BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LX (LXIV), Fasc. 1, 2014
Secţia
CONSTRUCŢII. ARHITECTURĂ

OVERVIEW OF ROMANIA’S SEISMICITY FOCUSING ON THE NORTH-EASTERN REGION

BY

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Received: November 5, 2013
Accepted for publication: December 23, 2013

Abstract. This paper presents the particularities of Romania’s seismicity, with emphasis especially on the North-Eastern part of the country. Firstly, an introduction into the Romania’s seismicity is made. Then, the recurrence interval relations with values specific for Vrancea region are presented, together with a seismic hazard analysis for Iaşi region. In this respect, information regarding the seismic scenarios for Iaşi region based, on the deterministic approach and on the probabilistic one, is presented. Also, an overview on the seismic vulnerability evaluation is presented. Considering that the hazard maps are based on MMI values, while the seismic codes – on PGA values, a correlation between these two was computed for Iaşi region.

Key words: earthquake; seismogenic zone; recurrence interval; fragility curves; Modified Mercalli Intensity Scale; Peak Ground Acceleration; seismic hazard.

1. Introduction

Natural hazards changed throughout history the shape of the environment and threatened the lives of both people and animals. However,

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only one of them is able to cause significant damage to the built environment in a couple of seconds – the earthquake. It is one of the most dangerous natural hazards because it may cause not only vibratory ground motion, but also fault rupture, inundation, fire, or various types of ground failure (liquefaction).

As it can be observed in Fig. 1 (Benetatos & Kiratzi, 2004), Romania's high level of seismic hazard is mostly governed by events of the Vrancea region, situated at the sharp bend of the South-East Carpathians. It is one of the well-defined seismically active areas of Europe. A narrow, near-vertical focal volume sub-ducted at intermediate depths (60...220 km), supposed to be in a relic stage at present, is the site of an unusually intense seismic activity – an average frequency of 3 shocks with magnitude greater than 7 per century (Radulian *et al.*, 2000).

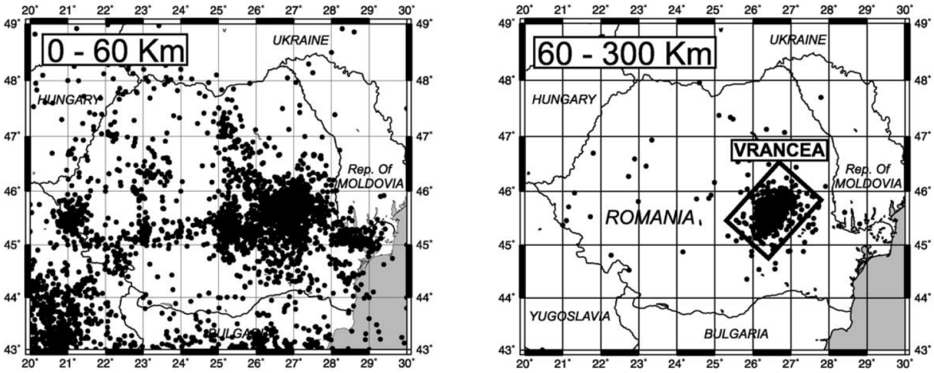

Fig. 1 – Epicenters of around 6,000 shallow depth (h < 60 km) and intermediate depth (60...300 km) earthquakes in Romania (Benetatos & Kiratzi, 2004).

2. Recurrence Interval Relations for Vrancea Earthquakes

The recurrence interval (also called "the return period") is an estimate of the likelihood of an event. The recurrence interval, T, is the number of years in the record, N, divided by the number of events, n:

$$T = \frac{N}{n}\,. \tag{1}$$

The probability, p_n , that a given event will be equaled or exceeded at least once in n years is given by relation

$$p_n = 1 - (1 - p_1)^n\,. \tag{2}$$

By analyzing the database with the records of known earthquakes in Vrancea, Elnashai & Lungu, (1995), suggested the following relation of the

