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Seismic Damage Index as a Function of Seismic Vulnerability for Structures in Non-Structural Masonry and Reinforced Concrete, in City of Sincelejo

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Abstract

Seismic Vulnerability Studies have been applied in various cities to determine the degree of damage due to the occurrence of an earthquake, at different seismic accelerations. The main objective of this work is to propose a methodology to obtain Vulnerability Functions between the Degree of Damage and the Vulnerability Index, without having to wait for a seismic phenomenon that causes damage to buildings. To obtain the Seismic Vulnerability, the Vulnerability Index Method was applied, and for the degree of Damage the Abrams Mathematical Model for structures in Non-Structural Masonry, and the Pushover Analysis for structures in Reinforced Concrete were used. The results obtained are Tables and Graphs of Vulnerability Functions, for the types of structures analyzed, which is a functional tool for future studies of Seismic Risk in the area.

Keywords: Seismic damage index, seismic vulnerability, non-structural masonry, reinforced concrete

I. INTRODUCTION

The Vulnerability functions, for the structures, relate the Vulnerability Index with the degree of damage, for a given Seismic acceleration [1], in which different levels of threat or danger are evaluated, considering the degree of damage, as an Economic Damage Index overall of the building [2]. The Seismic Vulnerability of the structures was determined by means of the Vulnerability Index Method or Italian Method [3], due to its effectiveness in studies of Seismic Risk in urban areas [4], since it is based on real data [5]. The Vulnerability functions were determined for structures in Non-Structural Masonry and in Reinforced Concrete, since the method only applies to these two types.

Vulnerability functions have been found in different cities, but in Colombia, few cities have these, as is the case of Bogotá, Bucaramanga and Manizales. In the Caribbean Region, the pioneer cities in this type of study have been Barranquilla and Sincelejo, where the first works were developed.

II. CAPACITY SPECTRUM

This part consists of determining the performance point of a structure when it is subjected to seismic movements of different intensities, that is, the capacity to resist lateral forces is compared with the seismic demand, represented by means of a reduced response spectrum. The true behavior of the structure is evaluated with three threat levels: service (0.065g), design (0.125g) and severe (0.15g), obtained from the seismic danger curve of the city of Sincelejo [6].

Obtaining the damage scenarios and Vulnerability functions can be done by simulating the results based on mathematical models of the structures. The application of the methods will require the description of the buildings as a structural model.

III. APPLICATION OF THE METHOD

In each of the two types of structures analyzed, Non-Structural Masonry and Reinforced Concrete, the Demand-Capacity balance philosophy includes the following general stages: structural modeling, vulnerability assessment, capacity assessment and damage determination.

For the evaluation of Seismic Vulnerability, the Vulnerability Index Method was used [3], in which the most important parameters that control the damage to buildings caused by an earthquake are identified. The method qualifies various aspects of buildings, trying to distinguish the differences existing in the same type of construction or typology, or year of construction [5]. The studies in plan and elevation configuration, the type and quality of the materials used, the position of the building's foundation, the arrangement of the structural elements, as well as the state of conservation, are individually rated on a numerical scale affected by a weight factor, which tries to highlight the importance of a parameter with respect to the rest.

In Tables 1 and 2 [7], the parameters are identified with their respective weight W.

Table 1. Numerical Scale of the Vulnerability Index for Non-Structural Masonry Structures

#	Parameter	KiA	KiB	KiC	KiD	Peso Wi
1	Resilient system organization	0	5	20	45	1.00
2	Robust system quality	0	5	25	45	0.25
3	Conventional Resistance	0	5	25	45	1.50
4	Building position and foundation	0	5	25	45	0.75
5	Horizontal diaphragms	0	5	15	45	1.00
6	Plant configuration	0	5	25	45	0.50
7	Elevation configuration	0	5	25	45	1.00
8	Maximum separation between walls	0	5	25	45	0.25
9	Roof type	0	15	25	45	1.00
10	Non-structural elements	0	0	25	45	0.25
11	State of conservation	0	5	25	45	1.00

Table 2. Numerical Scale of the Vulnerability Index for Reinforced Concrete Structures

#	Parameter	KiA	KiB	KiC	Peso Wi
1	Resilient system organization	0	1	2	4.0
2	Robust system quality	0	1	2	1.0
3	Conventional Resistance	-1	0	1	1.0
4	Building position and foundation	0	1	2	1.0
5	Horizontal diaphragms	0	1	2	1.0
6	Plant configuration	0	1	2	1.0
7	Elevation configuration	0	1	3	2.0
8	Maximum separation between walls	0	1	2	1.0
9	Roof type	0	1	2	1.0
10	Non-structural elements	0	1	2	1.0
11	State of conservation	0	1	2	2.0

