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THE USE OF VULNERABILITY, RISK AND SEISMIC HAZARD CONCEPTS IN MODERN CIVIL ENGINEERING

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Abstract. During past decades, in many seismically active countries, the need to assess the vulnerability of existing structures is becoming more and more important. Buildings' seismic vulnerability evaluation appears as an essential tool used to describe the seismic safety of structures, and is a useful component of disaster preparedness, assessment and loss estimation, buildings' maintenance schedule, etc. It is also an important part of seismic risk reduction. The safety level to a future seismic action corresponds to the vulnerability identified by means of technical assessments.

In order to objectively assess the seismic risk, it is necessary to accurately estimate the effects of previous earthquakes and also the behaviour of different structural types, especially for residential buildings.

The current paper presents general concepts regarding structural vulnerability and seismic hazard.

Key words: vulnerability; risk and seismic hazard.

1. Introduction

In the past decades, civil engineering has experienced a fast progress that led to significant changes both in its basic safety concepts as well as in the

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design codes. It has become necessary to enhance the safety level in relation to current requirements of existing structures – designed and built according to previous regulations. Such and effort should become the basis of response measures aimed at increasing structural safety.

The literature in the field of earthquake engineering studies seismically induced damages by means of vulnerability models. These analyses use fragility and vulnerability models to describe the risk of damage occurrence in those areas where there is a high probability of earthquakes incidence (Lungu *et al*., 2009; Lantada *et al.*, 2010).

2. Vulnerability, Risk and Seismic Hazard

2.1. Vulnerability

Vulnerability can be defined as the damage degree of a structural element exposed to seismic risk, or of a combination of such elements under the action of an earthquake with given characteristics. Vulnerability measures the probability relative to economic and social criteria for achieving or exceeding a given damage value, for a given site and assuming a given exposure period (Calvi *et al*., 2006).

Factors influencing vulnerability depend on the structural failure mode as a result of a seismic action that leads to loss of functionality or onsets the successive collapse of structural members. Structures can fail as a result of efforts exceeding strength capacity or by loss of stability. Failures may have a brittle or ductile characteristic.

Worldwide the seismic vulnerability concept is recognized and used widely both in research and in practical application (Lang & Bachmann, 2004; Erdik, 2003).

Given the multitude of factors, that need to be taken into account when assessing the seismic vulnerability, and accounting for their variability, performing an accurate deterministic vulnerability analysis is nearly impossible. An alternative method implies the use of probabilistic methods to assess the structural behaviour, structural vulnerability being represented by a distribution (probabilistic or statistics) of the damages induced by an earthquake.

According to the United Nations' Office for the Coordination of Humanitarian Affairs (OCHA) a disaster is defined as a "serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its own resources" (U.N. Doc. No. DHA/93/36, 1992).

To better understand the previously presented definition OCHA presents also the following formula:

$$\text{Disaster} = \text{Vulnerability} \times \text{Risk factors.}$$

To assess the vulnerability of damaged structure one needs to quantify the damage state prior to the seismic event. This involves uncertainties that need to be accounted using probabilistic means.

One of the major drawbacks in performing a vulnerability analysis is represented by the lack of statistical data related to a seismic event, especially those describing the *prior* and *posterior* damage state. When analytical and computational tools are used, the existence of statistic databases will help overcome the multitude of obstacles involved by such an analysis. This is due to the existing theories depicting material's constitutive laws and behaviour under loading. Using probabilistic methods to describe the structural behaviour, the vulnerability can be represented by a distribution (statistic or probabilistic) of the damages induced by the earthquake.

From the prediction point of view the vulnerability represents a damage degree distribution class that is function of a parameter, generally one that describes the seismic intensity.

During the design phase, when computing the vulnerability for a class of structures only one major seismic event is considered for a given interval, *T*. For the same class of structures, when computing the risk one accounts for several successive seismic actions, for the same time period, *T*.

2.2. The Seismic Risk Concept

The seismic risk concept is associated with the probability that a given event, based on a decision will produce other effects than those anticipated.

The risk is directly linked with factors and hypothesis that have unfavourable characteristics. As new risk related data become available, the level of understanding in this field is enhanced and also new assessment methodologies are developed.

