Inspection of School Buildings in Seismic Prone Areas in Venezuela

A. Marinilli, N. Fernández, O. A. López & G. Coronel
Instituto de Materiales y Modelos Estructurales IMME.
Facultad de Ingeniería.Universidad Central de Venezuela

SUMMARY:
The goal of this paper is to present the methodology and the results of seismic inspections performed in 293 school buildings in Venezuela. A data collection form was designed to gather structural and non-structural information for each school building. A risk index was defined as a function of a hazard index and a vulnerability index. A prioritization index was defined as a function of the risk index and an occupation index. About 31.4% of the inspected buildings showed risk index values equal or greater than those obtained for school buildings that collapsed during 1997 Cariaco Earthquake. About 41.4% of the inspected buildings showed prioritization index values equal or greater than those obtained for school buildings that collapsed during 1997 Cariaco Earthquake. The prioritization indexes so calculated will support technical and administrative decisions, such as establish priorities to perform detailed structural evaluations and seismic rehabilitation of school buildings in Venezuela.

Keywords: seismic inspections, school buildings, risk, prioritization, Venezuela

1. INTRODUCTION

There are about 29,000 schools distributed in Venezuela. 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 behaviour 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 in Venezuela.

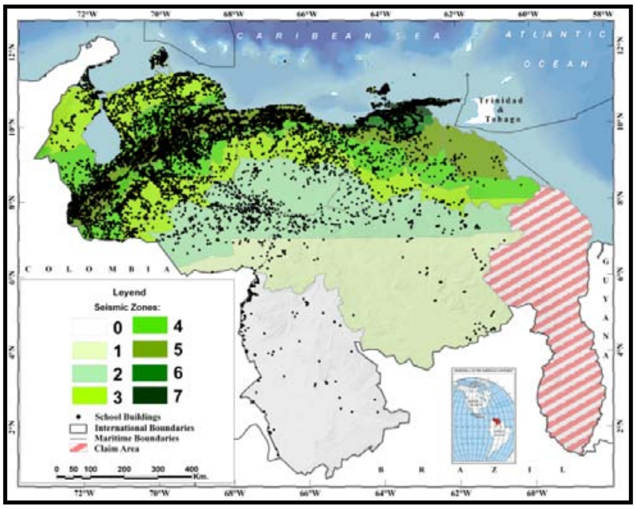

Figure 1. Seismic Zones according to Venezuelan Seismic Code showing the distribution of school buildings in the country (after Coronel and López, 2012)

The goals of this paper are to present the methodology used to perform seismic inspections, to evaluate risk and prioritization indexes of school buildings in Venezuela, and to report the results obtained. This research was performed as part of the project entitled “Seismic Risk Reduction in School Buildings in Venezuela” developed with the participation of IMME (Faculty of Engineering of the 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).

2. METHODOLOGY

The methodology followed to gather basic structural information, to perform the seismic inspections, and to calculate risk and prioritization indexes of school buildings in Venezuela is explained herein.

2.1. Basic Information

The first step to gather basic information 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, 334 “Box-Type” buildings, similar to Raimundo Martinez High School, and 114 “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. Figure 2 shows Valentin Valiente School and Raimundo Martinez High School that collapsed during the 07/09/1997 Cariaco Earthquake (Mw=6.9). 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. Finally, the third step was to perform seismic inspections of school buildings as explained herein.

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

2.2. Seismic Inspections

To gather more detailed information for a sample of school buildings in Venezuela, 293 seismic inspections were performed. 257 of the inspections were performed by CENAMB (2011) and the other 36 inspections were performed by Grippi and Rodriguez (2008) and Hernandez and Contreras (2008) as part of the research project. 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. Figure 3 shows that 78.5% of the inspected buildings were located in high hazard seismic zones (PGA values between 0.30g and 0.40g for return period of T=475 years) and 21.5% of the inspected buildings were located in intermediate hazard seismic zones (PGA values between 0.20g and 0.25g for T=475 years).