For the structures in Non-Structural Masonry, 26 buildings were analyzed, in which their structural and architectural plans were obtained, taking into account significant differences between one structure and another, so that the result was as representative as possible of the city of Sincelejo. In the analysis of this type of structures, the following expression is used, taking into account that the Seismic Vulnerability gives results between 0% (the least vulnerable), and 382.5% (the most vulnerable), so it is necessary, to work in the same range to the different types of structures, standardize it between 0% and 100%.

$$I_V = \sum_{i=1}^{11} (K_i * W_i) \qquad (1)$$

Similarly, 10 concrete structures were analyzed in which the following expression was used, giving results between 0% and 100%, as in the masonry structures.

$$I_V = 10 * \left| \frac{\sum_{i=1}^{11} Ki * Wi + 1}{4} \right| \qquad (2)$$

In buildings, in which the plans were not complete, were in poor condition, or simply did not have them, it was necessary to carry out a survey, in which the information was obtained to be able to apply the method. Once the Vulnerability Index was determined, the models were performed to find the degree of damage. In the non-structural masonry, the Abrams mathematical model was used [8], which detects how the wall fails, and evaluates its real capacity at lateral load. The key is to calculate the shear stresses associated with the different types of failure and to establish an order of occurrence. In figure 1 a diagram of the balance of forces on the wall is observed, in which the parameters to be taken into account appear.

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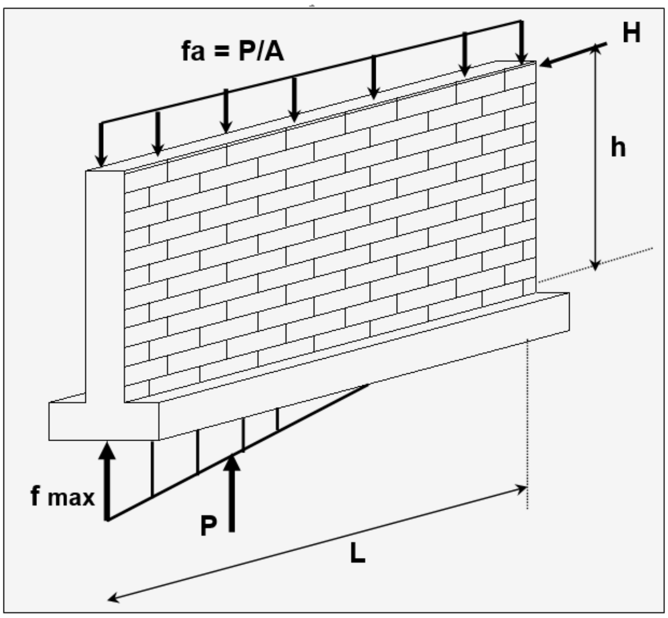

Fig. 1. Representative wall for the Abrams mathematical model for non-structural masonry

To obtain the capacity curve of the structures in Reinforced Concrete, a PUSHOVER analysis was performed using the SAP2000 software [9], [10]. The analysis requires knowing the sectional characteristics of the elements that constitute the main structure in the study direction, which can be defined through the same software, from the data supplied for each of the buildings, with the geometric characteristics of each element and with the reinforcement that was found in the structural plans. The capacity curve was obtained based on the parameters determined with the SAP2000 software, and by means of a non-linear static analysis of the model, the capacity curve was obtained for each of the analyzed structures.

The scale chosen to determine the ranges of the damage states is the one proposed by ATC-13 (1985). Table 3 represents the description of each of the damage states [11].

