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SEISMIC EVALUATION OF SCHOOL BUILDINGS IN VENEZUELA

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ABSTRACT

The goals of this paper are (1) to present the methodologies used to perform seismic inspections and to evaluate the associated risk of school buildings in Venezuela and (2) to report preliminary results. A data collection form was designed to gather structural and non-structural information about school buildings. A risk index was defined as function of a hazard index, an occupation index, and a vulnerability index. A total of 286 school buildings were inspected. Preliminary results of 55 inspections are presented in the paper: 19 inspections were performed in Sucre State (PGA=0.4g for T=475 years) and 36 inspections were performed in Carabobo State (PGA=0.3g for T=475 years). 80% of the inspected schools buildings showed vulnerability index values equal or greater than those obtained for the collapsed school buildings during the 1997 Cariaco Earthquake. 55% of the inspected school buildings showed risk index values equal or greater than those obtained for collapsed school buildings during Cariaco Earthquake. The risks indexes so calculated will support technical and administrative decisions, such as establish priorities to perform detailed structural evaluations and seismic rehabilitation of school buildings.

Introduction

There are 28,878 schools distributed in Venezuela. Figure 1 shows the distribution of about 18,700 schools that have been incorporated in a geographical information system (GIS). As can be seen in Figure 1, many of those schools are located in the higher seismic hazard zones in the country accordingly with geographic distribution of population. Several hundreds of those schools are located in old-type school buildings that showed inadequate behavior during past earthquakes. However, there is not detailed structural information available about most of the school buildings in the country. Gathering and processing this information is of most importance in order to estimate seismic vulnerability and to take adequate steps to mitigate seismic risk in school buildings. As an example, Figure 2 shows two school buildings collapsed during the 07/09/1997 Cariaco Earthquake (Mw=6.9): Valentin Valiente School and Raimundo Martinez Centeno High School.

The goals of this paper are (1) to present the methodologies used to perform seismic inspections

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and to evaluate the associated risk of school buildings in Venezuela and (2) to report preliminary results. This activity was performed as part of a project entitled “Seismic Risk Reduction in School Buildings in Venezuela” developed with the participation of IMME (Central University of Venezuela), FEDE (Ministry of Education), and FUNVISIS (Venezuelan Foundation for Seismological Research) with the financial support of FONACIT (Ministry of Science and Technology, Project 2005000188).

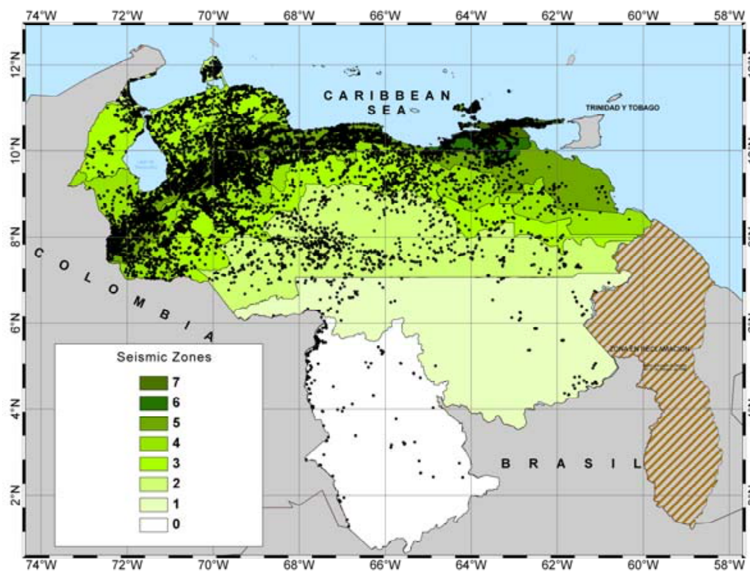


Figure 1. Seismic Zones according to Venezuelan Seismic Code showing the distribution of school buildings in the country (after López et al. 2010).

(a) (b)

Figure 2. School buildings collapsed during 07/09/1997 Cariaco Earthquake (Mw=6.9): (a) Valentin Valiente School and (b) Raimundo Martinez Centeno High School.