Gutenberg-Richter law for this area, which gives the number, n, of earthquakes of a certain magnitude, M, in any time period:

$$\log n(\geq M) = 3.49 - 0.72M \ . \tag{3}$$

Elnashai & Lungu, (1995), determined the following relation for the Vrancea region, based on Hwang & Hso modification of the Gutenberg-Richter relationship (Hwang & Hsu, 1991):

$$n(\geq M) = \mathrm{e}^{8.036-1.658M} \frac{1-\mathrm{e}^{-1.658(7.8-M)}}{1-\mathrm{e}^{-1.658(7.8-6)}} \ , \tag{4}$$

where the threshold magnitude was set to M_0 = 6 and the maximum credible magnitude was considered to be $M_{\max}$ = 7.8.

Fig. 2 (Lungu *et* al., 1997) shows a comparison between the Gutenberg-Richter and Hwang-Hso models, taking into account three maximum credible magnitudes, 7.5, 7.8 and 8 on Richter scale respective.

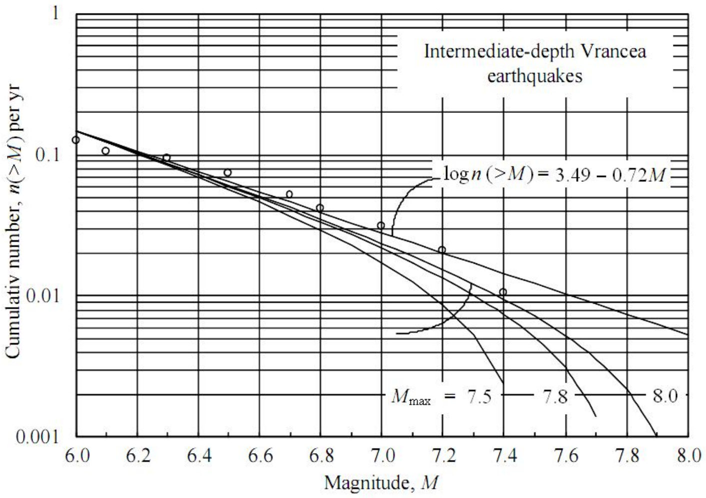

Fig. 2 – Magnitude *vs*. recurrence relation for the sub-crustal Romanian Vrancea source (Lungu *et al*., 1997).

3. Seismic Hazard Analysis for Iaşi Area

The mobility of the Vrancea epicenter toward the North is more dangerous to Moldavian sites (including Iaşi) located in North Eastern Romania, as it was the case of the November 10, 1940, earthquake, while the mobility toward South induces more damage in the Romanian capital, Bucharest, as it was the case of the March 4, 1977, earthquake. In the following sections, the hazard assessment for Iaşi region will be considered.

3.1. Seismic Scenario for Iaşi - Deterministic Approach

Through the years, the most utilized method for obtaining a seismic scenario was to characterize the maximum event that can be produced at a fault and then propagate the wave to the considered region. This deterministic method is based on the hypothesis that future events will have the same characteristics as those observed in the past, this implying that no larger effects than those registered will occur. The seismic events are generated considering information such as seismic sources that could affect the area, historical earthquakes and geological conditions (Oliveira *et al.*, 2006).

Taking into account the seismic and site conditions encountered in Romania, which are evaluated using the deterministic approach (existent instrumental data), the territory's zoning in terms of control period, T_C , of the response spectrum is done, the value corresponding to Iaşi area being 0.7 s (P100-1/2012).

The normalized elastic response spectrum of the absolute accelerations, $\beta(T)$, considering a damping ratio of ξ = 5%, for the site and seismic conditions of Iasi region are given in Fig. 3 (P100-1/2012).