Seismic risk analyses are bounded by the deterministic predictions regarding seismic events. Such predictions are used to compute the vulnerability of structural elements subjected to seismic loading and to assess the consequences of earthquake induced damages. This is due to the fact that the seismic risk is strongly connected to the building's structural performances.

History shows that due to lack of knowledge, ignorance, etc., wrong decisions had catastrophic effects and resulted in significant material damages and loss of human life.

2.3. Hazard

The hazard reflects the occurrence probability of a potentially destructive event within a well defined area and during a given time (floods, earthquakes, explosions, etc.).

A hazard anticipation measure is given by the probability associated with a certain event to exceed a given value and might be determined using probability distribution functions.

The mathematical models used in hazard prognosis are based on statistical methods and use a large number of events recorded during a very large period of time.

Strictly speaking the seismic hazard is independent with respect to the existing volume of data, being a fundamental natural characteristic. The accuracy of its approximated value can be improved by the use of a larger number of recordings and also by the choice of adequate mathematical models, especially probability distribution functions.

A high value of the hazard does not automatically involve a high level of risk, this being conditioned by a low value of the vulnerability.

The seismic risk (SR) is defined by the damage degree associated with event, *i*, that has an occurrence probability, H_i:

$$(\mathrm{SR})_i = V \times H_i\,. \qquad (1)$$

Nowadays there are two distinct approaches when assessing the seismic induced hazard: the deterministic method and the probabilistic one.

The deterministic method – based on a particular seismic event of a given intensity, on a specific site and used to evaluate ground displacements at the given site.

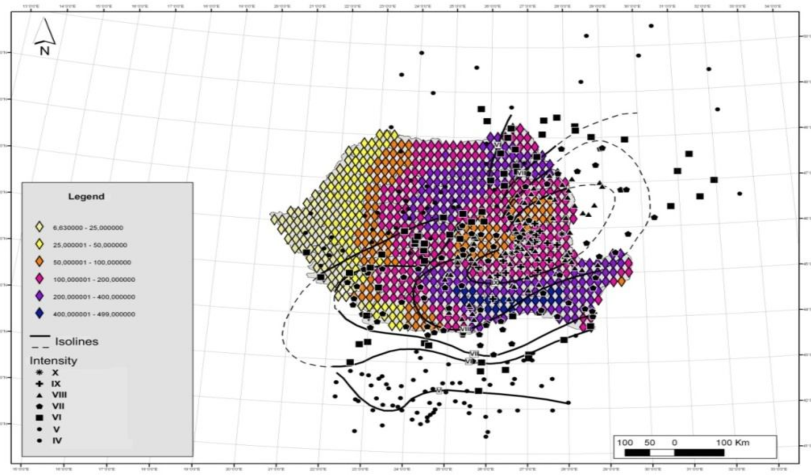

Fig. 1 – Seismic hazard determined using the strongest recorded earthquake with magnitude M_w = 7.7 (10th November 1940, Ardeleanu, 2010).

This method depicts the worst case scenario but fails to provide any information regarding the event’s occurrence. This leads to the method's inability to estimate the probability of a seismic event occurring during the structure's life-span at the given site.

When applying this method to our country, the seismic hazard has been computed using data from the strongest recorded earthquake – with a magnitude of $M_w = 7.7$ (November 10, 1940).

The probabilistic method was proposed, and subsequently accepted worldwide, by Cornell, (1968). Today it is the most commonly used method.

In this case, instead of a seismic event given for every source, a probabilistic distribution is used. For every source an earthquake with a maximum intensity is chosen in order to represent the superior boundary for all other seismic events that are to be considered in the analysis.

Comparing the two methods, it can be noticed that the deterministic approach is an intuitive one, based on choosing a well defined event and using it subsequently as a model.

