Evaluación de Riesgos Naturales
- América Latina -
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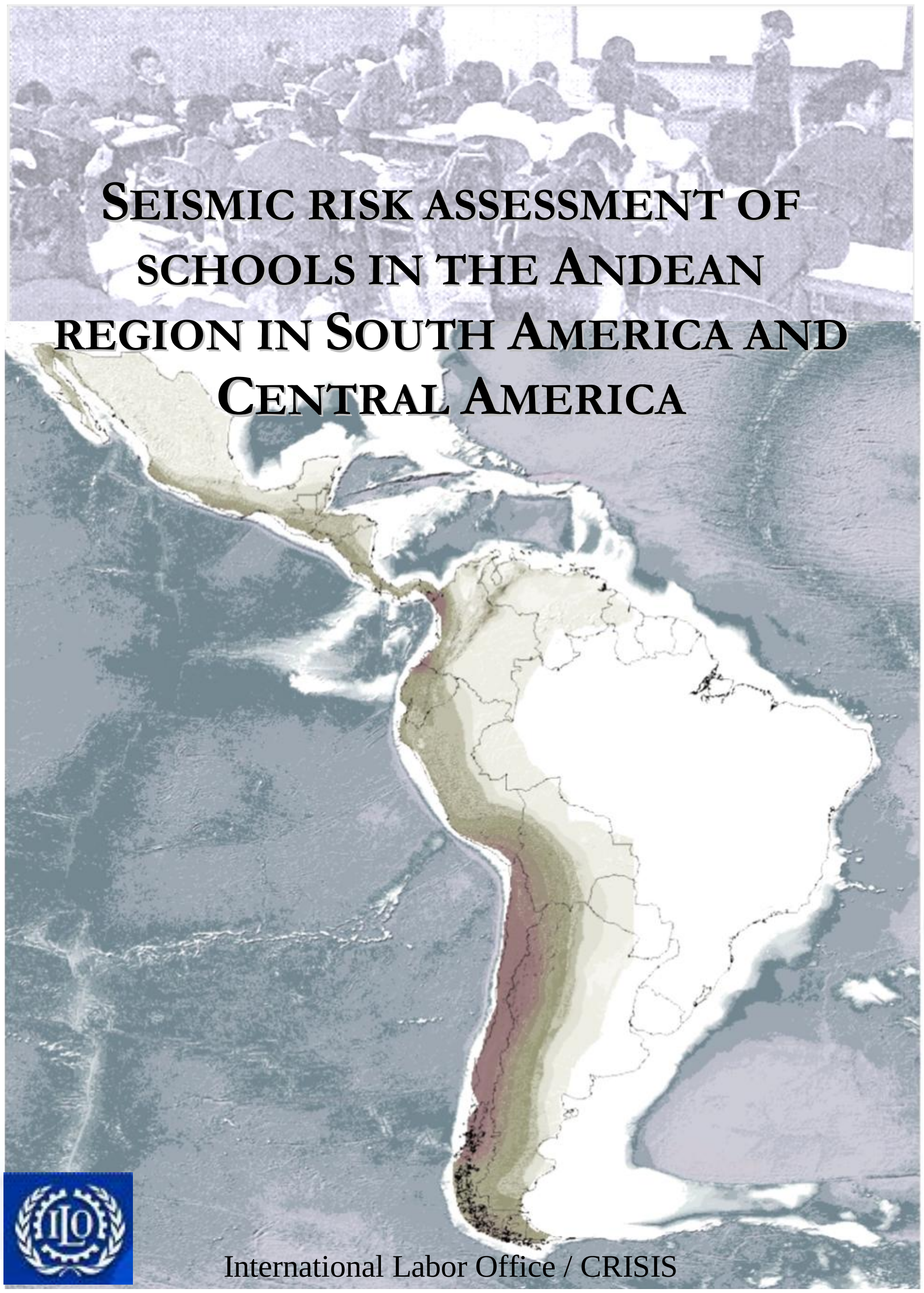
Seismic risk assessment of schools in the Andean region in South America and Central America



International Labor Office / CRISIS

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SEISMIC RISK ASSESSMENT OF SCHOOLS IN THE ANDEAN REGION IN SOUTH AMERICA AND CENTRAL AMERICA

EXPOSURE ESTIMATION AND SEISMIC RISK MODELING

International Labor Office / CRISIS

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ERN

Evaluación de Riesgos Naturales

- América Latina -

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1 INTRODUCTION

During seismic disasters schools have been severely affected. In the Molise Earthquake in 2002, the San Giuliano school colapsed and killed most of the occupants (EERI 2003). In the Earthquake of Bingol, Turkey in 2003, more than the 48% of the schools suffered damages between moderate to severe. From 27 schools in the zone, 4 collapsed or resulted heavily damaged, 9 suffered moderate damages, 11 light damages and 3 remain without damages. In the school of Celtiksuyu, the collapse of the building killed 84 people, the majority, children (Ellul y D'Ayala 2003).