Table 3. Damage degree scale

Damage level	Damage range (%)	Description
No damage	0	No material damage
Very slight	0-1	Minimal damage that requires no repair
Slight	1-10	Minor localized damage to some elements that does not always require repair
Moderate	10-30	Minor localized damage to many elements that must be repaired
Heavy	30-60	Extensive damage requiring major repairs
Very heavy	60-100	Widespread serious damage that may mean demolition of the structure
Destruction	100	Total destruction or collapse

Once the vulnerability index and the damage index at different seismic accelerations had been calculated for each building, a statistical analysis was carried out, where the Vulnerability functions were found. The correlations are shown in tables 4 and 5 for structures in Non-Structural Masonry and in Reinforced Concrete, respectively. The functions were obtained from a polynomial regression of degree three, in which the coefficients for the different accelerations are shown. The damage equation is as follows:

$$D(\%) = a*Iv + b*Iv^2 + c*Iv^3 \quad (3)$$

Table 4. Correlations between the Vulnerability Index and the Damage Index for Unreinforced Masonry structures

	a	B	c	R2
Aa=0.065	0.0009315	1.2934E-05	-2.9139E-08	0.87
Aa=0.125	0.0042979	-1.0967E-05	2.0232E-08	0.9
Aa=0.150	0.00827002	-3.9644E-05	7.7804E-08	0.92

Table 5. Correlations between the Vulnerability index and the damage index for structures in Reinforced Concrete

	a	B	c	R2
Aa=0.065	0.008723	-0.00022905	2.2006E-06	0.78
Aa=0.125	0.012284	-0.00025021	2.4981E-06	0.84
Aa=0.150	0.011755	-0.00017065	1.7852E-06	0.84

With figures 2 and 3, the correlations between the Vulnerability Index and the degree of damage for different accelerations can be obtained in a faster way.

