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Assessment of Vulnerability Curves Using Vulnerability Index Method for Reinforced Concrete Structures

F. I. Belheouane and M. Bensaibi

***Abstract*—**The seismic feedback experiences in Algeria have shown higher percentage of damages for non-code conforming reinforced concrete (RC) buildings. Furthermore, the vulnerability of these buildings was further aggravated due to presence of many factors (e.g. weak the seismic capacity of these buildings, shorts columns, Pounding effect, etc.).

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.

Within this paper, the state of the existing structures is assessed using "the vulnerability index" method. This method allows the classification of RC constructions taking into account both, structural and non structural parameters, considered to be ones of the main parameters governing the vulnerability of the structure. Based on seismic feedback from past earthquakes DPM (damage probability matrices) were developed too.

***Keywords*—**Seismic vulnerability, Reinforced concrete buildings, Earthquake, DPM, Algeria.

I. INTRODUCTION

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. These RC buildings were designed for gravity loads and the introduction of modern seismic design code provisions was done according ancient seismic code [1], [2]. 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 [3], [4].

Consequently Seismic risk assessments were carried out on populations of buildings to identify the buildings most likely to undergo losses during an earthquake [29-30]. 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.

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 [5]-[7], judgment [8], analytical [9]-[14] and Hybrid [15] based methods [16].

Regional damage assessment tool, such as HAZUS [17], for example, employs fragility curves to estimate the building vulnerability assessment. However, HAZUS does not consider the presence of different irregularities in the assessment, as a result, can underestimate level of expected losses. The effect of different irregularities on the vulnerability curves have been studied by different researchers [18]-[24], [31]-[33].

Within this paper Vulnerability index method is presented and applied on a example then damage probability matrices are derived and vulnerability curves are determined.

II. VULNERABILITY INDEX METHOD BACKGROUND

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 summing the numerical values expressing the “seismic quality” of the structural and non structural parameters which are deemed to play a significant role in the seismic response of the building [25], [26].

The parameters’ 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 classes are defined as follows:

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

C expresses a parameter inducing a bad behavior of the structure during an earthquake,

B expresses an intermediate behavior of the structure during

F. I. Belheouane. Is an assistant professor in Civil engineering department, University of Saad Dahlab, Blida, Algeria (phone: 213-25-433939; e-mail: fimenbb@yahoo.fr).

M. Bensaibi. Is a profesor in Civil engineering department, University of Saad Dahlab, Blida, Algeria (phone: 213-25-433939; e-mail: bensaibim@yahoo.co.uk).

an earthquake.

Table I gives the identified items with their coefficients.

TABLE I
ITEMS COEFFICIENTS

N°	ITEMS	Categories / Ki A	B	C
1	Frame system	0.00	0.09	0.16
2	Quality of the Frame system [27], [28]	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 “Details” parameter was specified as follows: studwork, dividing walls, balconies, railing, cornices, chimneys, ventilation space, electrical network, gas network, water network and sewage network.

The feedback of seismic experience was prevailing in the determination of the above coefficients, in the sens 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 figure1, between some single parameters and the total vulnerability index for both considered earthquakes.

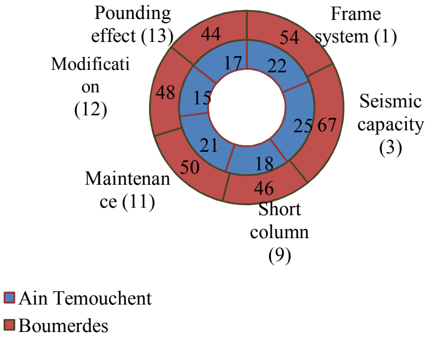

Fig. 1 Correlation coefficients changer

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 I, the vulnerability index is expressed as: [24] - [26].

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

This index varies from 0 to 1. According to the vulnerability index obtained, five classes of vulnerability were proposed: green 1, green 2, orange 3, orange 4 and red 5. This classification is presented in Table II.

TABLE II
VULNERABILITY INDEX CLASSES FOR RC BUILDING

CLASS	GREEN 1	2	ORANGE 3	4	RED 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 defined classes were correlated with observed damage which was established as: Negligible, Minor, Moderate, Serious and Collapse (Table III).

TABLE III
DAMAGE CATEGORIES

Damage categories	Class		Description
Negligible	1	Green1	Negligible to light damage.
Minor	2	Green2	Light for the structured elements and moderate for the not structured elements.
Moderate	3	Orange3	Moderated for the structural elements and heavy for the non -structural.
Serious	4	Orange4	Heavy for the structural and very heavy for the non -structural.
Collapse	5	Red5	Very heavy for the structured, collapse total or close.

III. DAMAGE PROBABILITY MATRICES

In this work five vulnerability classes associated to the damage categories were defined and arranged in an increasing order. Each building class (Table IV, V, VI, VII and VIII) was correlated with a relation between earthquake intensity and damage experienced. These building classes are called Damage Probability Matrices (DPM).