Methodology

Basic Information

The strategy followed to gather basic structural information of school buildings in Venezuela is explained herein. The first step was to identify the oldest, the most vulnerable and the most repetitive building types with the aid of FEDE offices located in the 24 states of Venezuela. This activity allowed us to identify 104 “Old-Type I” buildings, similar to Valentin Valiente School, 332 “Box-Type” buildings, similar to Raimundo Martinez Centeno High School, and 113 “Old-Type II” buildings, a school building type massively constructed between 1950 and 1960. All of these building types have reinforced concrete frames with masonry infill walls. The second step was to introduce some additional questions in a National School Survey carried out by the Ministry of Education between 2006 and 2008 in most of the schools in Venezuela. The additional questions were intended to gather basic structural information of school buildings such as type of structure, number of floors, and year of construction. This information is being integrated in a GIS based computational program, as another activity of the project, with the aim to estimate seismic damage and seismic loss distribution in school buildings in Venezuela for several earthquake occurrence scenarios (López et al. 2010). Finally, the third step was to perform seismic inspections of school buildings as explained bellow.

Seismic Inspections

To gather more detailed information for a sample of school buildings in Venezuela, 286 seismic inspections were performed. 250 of the 286 inspections were performed by (Cenamb 2009) and the other 36 inspections were performed by (Rodriguez and Grippi 2008) and (Hernandez and Contreras 2008). The school buildings were selected according to the following criteria: buildings with structural configuration similar to those collapsed during the 1997 Cariaco Earthquake, older buildings, and buildings located in the most hazardous seismic zones in the country. Table 1 shows the distribution of the 286 inspected school buildings. 84% of the inspected buildings are located in seismic zones with PGA values between 0.30g (Seismic Zone 5) and 0.40g (Seismic Zone 7) for a mean return period of T=475 years.

Table 1. Distribution of school selected for seismic inspections in Venezuela.

Seismic Zone	**PGA (g) T=475 years**	**States**	**Number of School Buildings**
3	**0.20**	Barinas	2
4	**0.25**	Anzoátegui, Barinas, Cojedes, Lara, Mérida, Monagas, Portuguesa, Sucre y Táchira	44
5	**0.30**	Dtto. Capital, Aragua, Carabobo, Lara, Mérida, Miranda, Monagas, Sucre, Táchira y Trujillo	170
6	**0.35**	Anzoátegui, Monagas y Sucre	50
7	**0.40**	Sucre	20