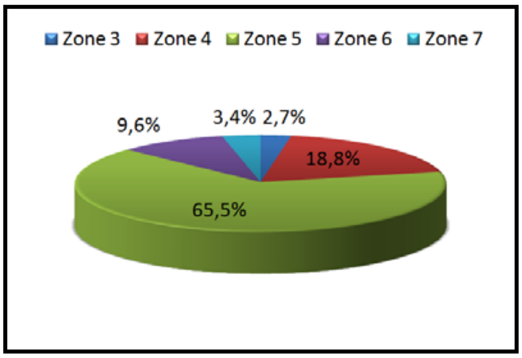

Figure 3. Distribution of inspected schools according to Seismic Zones in Venezuela

2.3. 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, as 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 according to the prescriptions contained in Venezuelan seismic code (Covenin 1756, 2001), reinforced concrete structures code (Covenin 1753, 1985), and steel structures code (Covenin 1618, 1998).

The information gathered during the inspections of a school can be grouped as follows: basic information including detailed identification and address, school staff members interviewed during the inspection, geographic coordinates, 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, and potential geotechnical hazard; state of structural maintenance; and a detailed photographic report. The inspectors were encouraged to comment the information reported with the data collection form and the photographic report for completeness. Figure 4 shows an example of a data collection form.

2.4. 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.

2.5. Risk and Prioritization Indexes

The information gathered for each school building was used to calculate a risk index (Ir) and a prioritization index (Ip) defined by Eqn. 2.1 and Eqn. 2.2, respectively. The risk index so defined is not intended to measure the actual seismic risk of a school building, but to estimate it as good as possible with the information gathered during seismic inspections. The prioritization index is intended to support technical and administrative decisions, such as establish priorities to perform detailed structural evaluations and seismic rehabilitation of school buildings.

$$Ir = Iz \cdot Iv \tag{2.1}$$

$$Ip = Iz \cdot Iv \cdot Io = Ir \cdot Io \tag{2.2}$$

The seismic hazard index (Iz) 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 (Io) depends on school capacity, ranging between 0.5 for capacities less or equal to 500 students and 1.0 for capacities greater than 1,000 students.

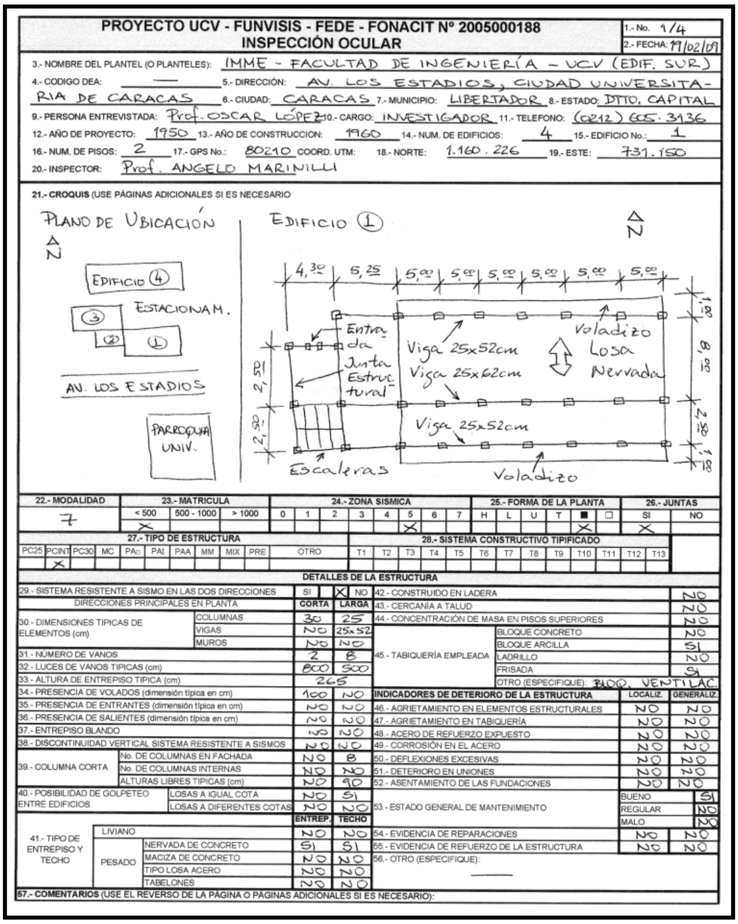

Figure 4. Data collection form developed for seismic inspection of school buildings (in Spanish)

The vulnerability index (Iv) 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 behaviour of school buildings during past earthquakes in Venezuela. Three benchmarks are of special interest: 1939 when the first structural code was established in Venezuela considering a rough seismic lateral loading and no special details for structural members, 1967 when 07/29/1967 Caracas Earthquake (Mw=6.6) occurred, 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. 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 2). 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 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 2). 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 1 shows the index values obtained for Valentin Valiente School and Raimundo Martinez High School.