In Perú, in 2007, the earthquake of Pisco destroyed 18 educational facilities and affected 118 (EERI 2007). In China, after the earthquake of Sichuan more than 7,000 classrooms collapsed. In the provinces of Sichuan and Gansu, more than 12,000 and 6,500 schools were affected respectively (Reliefweb 2009). In the earthquake of Balochistan, Pakistan, 100 primary schools in the Ziarat District and 28 primary schools of the Pishin district were partially damaged. The academic activities were postponed during a week. This interruption affect near 20,000 children in Pishin and 3.845 in Ziarat (OCHA 2008c).

In the earthquake of Southern Sumatra in 2009, 241 schools were severe damaged, 175 suffered moderate damages and 87 suffered light damages; leaving without educational resources to more than 90,000 students (OCHA 2009). In the earthquake of Haiti in 2010, more than 97% of the schools in Port Principe were destroyed. The half of the public schools and the three main universities suffered severe damages (Fierro y Perry 2010). After the earthquake of Maule, Chile in 2010, from 4,432 educational facilities evaluated, it was found that the 63% may be functional, the 14% were partially operative and the 23% were evacuated (CERF 2010).

Those negative effects in the educational sector have motivated the development of global campaigns and local projects in order to reduce the seismic vulnerability of these facilities. In this sense, the risk assessment of educational buildings is necessary in order to establish a reference of the potential losses and to estimate the resources that may be necessary for vulnerability reduction, in order to protect the life of the children and guarantee the safety of the structures and public investments in education. These goals are restricted by the socioeconomic context and the local seismic pre requisites; thus, the seismic vulnerability reduction must rely on robust benefit cost relations that encompasses the social, economic and financial dimensions.

For regional comparison and national screening purposes, this report presents rough estimates of the seismic risk of schools of the countries in the Andean Region and Central America from a probabilistic approach. The risk is expressed in terms of the exceedance loss rate and the Average Annual Loss of the schools portfolio of each country in both the current and retrofitted case.

The probabilistic methodology used is considered the most robust for this type of modeling and identifies the most important aspects of catastrophe risk from financial protection perspective in according to the fiscal responsibility of the State. In addition, the results of the analysis may be particularly useful in guiding the national seismic risk reduction programs of the educational sector. The methodological and technical foundations of this risk assessment are the models made by this consultant group for the development of **ERN-CAPRA** (Comprehensive Approach for Probabilistic Risk Assessment); an open architecture platform designed with support of the IDB, the World Bank and the UN International Strategy for Disaster Reduction. Details of the model and its implementation are available at www.ecapra.org

This report is organized in seven chapters. In chapters two and three are presented the objectives and scope of this consultancy. In chapter four are briefly described some recent campaigns and experiences of risk reduction on schools. It is useful in order to identify the methodological aspects in seismic risk assessment, the agents involved, and the information used on each analysis. In chapter five are presented the methodological procedures considered in this study for the estimation of losses due to seismic events. The results of the seismic risk assessment in schools are presented in chapter six; it includes a general overview of the educational context in Latin America and the estimates of the exceedance loss curve for the schools portfolio of each country included in the analysis. Finally in chapter seven are presented commentaries of the results and benefits of seismic reduction of educational facilities.

