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Vulnerability Curves of Reinforced Concrete Buildings

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ABSTRACT

In case of a seismic event, vulnerability studies of structures are of a major importance before any technical decision, such as reinforcement or demolition. For this purpose, reliable diagnosis tool is necessary and in order to prevent damages vulnerability curves must be used. In this study a vulnerability index for reinforced concrete (RC) structures in Algeria is developed. This one gives the state of a building before and/or after an earthquake. Based on this index, Damage Probability Matrices (DPM) were developed, and used to define the mean damage grade which leads to semi-empirical vulnerability curves. The obtained vulnerability curves were compared to those provided by Risk-UE project. In the framework of this project vulnerability and fragility curves were developed for European cities. The comparison shows that Algerian buildings are more vulnerable than European ones.

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INTRODUCTION

In Algeria, the reconnaissance reports from recent earthquakes such as Ain-Temouchent (1985) and Boumerdes (Rossetto, T., A. Elnashai, 2003) have shown higher percentage of damages for reinforced concrete (RC) buildings. To reduce these damages vulnerability curves can be used.

Vulnerability curves play a critical role in seismic risk and loss estimation as they give the mean damage ratio when a structure is subjected to a specified demand. Vulnerability curves may be generated through empirical (Celik, O.C., B.R. Ellingwood, 2009), judgment (ATC 1985), analytical (Ellingwood, B.R., 2007; Kappos, A.J., G. Panagopoulos, 2010) and/or Hybrid (FEMA (Federal Emergency Management Agency), 2003) methods (Rajeev 2009). Regional damage assessment tool, such as HAZUS (Dimova, S.L., P. Negro, 2006), for example, employs fragility curves to estimate the building vulnerability assessment.

It was also shown that vulnerability curves are greatly influenced by irregularities short columns, elevation irregularities, weak story, …) (Erberik, M.A., 2007; Belheouane, F.I., M. Bensaibi, 2012).

Within this paper vulnerability curves for RC buildings are derived. In order to take into account the effect of different irregularities, vulnerability index method was developed and DPM were built too, using feedbacks from past earthquakes. These tools were combined to derive RC structures vulnerability function.

Vulnerability Index Method:

The method consists in attributing a numerical value to each building representing its "seismic quality". The items' coefficients are determined on a basis of a statistical data containing constructions damaged by different Algerian earthquake. For RC buildings, each parameter considered can belong to one of the three defined categories C1, C2, and C3. The C1 expresses a parameter inducing a good behavior of the structure during an earthquake, The C2 expresses a parameter inducing a bad behavior of the structure during an earthquake and the C3 expresses an intermediate behavior of the structure during an earthquake. Table 1 gives the identified items with their coefficients (Belheouane, F.I., M. Bensaibi, 2012; Rajeev, P., S. Tesfamariam, 2009).

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 (ATC, 1985) and 567 buildings in the case of Boumerdes earthquake (Rossetto, T., A. Elnashai, 2003) was performed. According to Table 1, the vulnerability index is expressed as:

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

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Table 1: Vulnerability parameters and weighting factors.

Number	ITEMS	Categories / Ki		
		C1	C2	C3
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

Then three vulnerability classes are proposed for each category (Table 2).

Table 2: Vulnerability Index 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

Semi Empirical Vulnerability Curves:

Five vulnerability classes are defined. Each building class is correlated with a relation between earthquake intensity and damage experienced. These building classes are called Damage Probability Matrices (DPM).

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. This one can be expressed as:

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

The vulnerability curves obtained are called semi empirical vulnerability functions and are represented on Figure 1a. 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 1b.

Table 3: Class Green 1 and Green 2.

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

Table 4: Class Orange 3 and Orange 4.

Damage Intensity	Class Orange 3					Class Orange 4				
	1	2	3	4	5	1	2	3	4	5
V						Rare				
VI	Rare					Few				
VII	Few	Rare				Many	Few			
VIII	Many	Few	Rare				Many	Few		
IX		Many	Few	Rare				Many	Few	
X			Many	Few				Most	Many	Few
XI				Many					Most	Many
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.

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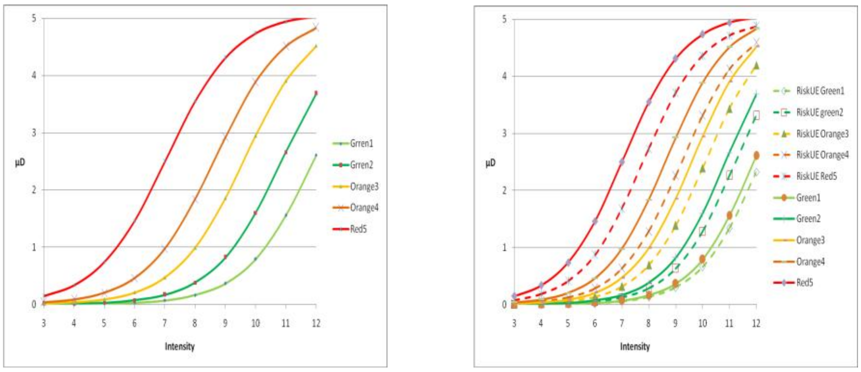
Table 5: Class Red 5.

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					

As it can be seen, most of Algerian RC buildings begin suffering damages from intensity 7, most important damages will occur for intensity between 8 and 11 and for intensity 12 most of them collapse.

It can be also noticed that the Algerian vulnerability curves are more conservative than those given by RISK-UE project. The difference between the two methods ranges from 4 to 12%. This is due essentially to the lack of maintenance and the transformation done in the Algerian structures, which are not in accordance with the Algerian seismic regulation code.



(a) (b)

Fig. 1: Vulnerability functions: (a) for Algerian RC buildings and (b) comparison.

Conclusion:

Seismic vulnerability studies of RC buildings can be conducted using vulnerability index method in order to have a diagnosis of the studied structures and by using vulnerability curves which give the mean damage ratio 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.

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