Data Collection Form

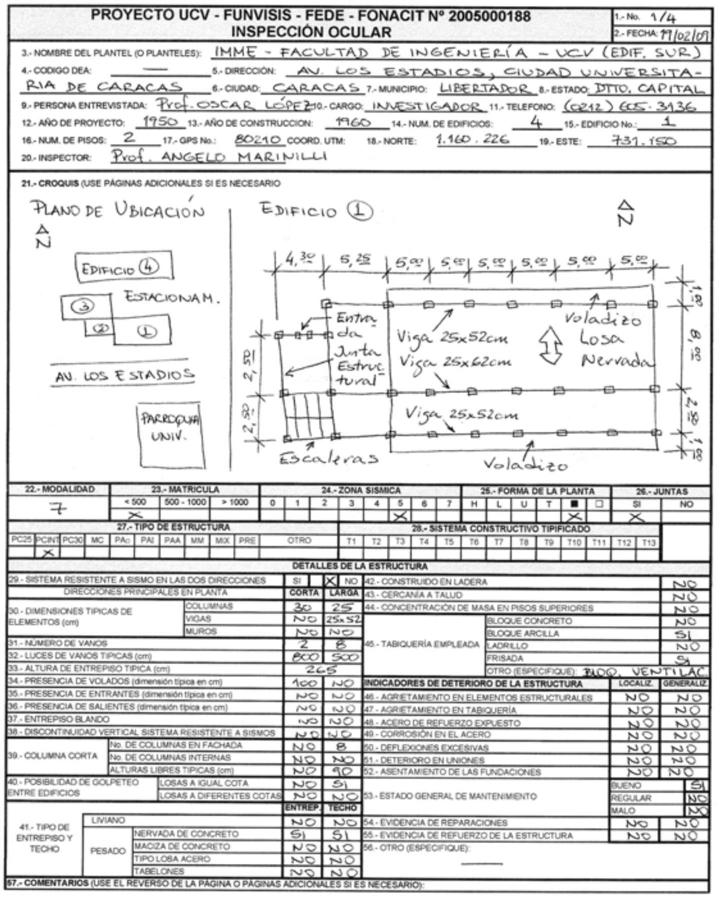
A data collection form to perform the seismic inspections was specially designed to gather structural and non-structural information about school buildings in Venezuela. To elaborate the data collection form several previous experiences were considered. Among these can be cited the data collection form proposed in (FEMA 154 2002) to perform rapid visual screening of buildings for potential seismic hazards in the USA, and the data collection form used by (Meneses and Aguilar 2004) to perform rapid inspections of school buildings for vulnerability evaluation purposes in Peru. The data collection form developed herein was prepared considering the experience of the 1997 Cariaco Earthquake, that led to the collapse of school buildings, and the prescriptions contained in Venezuelan structural codes, such as the seismic code (Covenin 1756 2001), the reinforced concrete structures code (Covenin 1753 1985), and the steel structures code (Covenin 1618 1998). Figure 3 shows the data collection form.

The information gathered during the inspections of a school can be grouped as follows:

- Basic information: including detailed identification and address, staff interviewed during inspection, geographic coordinates (GPS), year of design and/or construction, and identification of the inspector.
- Location plan.
- Schematic horizontal and vertical structural plans.
- Structural and non-structural information: including structural configuration, structural and non-structural details (paying special attention on existence or not of short columns and orthogonal lines of resistance), and potential geotechnical hazard.
- State of structural maintenance.
- Detailed photographic report.
- Commentaries: inspectors are encouraged to include all commentaries that they consider necessary to complement the information reported with the data collection form and the photographic report.

Inspectors and Training

The inspectors selected to perform the seismic inspections were firemen, engineering undergraduate students, and architecture undergraduate students. This selection was performed in order to guarantee an inspection staff with basic knowledge and abilities in structural and earthquake engineering. 3-days workshops were performed to instruct each group of inspectors. The workshop topics included a review of structural and earthquake engineering concepts, paying special attention on structural and non-structural details which may significantly influence the seismic response of a structure, two field training sessions in actual school buildings, and a discussion of the results obtained during the training sessions. To facilitate the use of the data collection form, as well as to guarantee the adequate acquisition and report of the information, a detailed instructive was elaborated to be used as a guide by inspectors during training and field activities.



PROYECTO UCV - FUNVISIS - FEDE - FONACIT Nº 2005000188
INSPECCIÓN OCULAR

1.- No. 1/4
2.- FECHA: 19/02/09

3.- NOMBRE DEL PLANTEL (O PLANTELES): IMME - FACULTAD DE INGENIERÍA - UCV (EDIF. SUR)
4.- CODIGO DEA: —— 5.- DIRECCIÓN: AV. LOS ESTADIOS, CIUDAD UNIVERSITARIA DE CARACAS
6.- CIUDAD: CARACAS 7.- MUNICIPIO: LIBERTADOR 8.- ESTADO: DTTO. CAPITAL
9.- PERSONA ENTREVISTADA: Prof. OSCAR LÓPEZ 10.- CARGO: INVESTIGADOR 11.- TELEFONO: (0212) 605-3136
12.- AÑO DE PROYECTO: 1950 13.- AÑO DE CONSTRUCCION: 1960 14.- NUM. DE EDIFICIOS: 4 15.- EDIFICIO No.: 1
16.- NUM. DE PISOS: 2 17.- GPS No.: 80210 COORD. UTM: 18.- NORTE: 1.160.226 19.- ESTE: 731.150
20.- INSPECTOR: Prof. ANGELO MARINILLI