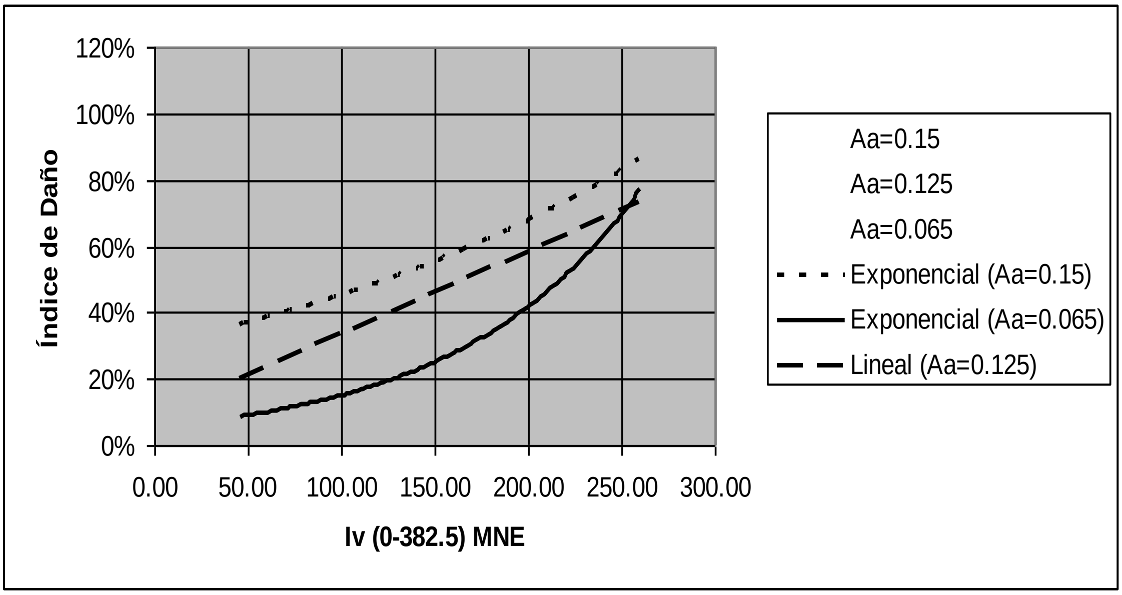

Fig. 2. Vulnerability functions for structures in Non-Structural Masonry

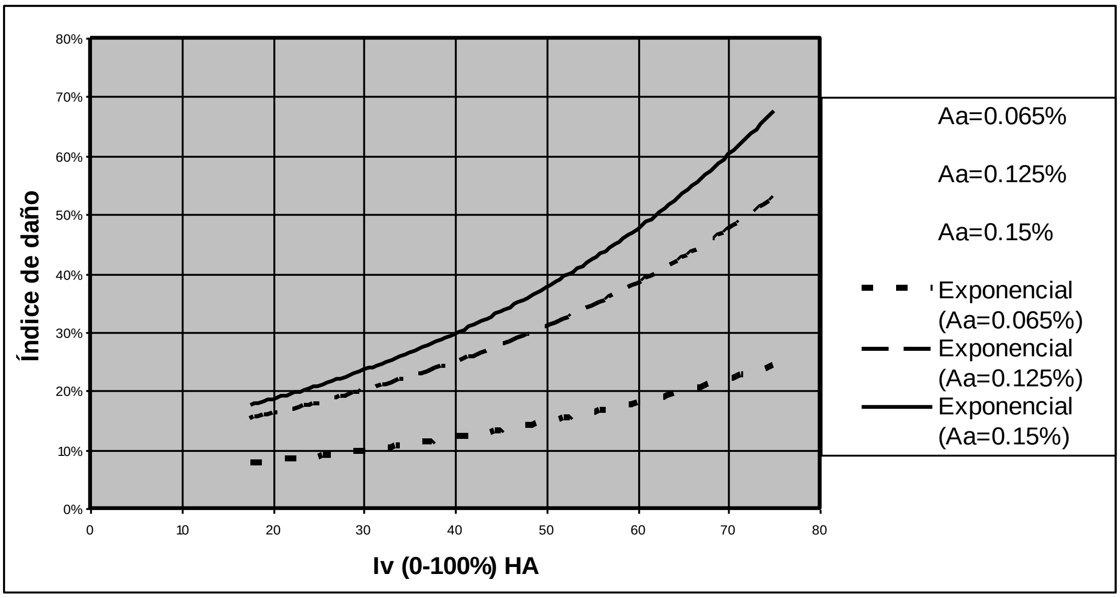

Fig. 3. Vulnerability functions for structures in Reinforced Concrete

VI. CONCLUSIONS

In assessing the damage, it is important to have the vulnerability functions calibrated for the study area, since the country factor is avoided.

The vulnerability functions related to the damage must be adjusted as new investigations are carried out, to reduce the uncertainty associated with their determination.

For urban areas or group of structures, the Pushover analysis should be done in the flat frames, to considerably reduce the project time, choosing the most critical axis.

The methodology developed for the construction of the database can be used to determine the indices related to other risks.

REFERENCES

[1] Bonett R.L. Vulnerabilidad y riesgo sísmico de edificios. Aplicación a entornos urbanos en zonas de amenaza alta y moderada. Tesi doctoral, UPC, Departament d'Enginyeria del Terreny, Cartogràfica i Geofísica, 2003.

[2] Mena U. Evaluación del riesgo sísmico en zonas urbanas. Tesi doctoral, UPC, Departament d'Enginyeria del Terreny, Cartogràfica i Geofísica, 2002.

[3] Benedetti D, Petrini V. Sulla Vulnerabilitá sismica di edifici in muratura: Proposte di un metodo di valutazione. L` industria delle construzioni, 149, 66-78. Roma. 1984.

[4] Yepez F, Barbat AH, Canas JA. 1) Riesgo, peligrosidad y vulnerabilidad sísmica de edificios de mampostería. Monografías de Ingeniería Sísmica CIMNE IS-12. España. 1995.

[5] Mena U. Tesis Doctoral: Evaluación del Riesgo Sísmico en zonas urbanas. Universidad Politécnica de Cataluña. Departamento de Ingeniería del terreno, Cartográfica y Geofísica. Barcelona. 2002.

[6] AIS, Asociación de Ingeniería Sísmica, Normas Colombianas de Diseño y Construcciones Sismo Resistente NSR-98. Colombia 1997.

[7] Yepez F, Barbat AH, CANAS JA. Evaluación probabilística de la Vulnerabilidad y riesgo sísmico de estructuras de hormigón armado por medio de simulación. Monografías de Ingeniería Sísmica CIMNE IS-20. España. 1996.

[8] Yepez F, Barbat AH, Canas JA. 2) Simulación de escenarios de daño para estudios de riesgo sísmicos. Monografías de Ingeniería Sísmica CIMNE IS-14. España. 1995.

[9] Martino R, Spacone E, Kingsley G. Nonlinear Pushover Analysis of RC Structures. Advanced Technology in Structural Engineering. 2000. Doi:10.1061/40492(2000)38.

[10] Daniel DM, John ST, Pushover Analysis of RC Building, International Journal of Scientific & Engineering Research. 2016; 7(10): pp. 88 -92.

[11] Caballero AR. Determinación de la vulnerabilidad sísmica por medio del método del índice de vulnerabilidad en las estructuras ubicadas en el centro histórico de la ciudad de Sincelejo, utilizando la tecnología del Sistema de Información Geográfica. Tesis de Maestría, Universidad del Norte, Barranquilla, 2007.