Table 2.1. Index values obtained for school buildings collapsed in the 1997 Cariaco Earthquake

School Building	Iz	Io	Iv	Ir	Ip
Valentin Valiente School	1.00	0.50	0.64	0.64	0.32
Raimundo Martinez High School	1.00	1.00	0.45	0.45	0.45

3. RESULTS

Figure 5 (left) shows the distribution of inspected schools according to year of design and/or construction. A total of 47.8% of the inspected buildings are dated before 1967, 33.4% between 1967 and 1982, and 18.8% after 1982. Figure 5 (right) shows the distribution of inspected school buildings according to the number of seismic resistance lines. Only in 31.1% of the inspected buildings two orthogonal lines of seismic resistance could be clearly identified.

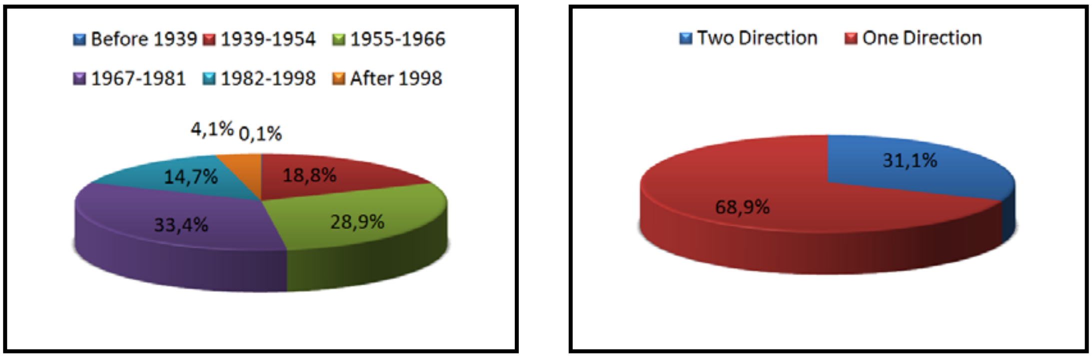

Figure 5. Distribution of inspected schools according to year of design and/or construction (left) and number of lines of seismic resistance (right)

Figures 6 to 9 show some examples of school buildings inspected in Sucre State (Seismic Zones 6 and 7 in northeast region of Venezuela). Figure 6 shows an old school building where it was observed the lack of clearly defined lines of seismic resistance in two orthogonal directions. Figure 7 shows two Old-Type I school buildings. It was observed only one clearly defined line of seismic resistance and several short columns in both buildings. Figure 8 shows a Box-Type school building where only one line of seismic resistance could be clearly identified during the inspection; however it is known that there are squat beams in the orthogonal direction. Figure 9 shows a modern school building where two orthogonal seismic resistance lines were clearly identified, but several short columns were identified as well.

Figure 6. Old school building inspected in Sucre State

Figure 7. Old-Type I school buildings inspected in Sucre State

Figure 8. Box-Type school building inspected in Sucre State

Figure 9. Modern school building inspected in Sucre State

3.1. Seismic Hazard, Occupation, Vulnerability, Risk, and Prioritization Indexes

Figure 10 (left) shows the seismic hazard index distribution for inspected schools. About 78.5% of the inspected buildings showed Iz ≥ 0.75 because, as it was previously discussed, they are located in high hazard seismic zones. Figure 10 (right) shows the occupation index distribution. About 68.9% of the inspected school buildings showed Io ≥ 0.75, corresponding to school capacities greater than 500 students.