21.- CROQUIS (USE PÁGINAS ADICIONALES SI ES NECESARIO

22.- MODALIDAD	23.- MATRICULA < 500	500 - 1000	> 1000	24.- ZONA SISMICA 0	1	2	3	4	5	6	7	25.- FORMA DE LA PLANTA H	L	U	T	■	□	26.- JUNTAS SI	NO
7	X								X							X		X	

27.- TIPO DE ESTRUCTURA PC25	PCINT	PC30	MC	PAo	PAI	PAA	MM	MIX	PRE	OTRO	28.- SISTEMA CONSTRUCTIVO TIPIFICADO T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13
	X																						

DETALLES DE LA ESTRUCTURA

		CORTA	LARGA
29.- SISTEMA RESISTENTE A SISMO EN LAS DOS DIRECCIONES		SI	X NO
DIRECCIONES PRINCIPALES EN PLANTA		CORTA	LARGA
30.- DIMENSIONES TIPICAS DE ELEMENTOS (cm)	COLUMNAS	30	25
	VIGAS	NO	25x52
	MUROS	NO	NO
31.- NÚMERO DE VANOS		2	8
32.- LUCES DE VANOS TIPICAS (cm)		800	500
33.- ALTURA DE ENTREPISO TIPICA (cm)		265	
34.- PRESENCIA DE VOLADOS (dimensión típica en cm)		100	NO
35.- PRESENCIA DE ENTRANTES (dimensión típica en cm)		NO	NO
36.- PRESENCIA DE SALIENTES (dimensión típica en cm)		NO	NO
37.- ENTREPISO BLANDO		NO	NO
38.- DISCONTINUIDAD VERTICAL SISTEMA RESISTENTE A SISMOS		NO	NO
39.- COLUMNA CORTA	No. DE COLUMNAS EN FACHADA	NO	8
	No. DE COLUMNAS INTERNAS	NO	NO
	ALTURAS LIBRES TIPICAS (cm)	NO	90
40.- POSIBILIDAD DE GOLPETEO ENTRE EDIFICIOS	LOSAS A IGUAL COTA	NO	SI
	LOSAS A DIFERENTES COTAS	NO	NO
41.- TIPO DE ENTREPISO Y TECHO		ENTREP.	TECHO
	LIVIANO	NO	NO
	PESADO: NERVADA DE CONCRETO	SI	SI
	PESADO: MACIZA DE CONCRETO	NO	NO
	PESADO: TIPO LOSA ACERO	NO	NO
	PESADO: TABELONES	NO	NO

42.- CONSTRUIDO EN LADERA		NO
43.- CERCANÍA A TALUD		NO
44.- CONCENTRACIÓN DE MASA EN PISOS SUPERIORES		NO
45.- TABIQUERÍA EMPLEADA	BLOQUE CONCRETO	NO
	BLOQUE ARCILLA	SI
	LADRILLO	NO
	FRISADA	SI
	OTRO (ESPECIFIQUE): BLOQ. VENTILAC.	

INDICADORES DE DETERIORO DE LA ESTRUCTURA	LOCALIZ.	GENERALIZ.
46.- AGRIETAMIENTO EN ELEMENTOS ESTRUCTURALES	NO	NO
47.- AGRIETAMIENTO EN TABIQUERÍA	NO	NO
48.- ACERO DE REFUERZO EXPUESTO	NO	NO
49.- CORROSIÓN EN EL ACERO	NO	NO
50.- DEFLEXIONES EXCESIVAS	NO	NO
51.- DETERIORO EN UNIONES	NO	NO
52.- ASENTAMIENTO DE LAS FUNDACIONES	NO	NO
53.- ESTADO GENERAL DE MANTENIMIENTO	BUENO	SI
	REGULAR	NO
	MALO	NO
54.- EVIDENCIA DE REPARACIONES	NO	NO
55.- EVIDENCIA DE REFUERZO DE LA ESTRUCTURA	NO	NO
56.- OTRO (ESPECIFIQUE): ——		

57.- COMENTARIOS (USE EL REVERSO DE LA PÁGINA O PÁGINAS ADICIONALES SI ES NECESARIO):

Figure 3. Data collection form developed for seismic inspection of school buildings (in Spanish).