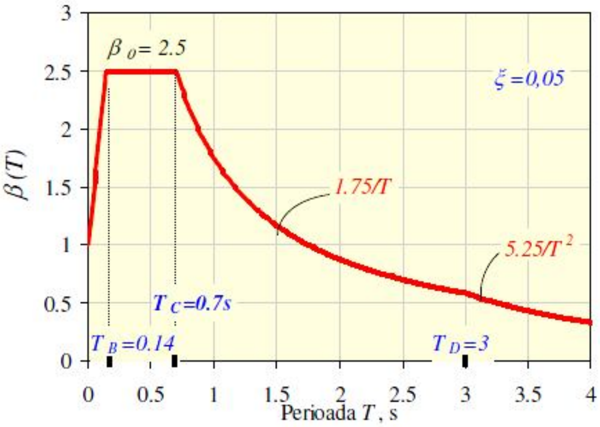

Fig. 3 – Normalized elastic response spectrum of the absolute accelerations for the horizontal components of the ground movement, in the area characterized by T_C = 0.7 s according to P100-1/2012.

The information found in P100-1/2012 is in accordance with SR EN 1998-1-2004 (EUROCODE 8). In EUROCODE 8, the elastic response spectrum depends on the type of soil (class A-E) that can be found in a specific area. In Romania, the classification schema of the soil types from SR EN 1998-1-2004 is not applicable today. In design, the site's local conditions are classified in three areas, depending on the corner period, T_C.

3.2. Seismic Scenario for Iaşi - Probabilistic Approach

The probabilistic approach, as concerns the seismic design, has been adopted by many international standards. In addition to the deterministic method, the probabilistic one takes also into account the influence of surrounding factors and social-economic development factors. Also, together with ensuring the structural and functional safety, the building's performance is also considered.

In literature (Monitorul Oficial al României, Bucureşti, 2004), the seismic hazard, H, is defined as a function, $P(Y > y)$, describing the probability that in a given place (M) and in a certain time interval (T), the value of the parameter, Y (macro-seismic intensity, ground acceleration, velocity or displacement), can overpass the given value (y) as an effect of a seismic event. Analytically expressed, the seismic hazard is defined as

$$H = P(Y > y)\,. \tag{5}$$

The probabilistic method is used in the Romanian building code P100-1/2012 in establishing the seismic hazard level, which is defined by the peak ground motion acceleration determined for a mean period of recurrence of seismic events. The design peak ground acceleration specific for Iaşi region, according to the latest seismic code, is equal to $a_g = 0.25$ g, considering a mean period of recurrence of 225 years and 20% probability of overpassing it in 50 years. With regard the roads' network for the North-Eastern part of Romania, it is characterized, according to P100-1/2012, by a design peak ground acceleration, a_g, having values in the interval $a_g = (0.20\ldots0.30)$ g.

In the previous Romanian seismic code, P100-1/2006, the peak ground acceleration values, a_g, are determined considering a mean recurrence period for earthquakes of 100 years (Cod de proiectare..., 2006). An important difference in the peak ground acceleration values between the old and new seismic code is observed, the ones proposed by P100-1/2006, related to the roads' network for the North-Eastern part of Romania, being $a_g = (0.16\ldots0.24)$ g.

The increasing of the seismic hazard level in P100-1/2012 with regard to the one found in the previous design code P100-1/2006, is justified by the following reasons: increasing the safety level of the buildings' inhabitants and of the sheltered assets; diminishing the expected losses due to seismic action during the buildings' design life cycle and the process of reaching the seismic hazard level suggested by SR EN 1998-1-2004 (P100-1/2012).

3.3. Fragility Curves

The seismic vulnerability of a building, due to possible damages that may appear after an earthquake having specific characteristics, can be evaluated by using fragility curves. Fragility curves represent functions which describe the probability that a given structure's response to various seismic excitations reaches or exceeds different structural or non-structural damage stages. For obtaining fragility curves, a series of uncertainties are taken also into account, related to the type of the building and its construction, and also to the seismic characteristics.

Fragility can be modeled using a two-parameter lognormal cumulative distribution function (Crow & Shimizu, 1988; Evans *et al.*, 2000):

$$F_r(x) = P(X \leq x)\,, \tag{6}$$

where the probability that the random variable, *X*, is less than or equal to *x*, for all real values of *x*. Each fragility curve is defined by a mean value of spectral displacement or spectral acceleration that corresponds to the threshold of the damage state and by the variability associated with the damage state (FEMA, 1999).