Figure 11 (left) shows the vulnerability index distribution for the inspected school buildings. Comparing the results with those obtained for school buildings that collapsed during 1997 Cariaco Earthquake, it was observed that about 68.6% of the inspected buildings showed Iv ≥ 0.45 and about 20.1% showed Iv≥ 0.64. Fi gure 11 (right) shows the risk index distribution for the inspected school buildings. Similarly, it was observed that about 31.4% of the inspected buildings showed Ir ≥ 0.45 and about 4.4% showed Ir ≥ 0.64.

Figure 12 shows the prioritization index distribution for the inspected school buildings. It was observed that about 41.4% of the inspected buildings showed Ip ≥ 0.32 and about 14.7% showed Ip ≥ 0.45.

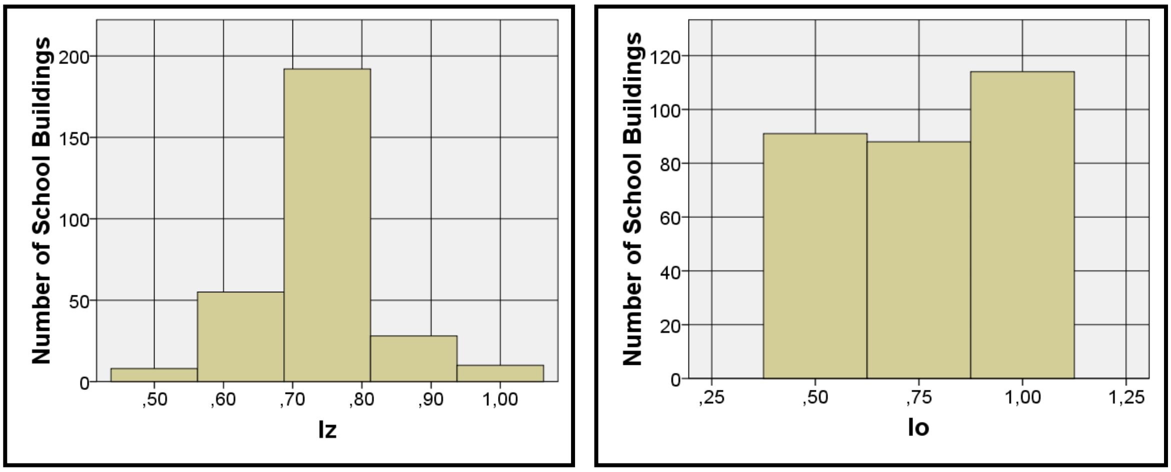

Figure 10. Distributions of seismic hazard index (left) and occupation index (right) for inspected schools

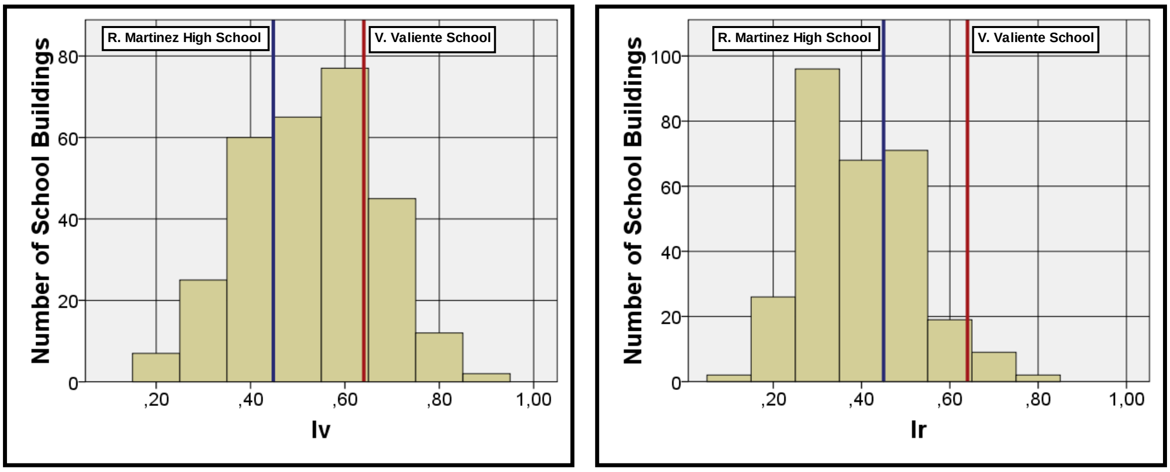

Figure 11. Distributions of vulnerability index (left) and risk index (right) for inspected schools

