in buildings prior to 1965. Building date and construction materials were found to be strongly correlated, so that similar remarks can be expressed for masonry buildings. Pre-code (prior to 1965) reinforced concrete buildings present also higher levels of seismic risk. Poor conservation state and pre-existing damage (previous earthquakes) have been shown to significantly increase seismic risk.
The identification of vulnerable buildings based on MDG results allows scheduling them for retrofitting/rehabilitation, change of use, replacement, demolition or other.
MDG results can be interpreted in terms of post-earthquake repair feasibility or expected human losses. For

MDG not greater that 2, repair is economically feasible and no human losses are expected. For MDG of 3, post-earthquake repair is on the verge of becoming economically unfeasible and non-negligible human losses can be expected in consequence of non-structural damage. For MDG of 4 and 5, post-earthquake repair is unfeasible. As to human losses, a significant number of human casualties can occur for MDG of 4 (due both to structural and non-structural damage) and only slightly over half of the building occupants are expected to survive the earthquake.

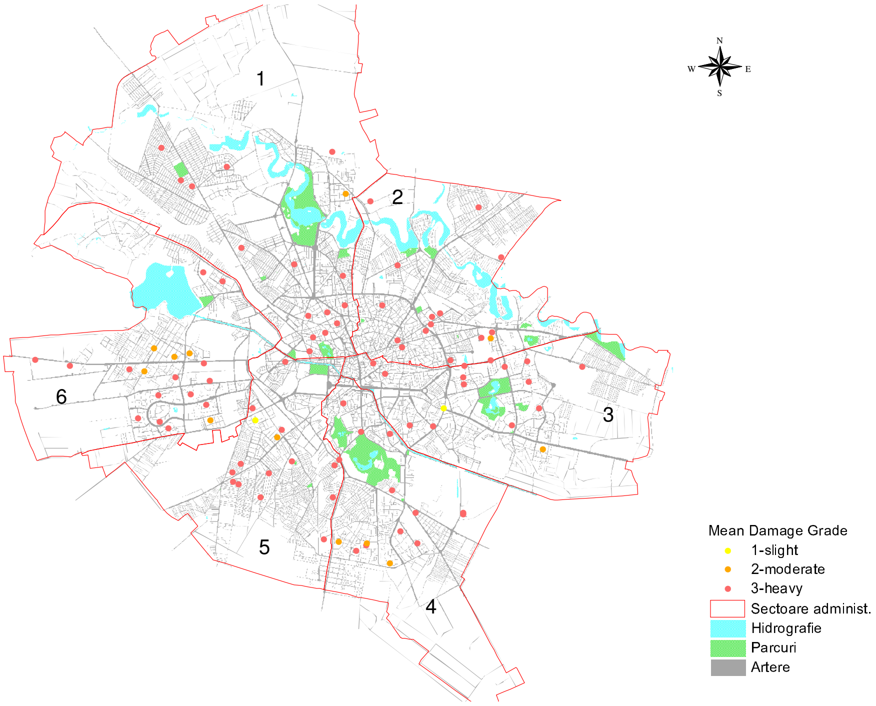

Figure 3 Mean damage grade – Bucharest schools

6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support of FCT, *Fundação para a Ciência e a Tecnologia*, through PhD Scholarship Grant Nº SFRH/BD/29980/2006, and EIB, European Investment Bank.

REFERENCES

Armas, I. (2006). Earthquake Risk Perception in Bucharest, Romania. Risk Analysis, Vol.26, n.º 5.

Freire da Silva, J. (2007). School Map for the Municipality of Bucharest (Volume I, Survey and Analysis Report, and Volume II, Executive Summary), Consultancy for a School Rehabilitation Strategy – European Investment Bank.

Giovinazzi, S. and Lagomarsino, S. (2004). Macroseismic Method for the Vulnerability Assessment of Buildings. Proceedings of 13th World Conference on Earthquake Engineering, Vancouver, B.C , Vancouver, Canada.

Grünthal, G. (1998). European Macroseismic Scale European Centre of Geodynamic & Seismology, Luxemburg, 15.

The Japan Building Disaster Prevention Association (2005). Standard for Seismic Evaluation of Existing

Reinforced Concrete Buildings. Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings and Technical Manual for Seismic Evaluation and Seismic Retrofit of Existing Reinforced Concrete Buildings, 2001.