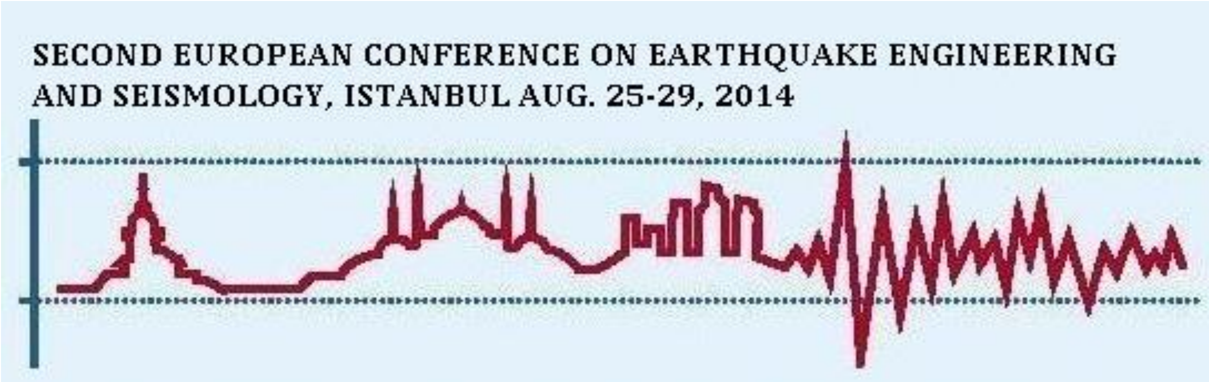

VULNERABILITY ASSESSMENT OF RC BUILDINGS

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ABSTRACT

Seismic vulnerability assessment of reinforced concrete (RC) existing structures can be performed through the use of reliable tools this is in order to reduce damages in case of an earthquake event. The present study deals with the evaluation of the seismic vulnerability of existing reinforced concrete (RC) buildings in Algeria. To do this, a vulnerability index was first developed, in the aim to give a diagnosis of the real state of the building under study. Then base on the developed index, vulnerability curves were derived.

The vulnerability index method is based on the identification of the major parameters that have an influence on the seismic behaviour of RC buildings. Then weighting factors for each parameter are defined based on the seismic feedback experience from Ain Temouchent earthquake (1999) and Boumerdes earthquake (2003). Note that each parameter can belong to one of three defined classes (A, B and C). Class A expresses a parameter inducing a good behaviour of the structure during an earthquake, class C expresses a parameter inducing a bad behaviour of the structure during an earthquake and class B expresses an intermediate behaviour of the structure during an earthquake.

Based on the previous vulnerability index a DPM (Damage Probability Matrices) were developed, and were used to define the mean damage grade which leads to semi-empirical vulnerability curves. These DPM were developed for the north of Algeria which is an area prone to seismicity. The obtained vulnerability curves were compared to those provided by Risk-UE project.

INTRODUCTION

Seismic event vulnerability study is important before any technical decision (AFPS, 2005), (Ansal et al., 2010), (Jayaram et al., 2012), (Giovinazzi, 2005) and (Schmid and Hegg, 2006), such as reinforcement or demolition. Reconnaissance reports from recent Algerian earthquakes, such as Ain-Temouchent in 1999 and Boumerdes in 2003 have shown higher percentage of damages for non-code conforming reinforced concrete (RC) buildings and buildings built according ancient seismic code (RPA, 1988), (RPA, 1999) and (RPA, 2003). As a consequence, they have inadequate lateral load resistance capacity and limited ductility. Furthermore, the vulnerability of these buildings was further aggravated due to presence of other irregularities (e.g.weak story and short columns, etc.). Thus, to illustrate impact of different irregularities and their interaction on building vulnerability assessment, vulnerability index method is undertaken (Belheouane and Bensaibi, 2012), in the first part of this paper.

Consequently Seismic risk assessments were carried out on populations of buildings to identify the buildings most likely to undergo losses during an earthquake. The results of such studies are important in the mitigation of losses under future seismic events as they allow strengthening intervention and disaster management plans to be drawn up.

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Vulnerability curves play a critical role in seismic risk and loss estimation as they give the probability of attaining a certain damage state when a structure is subjected to a specified demand. Such loss estimations are essential for the important purposes of disaster planning and formulating risk reduction policies.

Vulnerability curves may be generated through empirical (Orsini, 1999), (Rossetto and Elnashai, 2003), (Shinozuka et al., 2000), judgment (ATC, 1985), analytical (Mosalam et al., 1997), (Chryssanthopoulos et al., 2000),(Celık and Ellıngwood, 2009), (Ellıngwood et al., 2007), (Rossetto and Elnashaı, 2005) and Hybrid (Kappos et al., 1995) based methods (Rajeev and Tesfamarıam, 2012).