TABLE IV
CLASS GREEN 1

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

TABLE V
CLASS GREEN 2

Damage Intensity	1	2	3	4	5
V					
VI					
VII	Rare				
VIII	Few				

IX	Many	Few			
X		Many	Few		
XI			Many	Rare	
XII					

TABLE VI
CLASS ORANGE 3

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

TABLE VII
CLASS ORANGE 4

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

TABLE VIII
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 5 and 20%

Many : The percentage of damaged buildings range between 20 and 60%

Most : More than 60% of the buildings were damaged for a given intensity.

IV. VULNERABILITY CURVES

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 Fig. 2.

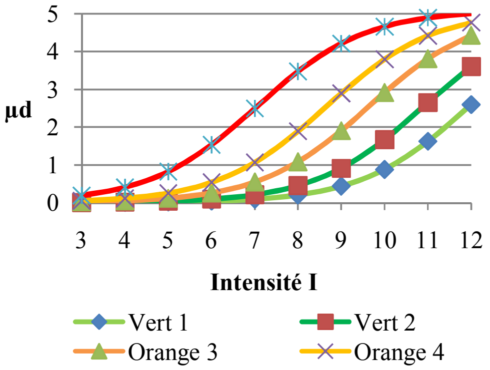

Fig. 2 Vulnerability curves for RC structures

These vulnerability curves are in adequacy with the observation made in situ after past earthquake in Algeria.

V. APPLICATION

Several examples of reinforced concrete constructions were treated; an example is presented here after.

The present case study is about 48 bungalows located at Rechgoun a locality west Algiers (about 400KM) and near Ain Temouchent.

A view of a bungalow is given on Fig. 3.

Fig. 3 View of a bungalow

The results of the survey are given in Table IX.

TABLE IX
RESULTS FOR BUNGALOWS

Parameter	class	Ki
Frame system	A	0
Quality of the Frame system	A	0.01
Seismic capacity	A	0
Type of soil	C	0.06
Horizontal diaphragm	A	0.01
Plan Regularity	C	0.06
Elevation Regularity	A	0
Quality of the nodes	B	0.03
Short column	A	0.01
Details	A	0.01

Maintenance conditions	A	0
Modifications	A	0.01
Pounding effect	A	0.01
Ground conditions	A	0.01

A vulnerability index of 0.22 was found, this indicates that the structure belong to the Green 1 class. The conclusion provided by the Structural Engineering Control (CTC) is: According to the Algerian standard, the structural elements are able to sustain the efforts that are subjected to.

So the tow conclusions are in adequacy.

Several other cases were treated and the results were compared to those provided by the CTC or other national organization. The adequacy of the conclusions was observed in a large proportion (more than 85%).

Note that, following Ain Temouchent earthquake, no damages were observed on these constructions. So this corroborates the conclusion of the vulnerability curves.

VI. CONCLUSION

Vulnerability index method was developed in order to classify RC buildings according their seismic resistance to earthquakes. Damage probability matrices (DPM) were developed also for this kind of structure. These matrices are based on seismic feedback from past earthquakes in Algeria (Ain Timouchent 1999 and Boumerdes 2003). These DPM give the percentage of the damage according to the seismic intensity and the building vulnerability class. Then using the continuous form of these DPM and the vulnerability index, 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.

REFERENCES

[1] RPA88, Règlement parasismique Algérien, Centre National de Recherche en Génie Parasismique, Algiers, 1988.

[2] RPA99, Règlement parasismique Algérien, Centre National de Recherche en Génie Parasismique, Algiers, 1999.

[3] F I Belheouane and M Bensaibi, “Seismic vulnerability index for reinforced concrete construction in Algeria”, Advanced Science Letter, Vol. 13, 2012, pp. 364-368.

[4] F I Belheouane and M Bensaibi, “Evaluation of the vulnerability index for reinforced concrete construction in Algeria under seismic action”, International Journal of Advances and Trends in Engineering Materials and their Applications (IJATEMA), Vol. 1, No 1, 2012, pp 101 – 106.

[5] G Orsini, “A model for buildings’ vulnerability assessment using the parameter less scale of seismic intensity (PSI)”, Earthquake Spectra, Vol. 15, No 3, 1999, pp 463–483.

[6] T Rossetto And A. Elnashai, “Derivation of vulnerability functions for European-type RC structures based on observational data”, Engineering Structure, Vol. 25, No 10, 2003, pp1241– 1263.

[7] M Shinozuka, Q Feng, J Lee And T Naganuma, “Statistical analysis of fragility curves”, ASCE Journal Engineering, Vol. 126, No 12, March 2000, pp 1224–1231.

[8] ATC. Earthquake damage evaluation data for California. ATC-13 report, Redwood City, Applied Technology Council, California, 1985.

[9] K M Mosalam, G Ayala, R N White AND C Roth, “Seismic Fragility Of LRC Frames with and without masonry infill walls”, Earthquake Engineering, Vol. 1, No 4, 1997, pp 693–720.

[10] A M Reinhorn, R Barron-Corvera AND A G Ayala, “Spectral evaluation of seismic fragility of structures”, Structural safety and reliability, ICOSSAR 2001, 2001.