2 OBJECTIVES

The main objective of this consultancy is to develop a rough estimate of the seismic risk of the schools in the countries of the Andean region and Central America, as well as an indicative evaluation of the benefits of the reduction of the structural vulnerability of those facilities. This task is divided in specific objectives as follows:

- To develop a proxy of the schools built area and their vulnerability in the Andean region of South America and in Central America.
- To develop a coarse-grain disaster risk analysis (the potential damage and loss) of the portfolio of schools by country based on the proxy estimated.
- To obtain a rough estimate of the cost-benefit relation of the seismic risk mitigation on schools

3 SCOPE

The scope of this consultancy is defined by the countries included in the analysis, the information, methods and procedures used for modeling the exposure, hazard, vulnerability and risk. The countries included in the analysis are those belonging to the Andean Region and Central America, which already have a probabilistic seismic hazard model. A list of the countries considered is presented below:

1) Argentina (ARG)
2) Bolivia (BOL)
3) Chile (CHL)
4) Colombia (COL)
5) Costa Rica (CRI)
6) Ecuador (ECU)
7) El Salvador (SLV)
8) Guatemala (GTM)
9) Honduras (HON)
10) Mexico (MEX)
11) Nicaragua (NIC)
12) Panama (PAN)
13) Peru (PER)
14) Venezuela (VEN)

A brief summary of the procedures and assumptions considered in the risk assessment of school is presented in this section. It is done in order to identify the limitations and scope of the study. A more detailed description of the loss estimate framework is shown in chapter five.

Exposure is modeled for each municipality, or administrative unit considered on each country, as an estimate of the schools building area. These values are calculated in terms of the population of the administrative unit, the estimated number of students and indicators of scholar areas per pupils, based the information available in the national census and the national databases of the correspondent Ministry of Education. The economic value of this infrastructure is estimated using information of the national census. The lack of information was sorted by means of relations between the exposed value per student and the GDP per capita. Therefore, the information of the elements at risk must be considered as a proxy useful for comparisons within the region at a national level.

A Probabilistic Seismic Hazard model is considered in this analysis. For each country, the probability of exceedance of a defined intensity for a specific return period and in a specific location is obtained by using the CRISIS 2007 V7.2 software.

The expected losses of each exposed element to the seismic hazard is modeled with the aid of vulnerability curves that represent, for a specific value of the hazard intensity, the relative value of the loss (0 for no damage and 1 for reconstruction). Vulnerability curves are defined for structural typologies representative of the building stock in Latin America. For each country, it is applied a common composition of structural typologies for both the current state and retrofitted portfolios. This assumption is useful for comparisons at national and regional level. A more detailed description of the vulnerability of the elements exposed is outside of the scope of this project. In the vulnerability curves, the expected loss is considered as a random variable that follows a Beta cumulative distribution function.

Given the limitations in the description of the exposed elements and its vulnerability, the results obtained from this report must be considered as an indicative measure useful for a regional screening. The values obtained should be used for preliminary decisions in order to perform more detailed analysis with more accurate information about the exposure and its vulnerability.

4 SEISMIC RISK REDUCTION IN SCHOOLS: RECENT CAMPAIGNS AND EXPERIENCES

In emergency situations, schools are considered as alternative facilities for shelter, supply centers, temporal emergency clinics, among other functions. Over those secondary functions for emergency response, schools play a vital role in every community and contribute to human development. In this sense, risk mitigation in schools must be considered as the reduction of negative effects in the educational sector and an opportunity to increase the response capacity of the community when it is developed simultaneously with the training of teachers and pupils for emergency situations and risk management. The International Strategy for Risk Reduction (ISDR) in cooperation with UNESCO, coordinated during 2006-2007 the campaign:" *Disaster Risk Reduction begins at school*", in order to promote the inclusion of risk management topics in the school curricula as well as the development of structural interventions for vulnerability reduction (Fujieda et al 2008).

The United Nations Centre for Regional Development promoted, in Asia and the Pacific region during the 2008, the initiative of the seismic safety of schools through the project, "Reducing the children vulnerability in schools to earthquakes". This project included the seismic retrofitting of schools with the participation of communities, local governments and the training of construction technicians. Schools were ranked based on its location, the construction typology and vulnerability as well as their potential use as emergency facilities (Fujieda et al 2008). Nowadays, the ISDR promotes the campaign "A million of schools and hospitals safe from disasters" which is a global initiative included in the program "Building resilient cities" (ISDR 2010).

In Italy, after de Molise earthquake in 2002, by order of the local authority, the National Council of Research and the Institute of Construction Technologies of L'Aquila, prepared guidelines for vulnerability assessment in schools, a set of forms[1] for data acquisition and a data base with the necessary information for the analysis. Also, it was developed a priorization study of the schools in the region. This study implies the compilation of administrative data and the research of geotechnical, structural and geologic properties considered useful for the vulnerability assessment. Also, there were identified the most probable collapse mechanisms and simplified models were applied for each building (Martinelli et al 2008).