Regional damage assessment tool, such as HAZUS (FEMA, 2003), for example, employs fragility curves to estimate the building vulnerability assessment. However, HAZUS does not consider the presence of different irregularities. As a result, the expected losses can be underestimate. The effect of different irregularities on the vulnerability curves have been studied by different researchers (Dımova and Negro, 2006), (Erberık, 2007), (Kappos and Panagopoulos, 2010), (Lagaros, 2007), (Lagaros, 2008), (Tesfamarıam and Saatcıoglu, 2008), (Tesfamarıam and Saatcıoglu, 2010), so in the second part of this paper vulnerability curves will be derived using the vulnerability index method, which take into account different irregularities.

VULNERABILITY INDEX METHOD

The method consists in attributing a numerical value to each building representing its "seismic quality". This number is called vulnerability index (VI); it is obtained by a sum of the numerical values expressing the "seismic quality" of the structural and non structural items which are deemed to play a significant role in the seismic response of the building (Benedetti et al., 1988), (Yépez et al., 1996).

The items' coefficients are determined on a basis of a statistical data containing constructions damaged by different earthquakes (Ain Temouchent (1999) and Boumerdes (2003)). The considered parameter can take only one factor. For RC buildings, each parameter considered can belong to one of the three defined classes A, B and C.

These categories are declined as follows:

A expresses a parameter inducing a good behaviour of the structure during an earthquake,

B expresses a parameter inducing a bad behaviour of the structure during an earthquake,

C expresses an intermediate behaviour of the structure during an earthquake.

Table 1 gives the identified items with their coefficients.

Table 1. Items Coefficients

N°	Items	Classes / Ki		
		A	B	C
1	Frame System	0.00	0.09	0.16
2	Quality of the Frame System	0.01	0.03	0.06
3	Seismic Capacity	0.00	0.01	0.03
4	Type of Soil	0.01	0.03	0.06
5	Horizontal Diaphragm	0.01	0.03	0.06
6	Plan Regularity	0.01	0.03	0.06
7	Elevation Regularity	0.00	0.06	0.12
8	Quality of the Nodes	0.01	0.03	0.06
9	Short Column	0.01	0.03	0.06
10	Details	0.01	0.03	0.06
11	Maintenance Conditions	0.00	0.06	0.09
12	Modifications	0.01	0.03	0.06
13	Pounding Effect	0.01	0.03	0.06
14	Ground Conditions	0.01	0.03	0.06

The feedback of seismic experience was prevailing in the determination of the above coefficients, in the sense that a statistical analysis relative to 87 buildings in the case of Ain Temouchent Earthquake (1999) and 567 buildings in the case of Boumerdes earthquake (2003) was performed. This allows providing the correlation coefficients, given in figure 1, between some single parameters and the total vulnerability index for both considered earthquakes.