Given the peak response, the conditional probability of exceeding a limit or damage state, *r*, is defined by:

$$F_r(x \mid m_r, \beta_r) = \varphi\left(\frac{\ln\left(x / m_r\right)}{\beta_r}\right), \tag{7}$$

where: φ is the standard normal probability integral, m_r – the mean fragility, β – the normalized composite log-normal standard deviation and x – the peak ground or spectral acceleration (Shinozuka *et al.*, 2003).

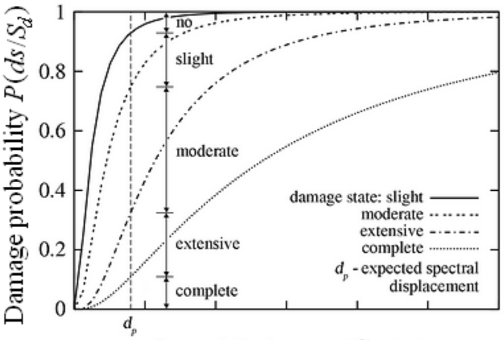

Fig. 4 – Spectral displacement based fragility curves of building structures for different damage states, adapted after Molina *et al.*, (2010).

The damage states include slight, moderate, extensive, and complete damage, according to HAZUS methodology (FEMA, 1999). Fragility curves are described in HAZUS software, in terms of spectral displacements, which in turn are calculated from the estimated mean inelastic drift capacities of buildings for various damage states. A set of spectral displacement based fragility curves is presented in Fig. 4 (Molina *et al.*, 2010).

The spectral displacement demand for a given building type under a specified earthquake motion is based on the intersection of the seismic demand spectrum with the capacity spectrum for the building class considered.

The typical shape of a set of fragility curves obtained for Iaşi municipality is displayed in Fig. 5, adapted after Mander, (1999) and Atanasiu & Leon, (2007).

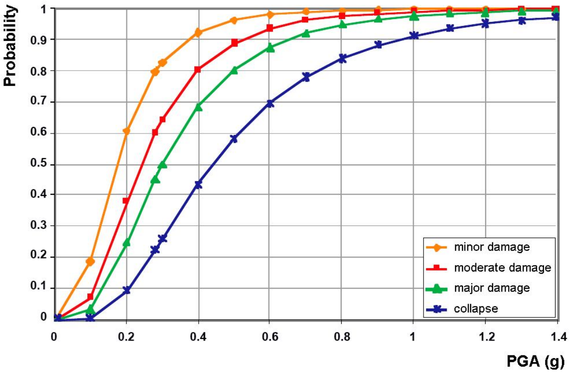

Fig. 5 – Typical set of fragility curves of building structures for Iaşi municipality (Atanasiu & Leon, 2007).

3.4. Probabilistic Assessment of MMI and PGA for Iaşi Region

Few studies have particularized the general framework of Vrancea to the specific case of seismic hazard analysis of Iasi municipality. There are also several methods to evaluate the Modified Mercalli Intensity (MMI) and the Peak Ground Acceleration (PGA) of an earthquake and the shapes of attenuation curves. In our case, the Joyner-Boore (1997) attenuation model can be used, for which the specific coefficients for Moldova and thus Iaşi region have been determined (Atanasiu & Leon, 2007):

$$\ln \mathrm{PGA} = 4.601 + 0.929M - 1.03\ln R - 0.008h + \varepsilon, \tag{8}$$

where: PGA is the maximum peak ground acceleration at the site, M – the earthquake’s magnitude, R – the hypo-central distance to the site, h – the focal depth, ε – modeled as a random variable with zero mean and the standard deviation $\sigma_{\ln \mathrm{PGA}} = 0.465$.

Therefore, it is possible to estimate a probability of PGA for a given earthquake, with statistically estimable characteristics. Considering the characteristics of the Romanian major earthquakes from 1977, 1986 and 1990, and taking into account the corner period characteristic for Iaşi region, T_C = 0.7 s, maps for the entire country presenting the peak ground acceleration (PGA) and peak ground velocity (PGV) were made, the values specific for Iaşi municipality being given in Table 1.