Risk Index

The information gathered for each school building was used to calculate a risk index (Ir), which is a number between 0 and 1, obtained as a multiplication of a seismic hazard index (Iz), a vulnerability index (Iv), and an occupation index (Io). The risk index so defined is not intended no measure the actual seismic risk of a school building, but to support technical and administrative decisions, such as establish priorities to perform detailed structural evaluations and seismic rehabilitation of school buildings.

The seismic hazard index depends on the seismic zone where the inspected building is located, according to Venezuelan seismic code (Covenin 1756 2001). The proposed index ranges linearly between 0.25 for Seismic Zone 1 (PGA=0.1g for T=475 years) and 1.00 for Seismic Zone 7 (PGA=0.4g for T=475 years). The occupation index depends on school population, ranging between 0.5 for school population less or equal to 500 and 1.0 for school population greater than 1,000.

The vulnerability index depends on structural and non-structural details and was developed to consider construction practice and typical characteristics of school buildings in Venezuela. The proposed index considers the structural type (with a relative weigh up to 20% of the vulnerability index), year of structural project and/or construction (relative weigh up to 20%), existence of plan irregularities (relative weigh up to 18%), existence of vertical irregularities (relative weigh up to 18%), evidence of structural pathologies and/or lack of adequate structural maintenance (relative weigh up to 18%), and geotechnical hazard (relative weigh up to 6%). Special attention is focused in the amount of short columns and the absence of well defined structural lines of resistance in two orthogonal directions, because these characteristics conditioned inadequate behavior of school buildings during past earthquakes in Venezuela. Two benchmarks are of special interest: 1939 when the first structural code was established in Venezuela, considering rough seismic lateral loading and no special details for structural members, and 1982 when seismic and structural codes commenced to meet modern requirements for earthquake resistant structures.

The school buildings that collapsed during the 1997 Cariaco Earthquake were used to calibrate the proposed indexes. The school buildings were located in the town of Cariaco (Sucre State in the northeast region of Venezuela), which is located in the Seismic Zone 7 (PGA=0.4g for T=475 years). Valentin Valiente School was constructed in mid-1950 decade and was composed by two "Old-Type I" buildings separated by a structural joint (see for instance Figure 2a). It was distinguished by the lack of earthquake resistant lines in its longitudinal direction and the presence of a large amount of short columns in both of its stories. Raimundo Martinez Centeno High School was constructed in mid-1980 decade and was a "Box-Type" building composed by two c-shaped buildings separated by a structural joint (see Figure 2b). It possessed earthquake resistant lines in two orthogonal directions and was distinguished by a large amount of short columns in all of its stories. Table 2 shows the index values obtained for Valentin Valiente School and Raimundo Martinez Centeno High School.

Table 2. Index values obtained for school buildings collapsed in the 1997 Cariaco Earthquake.

Index	**School Building**	
	Valentin Valiente	**Raimundo Martinez Centeno**
Seismic Hazard Index (Iz)	1.00	1.00
Vulnerability Index (Iv)	0.64	0.45
Occupation Index (Io)	0.50	1.00
Risk Index (Ir)	**0.32**	**0.45**

Results

The results of 55 inspections are presented herein as an example of the preliminary results obtained during this activity. 19 inspections were performed in Sucre State (northeast region of Venezuela) and 36 inspections were performed in Carabobo State (central region of Venezuela). The school buildings inspected in Sucre State are located in Seismic Zone 7

(PGA=0.4g for T=475 years) and those inspected in Carabobo State are located in Seismic Zone 5 (PGA=0.3g for T=475 years).

Figure 4 shows the distribution of year of design and/or construction for all the inspected school buildings. A total of 80% of the inspected buildings are dated before benchmark year 1982 and 5% before benchmark year 1939. Figure 5 shows the distribution of building type for all the inspected buildings. It can be seen that 36% of the inspected buildings are similar to those collapsed during 1997 Cariaco Earthquake (Box-Type and Old-Type I).