[11] M K Chryssanthopoulos, C Dymiotis And A J, Kappos, “Probabilistic evaluation of behaviour factors in EC8-designed R/C frame”s. Engineering Structure, Vol. 22, No 8, 2000, pp 1028–1041.

[12] O C Celik And B R Ellingwood, “Seismic risk assessment of gravity load designed reinforced concrete frames subjected to Mid-America ground motions.” ASCE Journal of Structure Engineering, Vol. 135, No 4, 2009, pp 414–424.

[13] B R Ellingwood, O C Celik And K Kinali, “Fragility assessment of building structural systems in Mid America”, Earthquake Engineering Structure Dynamic, Vol. 36, No 13, 2007, pp1935–1952.

[14] T Rossetto And A Elnashai, “A new analytical procedure for the derivation of displacement-based vulnerability curves for populations of RC structures”, Engineering Structure , Vol. 27, No 3, 2005, pp397–409.

[15] A Kappos, K Pitilakis, K Stylianidis, K Morfidis And D Asimakopoulos, “Cost-benefit analysis for the seismic rehabilitation of buildings in Thessaloniki, based on a hybrid method of vulnerability assessment”. Proceedings of the fifth international conference on seismic zonation, pp 406–413, 1995.

[16] P Rajeev And S Tesfamariam, “Seismic fragilities for reinforced concrete buildings with consideration of irregularities”, Structural Safety, No39, 2012, pp. 1-13

[17] FEMA (Federal Emergency Management Agency). HAZUS-MH MR3 technical manual, Washington, DC FEMA, 2003.

[18] S L Dimova And P Negro, “Assessment of seismic fragility of structures with consideration of the quality of construction”. Earthquake Spectra, Vol 22, No 4, 2006, pp 909–936.

[19] M A ERBERIK, “Generation of fragility curves for Turkish masonry buildings considering in-plane failure modes”. Earthquake Engineering and Structural Dynamics, Vol. 37, No 3, 2007, pp 387–405.

[20] A J, Kappos, G Panagopoulos, “Fragility curves for reinforced concrete buildings in Greece”, Structural Infrastructure Engineering, Vol. 6, No 1, 2010, pp 39–53.

[21] D N Lagaros, “Life-cycle cost analysis of design practices for RC framed structures”. Bulletin of Earthquake Engineering, Vol. 5, 2007, pp 425–42.

[22] N D LAGAROS, “Probabilistic fragility analysis: a tool for assessing design rules of RC buildings”. Earthquake Engineering and Engineering Vibration, Vol. 7, No 1, 2008, pp 45–56.

[23] S Tesfamariam And M Saatcioglu, “Risk-based seismic evaluation of reinforced concrete buildings”. Earthquake Spectra, Vol. 24, No 3, 2008, pp 795–821.

[24] S Tesfamariam And M Saatcioglu, “Seismic vulnerability assessment of reinforced concrete buildings using hierarchical fuzzy rule base modeling”, Earthquake Spectra, Vol. 26, No 1, 2010, pp 235–56.

[25] RPA99 V.2003, Règlement parasismique Algérien, Centre National de Recherche en Génie Parasismique, Algiers, 2003.

[26] F I Belheouane and M Bensaibi, “Evaluation de l’indice sismique des structures en béton armé, Cas d’étude : structures en béton armé en Algérie “, 8ème Colloque National AFPS 2011 ,Paris, France, 06-08 Séptembre 2011

[27] F I Belheouane and M Bensaibi, F. Djaalali., “Seismic Vulnerability Index for Reinforced concrete construction”, 7th national Conference on Earthquake Engineering, Istanbul, Turkey, 30 Mai-3 June 2011. pp86

[28] F I Belheouane and M Bensaibi, “Evaluation of the Vulnerability Index for Reinforced Concrete Constructions in Algeria”, Seventh International conference on Advances and Trends in Engineering Materials and their Applications, AES-ATEMA , Milan, Italy, 04-08 July 2011 PP113-118

[29] D Benedetti, G Benzoni And M A Andparisi, (), “Seismic vulnerability and risk evaluation for old urban nuclei”, Earthquake Engineering and Structure Dynamic, 1988, Vol. 16, pp 183-201.

[30] F. Yépez, A H. Barbat And J A. Canas., “A Method to Perform Computer Simulations of Damage in Buildings for Seismic Risk Evaluation”, Technical University of Catalonia, Spain, 1996.

[31] S. Giovinazzi And Lagomarsino S., “Seismic risk analysis: a method for the vulnerability analysis of built-up areas”, European Safety and Reliability Conf. ESREL, Maastricht, The Netherlands. June 2003.

[32] S. Lagomarsino And S. Podestà, “Seismic vulnerability of ancient churches. Part 2: statistical analysis of surveyed data and methods for risk analysis”, Earthquake Spectra, 2004, vol 20, no2, pp395-412.

[33] S. Lagomarsino. And S. Podestà. “Damage and vulnerability assessment of churches after the 2002 Molise, Italy, earthquake”. Earthquake Spectra, 2004, vol 20, noS1, pp S271-S283.