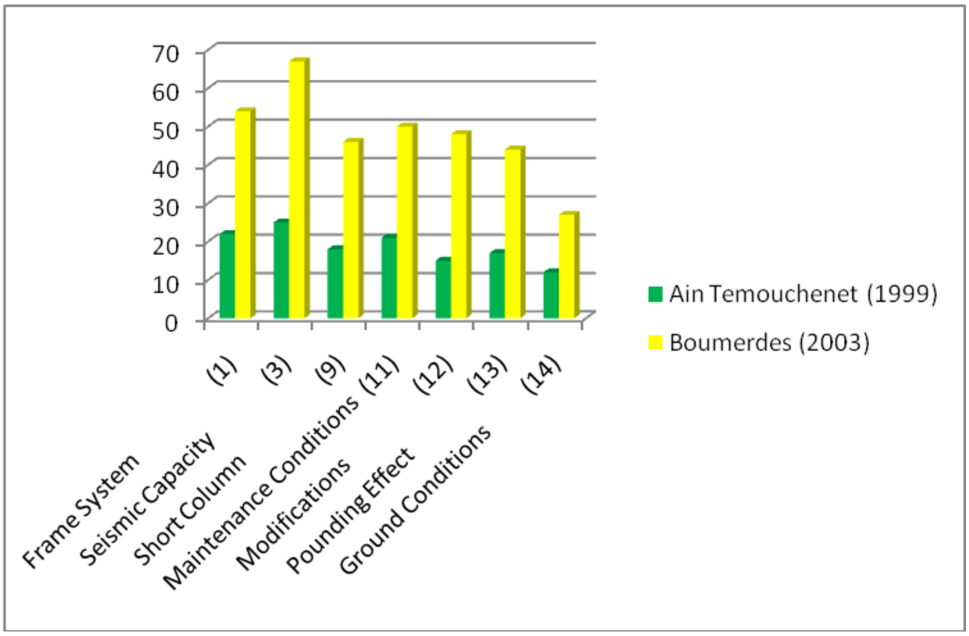

Figure 1. Correlation Coefficients of total VI to Partial VI of some parameters

This figure shows that the Seismic capacity is the most influent parameter, followed by the Frame system. The parameters: Short columns, Maintenance conditions, Modification and Pounding effect have quite the same weight.

According to table 1, the vulnerability index is expressed as:

$$VI = \sum_{i=1}^{14} Ki \qquad (1)$$

According to the vulnerability index value obtained, three vulnerability classes are proposed (Table 2).

Table 2. Vulnerability Classes for RC Building

Class	Green		Orange		Red
	1	2	3	4	5
VI	0.10- 0.20	0.20 – 0.40	0.40 – 0.55	0.55– 0.70	0.70 – 1.00
VImean	0,150	0,300	0,475	0,625	0,850

The first class associated to the Green color classifies the construction as resistant with no requirement to any repairs.

The second class associated to the Orange color classifies the construction as moderately resistant requiring reinforcement.

The third class associated to the Red color classifies the construction to be a construction with low resistance requiring demolition or significant strengthening.

SEMI EMPIRICAL VULNERABILITY CURVES

In Table 3, five damage categories are defined; the description of each one is given here after:

Table 3. Damage Categories

Class	Grade	Description
Green	1	Negligible to Light Damage.
Green	2	Light for the Structured Elements and Moderate for the not Structured Elements.
Orange	3	Moderated for the Structural Elements and Heavy for the Non -Structural.
Orange	4	Heavy for the Structural and Very Heavy for the Non -Structural.
Red	5	Very Heavy for the Structured, Collapse Total or Close.

In this work five vulnerability classes associated to the damage categories are defined and arranged in an increasing order. Each building class (Table 4, 5, 6, 7 and 8) is correlated with a relation between earthquake intensity and damage experienced. These building classes are called Damage Probability Matrices (DPM).

Table 4. Class Green 1

Damage Intensity	1	2	3	4	5
III					
IV					
V					
VI	Rare				
VII	Few	Rare			
VIII	Many	Few	Rare		
IX		Many	Few	Rare	
X			Many		
XI					
XII					

Table 5. Class Green 2

Damage Intensity	1	2	3	4	5
III					
IV					
V	Rare				
VI	Few				
VII	Many	Few			
VIII		Many	Few		
IX			Many	Rare	
X					
XI					

Table 6. Class Orange 3

Damage Intensity	1	2	3	4	5
III					
IV	Rare				
V	Few	Rare			
VI	Many	Few	Rare		
VII		Many	Few	Rare	
VIII			Many	Few	
IX				Many	
X					
XI					
XII					

Table 7. Class Orange 4

Damage / Intensity	1	2	3	4	5
III	Rare				
IV	Few				
V	Many	Few			
VI		Many	Few		
VII			Many	Few	
VIII			Most	Many	Few
IX				Most	Many
X					
XI					
XII					

Table 8. Class Red 5

Damage / Intensity	1	2	3	4	5
III	Rare				
IV	Few	Rare			
V	Many	Few			
VI		Many	Few		
VII			Many	Few	
VIII			Most	Many	Few
IX				Most	Many
X					Most
XI					
XII					

The used terms Rare, Few, Many and Most are defined as follow:
Rare : The percentage of damaged buildings range between 0 and 5%
Few : The percentage of damaged buildings range between 0 and 20%
Many : The percentage of damaged buildings range between 0 and 40%
Most : More than 60% of the buildings were damaged for a given intensity.

Beta distribution can be used to calculate continuous DPM for every vulnerability class. The parameters of the Beta distribution are then correlated with the Mean Damage grade μ_D.

The mean damage grade shall be estimated for buildings vulnerability index and the corresponding seismic intensity as follows:

$$\mu_D = 2{,}55*(1+TANH((I+(7*VImean)-13)/2{,}5)) \quad (2)$$

The vulnerability curves obtained are called semi empirical vulnerability functions and are represented on figure 2.