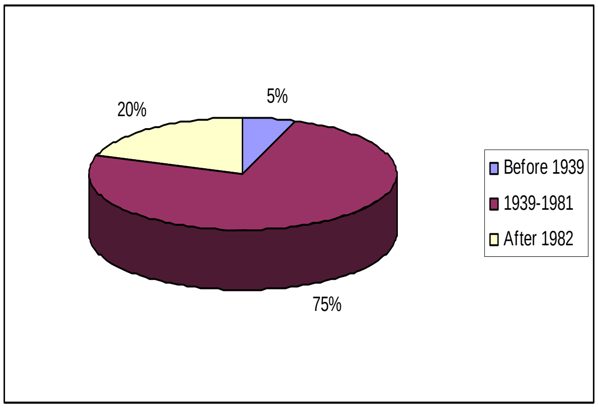


Figure 4. Year of design and/or construction for the inspected school buildings.

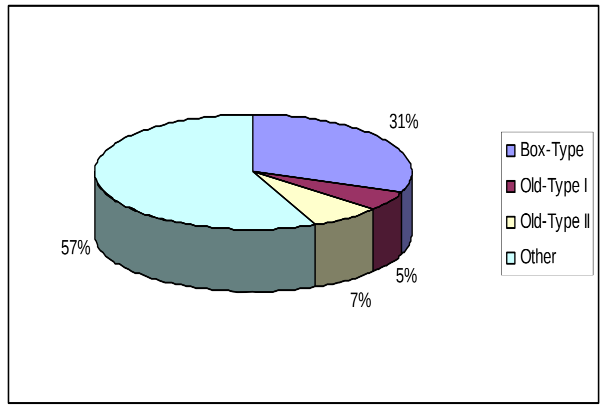


Figure 5. Building type for the inspected school buildings.

Figure 6 shows if the inspected school buildings have lines of resistance in one direction or two orthogonal directions. 71% of the inspected buildings have lines of resistance in just one direction. Figure 7 shows the percentage of short columns of the total amount of columns in a given story. 68% of the inspected school buildings showed 50% or more short columns in at least one of their stories, usually at the ground level.

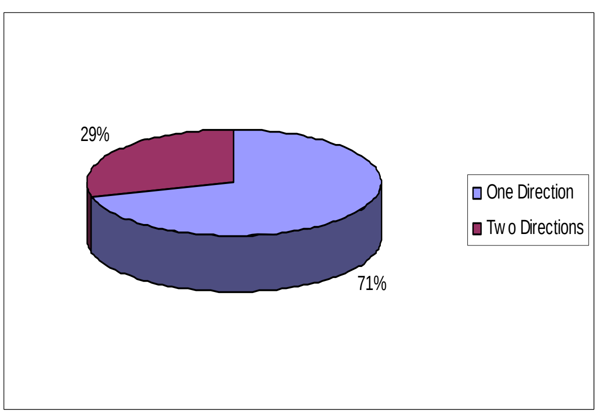


Figure 6. Presence of lines of resistance for the inspected buildings.

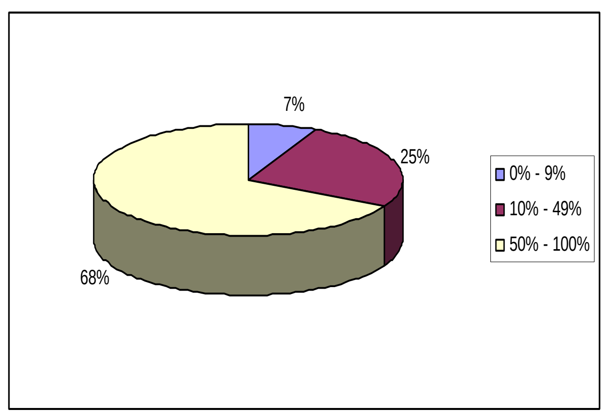


Figure 7. Amount of short columns for the inspected buildings.