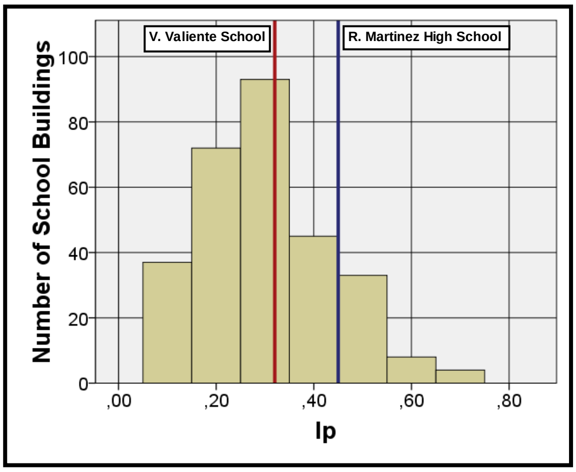

Figure 12. Distributions of prioritization index for inspected schools

4. CONCLUSIONS

The methodology used to perform seismic inspections, to evaluate risk and prioritization indexes, and the results obtained for 293 school buildings inspected in Venezuela were 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 a function of a hazard index and a vulnerability index. The risk index so defined is not intended to measure the actual seismic risk, but to estimate it with the information gathered during the inspections. A prioritization index was defined as a function of the risk index and an occupation index. The prioritization index is intended to support technical and administrative decisions, such as establish priorities to perform detailed structural evaluations and seismic rehabilitation of school buildings.

A total of 293 school buildings were inspected in Venezuela. Results show that 78.5% of the inspected buildings were located in high hazard seismic zones and 21.5% were located in intermediate hazard seismic zones. It was observed that about 31.4% of the inspected buildings showed risk index values equal or greater than those obtained for school buildings that collapsed during 1997 Cariaco Earthquake. It was also observed that about 26.7% of the inspected buildings showed prioritization index values between those obtained for Raimundo Martinez High School (Ip = 0.45) and Valentin Valiente School (Ip = 0.32), and about 14.7% showed prioritization index values equal or greater than the value obtained for Raimundo Martinez High School. As a first approach to prioritization, it could be said that the former group of school buildings requires detailed structural evaluations, and the latter group requires seismic rehabilitations.

ACKNOWLEDGEMENT
This research was funded by FONACIT (Ministry of Science and Technology) with Project 2005000188. The support provided by FEDE, FUNVISIS, and IMME is highly appreciated.

REFERENCES

CENAMB (2011). Auditoria de vulnerabilidad de edificaciones escolares. Universidad Central de Venezuela, Centro de Estudios Integrales del Ambiente, Caracas. (In Spanish).
Coronel, G. and Lopez, O. A. (2012). Regional seismic risk, damage and loss scenarios of Venezuela school buildings. *15th World Conference on Earthquake Engineering*.
Covenin 1618 (1998). Estructuras de acero para edificaciones. Método de los estados límites. Comisión Venezolana de Normas Industriales, Caracas. (In Spanish).
Covenin 1753 (1985). Estructuras de concreto armado para edificaciones. Análisis y diseño. Comisión

Venezolana de Normas Industriales, Caracas. (In Spanish).
Covenin 1756 (2001). Edificaciones sismorresistentes. Comisión Venezolana de Normas Industriales, Caracas. (In Spanish).
FEMA 154 (2002). Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook. Second Edition. Applied Technology Council, Redwood City.
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, Venezuela (In Spanish).
Hernández, E. and Contreras, O. (2008). Indice del grado de vulnerabilidad sísmica de edificaciones escolares en Venezuela. T. E. G. para optar al título de Ingeniero Civil, Universidad de Carabobo, Venezuela. (In Spanish).
Lopez, O. A., Marinilli, A., Coronel, G., Dominguez, J., Bonilla, R. and Vielma, R. (2012). Improving seismic safety in Venezuelan school buildings. *15th World Conference on Earthquake Engineering*.
Meneses, J. and Aguilar, Z. (2004). Seismic Vulnerability of School Buildings in Lima, Peru. *13th World Conference on Earthquake Engineering*. Paper No. 1683.