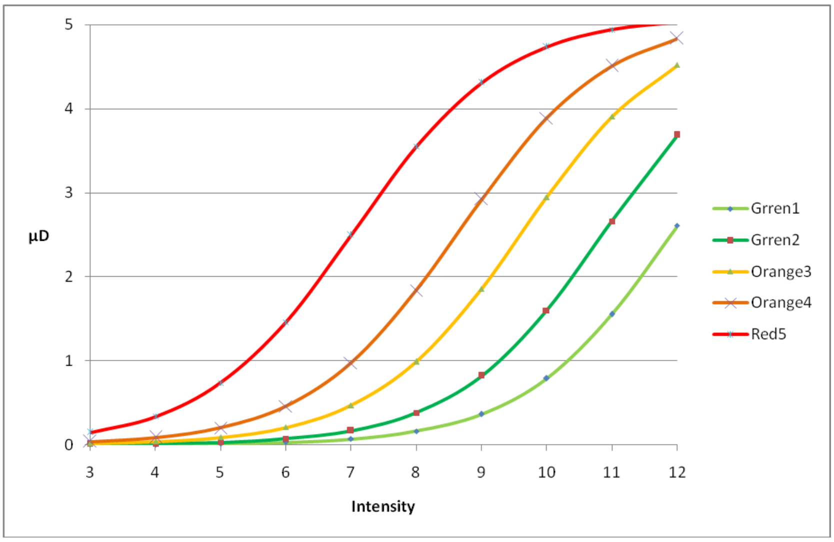

Figure 2. Mean Semi Empirical Vulnerability functions

Using RISK-UE method, vulnerability functions were drawn in order to compare with those obtained for Algeria. The RISK-UE functions were derived for European buildings. The obtained curves are given in figure 3.

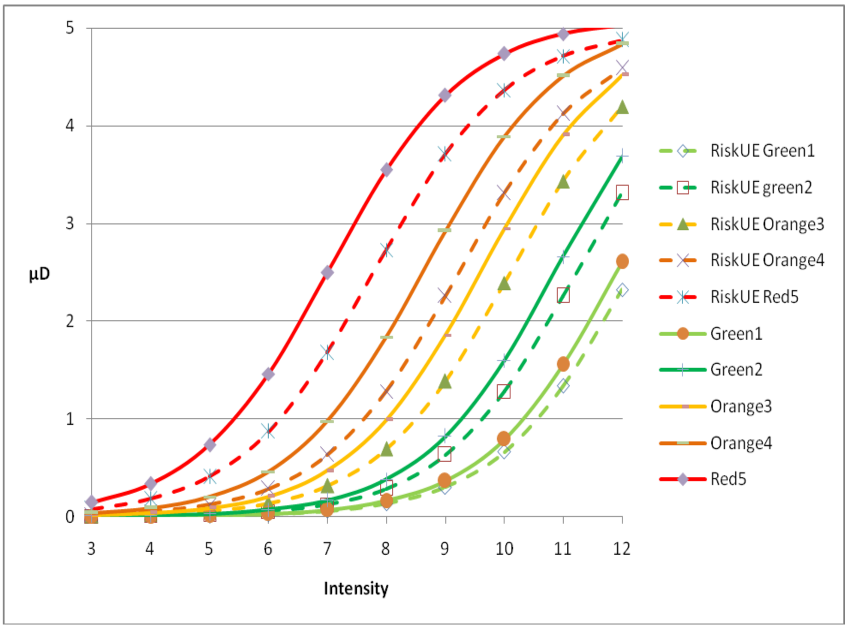

Figure 3. Vulnerability Curves

It can be noticed that the Algerian vulnerability curves are more conservative than those given by RISK-UE, this is due to the lack of maintenance and the transformation done which are not in accordance with the Algerian seismic regulation code in practice.

CONCLUSIONS

The paper deals with the seismic vulnerability of Reinforced Concrete (RC) buildings. In the first part vulnerability index method was developed. The parameters that have an influence on the seismic behaviour of a structure were identified and a weighting factor was given to each parameter according the defined building categories. The feedback of Ain temouchent (1999) and Boumerdes (2003) earthquakes was used. This method allows classifying RC buildings according to their vulnerability through a calculated index (VI).

In the second part Damage Probability Matrices (DPM) were defined. Then using the continuous form of these DPM and the vulnerability index, semi empirical vulnerability functions were derived. These ones represent the vulnerability curves for Algerian RC buildings. These vulnerability functions take into account implicitly different irregularities that can exist in the structure.

At least a comparison between the obtained vulnerability curves and the ones given by RISK-UE was done. This comparison shows that the Algerian RC buildings are more vulnerable to seismic action than those of European countries. This is due to the lack of maintenance and the non respect of the seismic code in practice by the population.

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