Figure 8 and Figure 9 show the vulnerability index and risk index values obtained at each school building in Sucre State and Carabobo State, respectively. Figure 10 shows that 80% of the sample showed vulnerability index values equal or greater than the value obtained for Raimundo

Martinez Centeno High School (Iv = 0.45), regardless of the seismic zone where they are located. Otherwise, Figure 11 shows that 55% of all of the inspected school buildings showed risk index values equal or greater than the value obtained for Valentin Valiente School (Ir = 0.32).

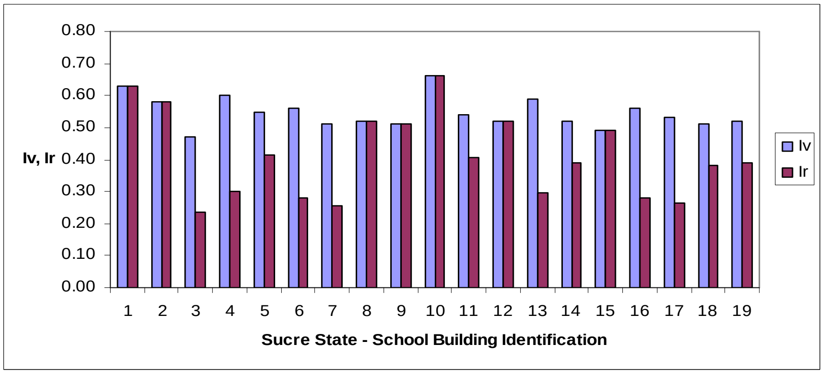


Figure 8. Vulnerability Index (Iv) and Risk Index (Ir) obtained for school buildings inspected in Sucre State.

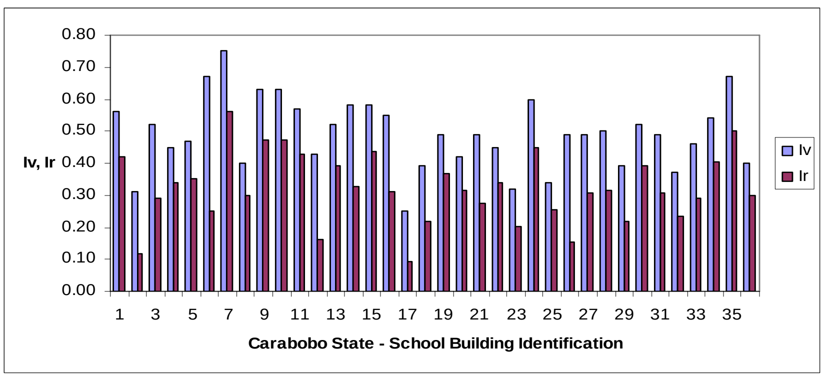


Figure 9. Vulnerability Index (Iv) and Risk Index (Ir) obtained for school buildings inspected in Carabobo State.

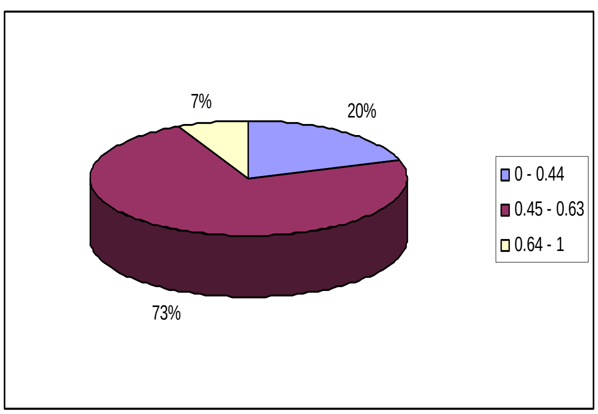


Figure 10. Vulnerability Index (Iv) obtained for the inspected buildings.