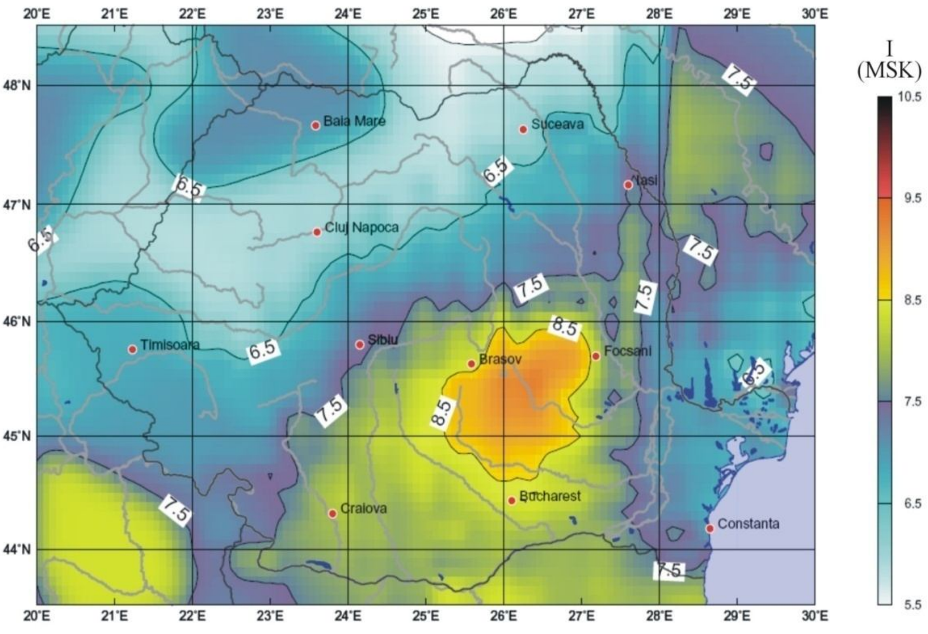

Fig. 2 – Probabilistic seismic hazard computed in terms of microseismic intensity (MSK scale), resulted by considering all seismic zones, with a return period of 475 years (Ardeleanu, 2010).

The hazard includes effects of all earthquakes that are more or less likely to occur at a given site and can use more attenuation models – each with its specific uncertainties. Hazard analysis can include events with different characteristics.

Both methodologies play a significant role in seismic risk and hazard analyses and are designed to support decision making processes as well as criteria selection to initiate structural retrofitting.

In Romania, the highest level of seismic hazard can be found on the curvature area of the Oriental Carpathians. This area generates intermediate depth earthquake that can affect large parts of Central Europe.

3. Conclusions

The hazard is different from the potential natural phenomena that might lead to economic losses and/or human life casualties. It is quantified by the probability that certain parameters that define a phenomenon exceed a certain value at a given time or during a given time interval.

The hazard is the cause of negative effects and not the consequences of the phenomena itself: damage, loss of human life, etc. It can be said that the hazard has as a consequence the fact that losses are quantified through the risk notion.

The risk expresses the probability of economic or human life losses occurrence and it is quantified by the probability that, within a given time interval, the negative effects exceed a given level.

Seismic hazard analyses try to estimate the parameters of ground movement at a given site.

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UTILIZAREA CONCEPTELOR DE VULNERABILITATE, RISC ŞI HAZARD SEISMIC ÎN INGINERIA CIVILĂ NODERNĂ

(Rezumat)

În ultimele decenii a apărut cu prioritate în multe ţări cu risc seismic ridicat, necesitatea evaluării vulnerabilităţii construcţiilor existente. Evaluarea vulnerabilităţii seismice a construcţiilor apare ca un instrument esenţial în vederea descrierii siguranţei seismice a structurilor, fiind utilă în pregătirea pentru dezastre, evaluarea şi estimarea pierderilor, planificarea reparării şi consolidării clădirilor şi reprezintă un aspect important în reducerea riscului seismic. Nivelul de asigurare antiseismică al unei construcţii existente corespunde vulnerabilităţii seismice determinate prin expertiza tehnică.

Pentru o evaluare cât mai obiectivă a riscului seismic este necesar a se cunoaşte efectele cutremurelor anterioare, dar şi comportarea diferitelor tipologii structurale, mai ales pentru clădirile de locuit.

Lucrarea de faţă prezintă concepte generale despre vulnerabilitatea structurilor, hazard şi risc seismic.