Table 1

PGA and PGV for Iaşi Region

Date	Moment Magnitude	Depth, [km]	PGA, [g]	PGV, [cm/s]
04.03.1977	7.4	94.00	0.14	10
30.08.1986	7.1	131.40	0.06	6
30.05.1990	6.9	91.00	0.08	8

Alternatively, the PGA can be computed by using the modified Mercalli intensities instead of earthquake magnitudes on the Richter scale. The HAZUS software (FEMA, 1999) methodology, represented in Table 2, gives an approximate relation between MMI and PGA.

Table 2

MMI to PGA Conversion Table

MMI	IV	V	VI	VII	VIII	IX	X	XI	XII
PGA, [g]	0.02	0.055	0.12	0.21	0.36	0.53	0.71	0.86	1.15

Based on this table, it can be deduced an empirical relation for PGA as a function of MMI by regression, presented in Fig. 6 (Atanasiu & Leon, 2007).

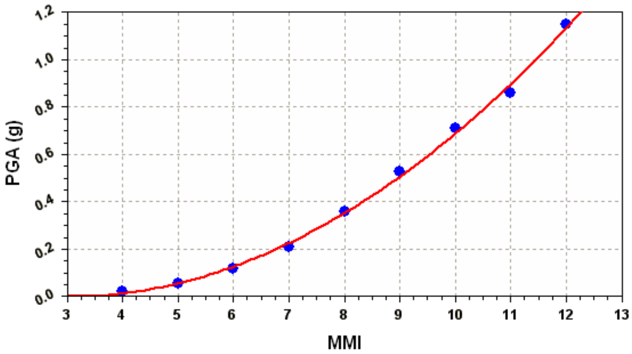

Fig. 6 – The relation between MMI and PGA (Atanasiu & Leon, 2007).

The regression formula using quadratic fit is the following:

$$\mathrm{PGA} = 0.1123 - 0.0801\mathrm{MMI} + 0.0138\mathrm{MMI}^2 . \tag{9}$$

This approach enables us as well to evaluate the damage of a particular building by using the estimated PGA of a seismic event.

4. Final Remarks

This paper describes the existing seismicity in Iaşi municipality, along with a general overview on Romania. Being situated in a high seismicity area, there is an imperious need of evaluating the seismic risk in Iaşi municipality, starting from the seismic hazard assessment presented above. All the methods of analysis presented here have the purpose of diminishing future damages occurred after a large earthquake and also of evaluating the damage state.

The information gathered here about the seismic hazard characteristics of the North-Eastern part of Romania will be developed in the future by using the artificial intelligence method. By using it, the worst case scenario for the North-Eastern Romania will be defined, along with the risk evaluation.

Acknowledgements. The authors acknowledge the participation within ERA Net FP7 – Concert Japan, Road Networks for Earthquake Resilient Societies - Roaders Project, a fruitful researching environment.

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PREZENTARE GENERALĂ A SEISMICITĂȚII ROMÂNIEI CU ACCENT PE REGIUNEA DE NORD-EST

(Rezumat)

Se prezintă aspecte ale seismicității României, punând accent pe partea de Nord-Est a acesteia. După o scurtă introducere pe tema seismicității României în ansamblu, se prezintă relații de recurență, specifice zonei Vrancea, în ce priveşte atât probabilitatea apariției unui cutremur, cât şi numărul de cutremure de o anumită magnitudine ce pot apărea. În lucrare se prezintă, de asemenea, analiza hazardului seismic pentru regiunea Iaşului, cu informații referitoare la scenariile seismice. Această prezentare are la bază atât abordarea deterministă, cât şi cea probabilistă. În lucrare se prezintă şi aspectele principale privind evaluarea vulnerabilității seismice, necesare pentru evaluarea fragilității seismice a structurilor de construcții situate în zone seimice active. Având in vedere faptul că hărțile de hazard seismic sunt realizate în funcție de scara Mercalli Mofidicată (MMI), în timp ce codurile seismice folosesc valorile de vârf ale accelerației solului (PGA), s-a dedus şi relația între aceste două tipuri de valori în evaluarea seismicității zonale din regiunea Iaşului.