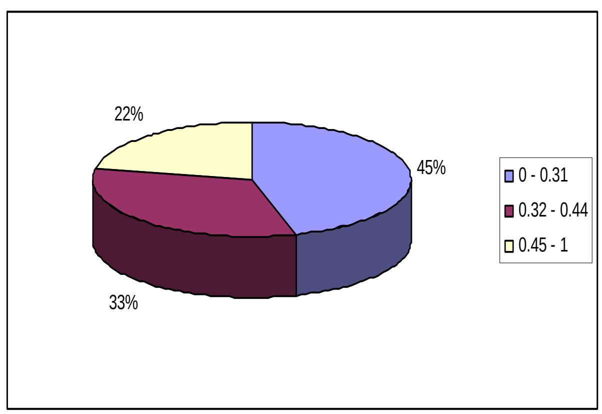


Figure 11. Risk Index (Ir) obtained for the inspected buildings.

Conclusions

The methodologies used to perform seismic inspections and to evaluate the associated risk of school buildings in Venezuela, as well as preliminary results, are presented in this paper.

A data collection form was designed to gather structural and non-structural information about school buildings. A risk index was defined as function of a hazard index, an occupation index, and a vulnerability index. The risk index so defined is not intended no measure the actual seismic risk, but to prioritize the school buildings for risk mitigation purposes. Special attention in the vulnerability index is focused in the amount of short columns and the absence of well defined structural lines of resistance in two orthogonal directions. The school buildings that collapsed during the 1997 Cariaco Earthquake, Valentin Valiente School and Raimundo Martinez Centeno High School, were used to calibrate the proposed indexes.

A total of 286 school buildings were inspected in Venezuela. Preliminary results of 55 inspections are presented in the paper. 19 inspections were performed in Sucre State (Seismic Zone 7 with PGA=0.4g for T=475 years) and 36 inspections were performed in Carabobo State (Seismic Zone 5 with PGA=0.3g for T=475 years). 80% of the inspected schools buildings showed vulnerability index values equal or greater than the value obtained for Raimundo Martinez Centeno High School, regardless of the seismic zone where they are located. 55% of all the inspected school buildings showed risk index values equal or greater than the value obtained for Valentin Valiente School.

The seismic inspections and risk index results will support technical and administrative decisions, such as establish priorities to perform detailed structural evaluations and seismic rehabilitation of school buildings.

Acknowledgments

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References

CENAMB, 2008. *Inspección de Edificios Escolares. Estudio para el Proyecto FONACIT No 20005000188*, Universidad Central de Venezuela (In spanish).

Covenin Mindur 1756, 2001. *Edificaciones sismorresistentes*. Covenin, Caracas, (In Spanish).

Covenin Mindur 1753, 1985. *Estructuras de concreto armado para edificaciones. Análisis y diseño*. Covenin, Caracas, (In Spanish).

Covenin Mindur 1618, 1998. *Estructuras de acero para edificaciones. Método de los estados límites*. Covenin, Caracas, (In Spanish).

FEMA 154, 2002. *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook.*

Second Edition. Applied Technology Council, Redwood City.

Hernández E. and Contreras O., 2008. *Índice del grado de vulnerabilidad sísmica de edificaciones escolares en Venezuela*. T. E. G. para optar al título de Ingeniero Civil, Universidad de Carabobo, (In Spanish).

Grippi L. and Rodríguez M., 2008. *Evaluación general del grado de riesgo sísmico de un grupo de estructuras escolares públicas de los Municipios Valencia, Guacara y Diego Ibarra del Estado Carabobo*. T. E. G. para optar al título de Ingeniero Civil, Universidad de Carabobo, (In Spanish).

López O. A., Marinilli A., Bonilla R., Fernández N., Domínguez J., Coronel G., Rodriguez D., Tenreiro E., and Vielma R., 2010. Seismic Risk Reduction in Venezuelan Schools. *Proceedings of the 9th National Conference on Earthquake Engineering*, Toronto.

Meneses J. and Aguilar Z., 2004. Seismic Vulnerability of School Buildings in Lima, Peru. *Proceeding of the 13th World Conference on Earthquake Engineering*, Vancouver, Paper No. 1683.