The procedure for school ranking was developed under several stages, from simplified analysis to detailed models. In the first level, a seismic risk indicator was obtained by the comparison between the seismic design Peak Ground Acceleration (PGA), according to the year of construction of the building, with the PGA corresponding to events of 475 years return period. In this analysis is just considered the year the construction and the building location (Martinelli et al 2008).

The first criteria indicates how much risky is a structure compared to those designed with the current seismic previsions (Casciati et al 2004). The second level estimates the mean damage grade of each building by considering the EMS-98 Macroseismic Scale as the seismic demand. Structural typologies and vulnerability factors are used according to the vulnerability index developed by Lagomarsino and Giovannazzi. The third level is associated with the verification of the mechanical properties of the building by using simplified models. The forth model is considered as the verification of resistance and deformation characteristics of the building. The most detailed level is associated to the development of capacity curves (Martinelli et al 2008).

In order to set a schedule of the interventions, it was considered an additional criterion referred to the estimation of the benefits-cost ratio of the structural intervention. The intervention costs were estimated in terms of the buildings area and the expected damage. The buildings area were determined as a function of the number of students, the number of classes and the level of instruction based on the data defined by the education department (Martinelli et al 2008). For a more refined priorization and resources distribution, schools were grouped considering the risk estimated. Inside of each group, schools were ranked in terms of the number of students. (Casciati et al 2004).

Detailed methods of vulnerability assessment require the availability of information, time and resources that made them not feasible because of the extent of elements at risk. Thus, simplified approaches are useful when the sample of exposed elements is too large. Nevertheless, the results of those methods are not enough for priorization tasks. Therefore, it is promoted a procedure in which the detail of the assessment and the extent of the elements are balanced and rehabilitation strategies may be defined (Casciati et al 2004).

[1] See Anagrafe Edilizia Scolastica, Available at: http://edilizia.regione.marche.it/web/Edilizia/Edilizia-s/Anagrafe-r/index.htm

Another regional assessment of schools vulnerability was developed in the Faial Island in Portugal. In this study was applied a method based on the EMS-98 macro seismic scale in order to estimate de mean damage grade considering the structural type, and vulnerability factors such as the in plan and height regularity, the number of floors, the state of conservation , the presence of captive columns and the possibility of hammering occurrence (Ferreira et al 2008).

A similar project was developed in Bucharest by order of the European Bank of Investment, following the Rehabilitation Strategy of Schools. A survey was carried out as well as the evaluation of the mean damage grade of all scholar buildings in the city. The importance of this project is highlighted due to the fact that all buildings were built before 1940 without seismic previsions and must be updated to the safety standards of the European Union. In this project, the vulnerability assessment was developed by estimating the mean damage grade of each building given the structural type and vulnerability factors following the relationship proposed by Lagomarsino y Giovinazzi. This study encompasses 470 schools; for data acquisition, a survey in an internet site were developed. This survey was composed by 9 categories, related to general information of the school (name, address), as well as properties of external and sport areas, characteristics of each building, the quality of lifelines, the availability of thermal and acoustic insulation, as well as the ventilation and safety conditions related to the evacuation routes, fire extinguishers, among others (Ferreira y Proença 2008).

In Istanbul, the collapse of the dormitory in the primary school of Çeltiksuyu in Bingol in 2003, motivates the local government to adopt the Project “Istanbul Seismic Risk Mitigation and Emergency Preparedness” (ISMEP). This project was focused in the inspection of each facility in order to obtain its structural drawings, the size and geometry of the elements and the properties of the materials. The vulnerability assessment was carried out considering the Turkey rehabilitation code as a reference for linear an non linear analysis, which are useful for identify the needs and alternatives of rehabilitation, as well as an indicative of demolition requirements.

In Canada, the University of British Columbia with the Association of Professional Engineers and Geoscientist of BC and the support of the local Ministry of Education, developed a set of guidelines oriented to reduce the overall seismic risk of public school buildings in British Columbia by identifying minimum evaluation procedures and mitigation measures, useful for the School Boards in the development of a balanced seismic safety program for their existing stock of buildings. In May, 2004, the Ministry of Education announced a $1.5 billion seismic mitigation program for the province’s school buildings. In March of 2005, the Ministry announced $254 million in funding for the first capital construction phase of this program. (Ventura et al 2006)

In Venezuela, a national Program was considered in order to evaluate and mitigate the risk in the existent schools of the country. The number of schools considered in the analysis was about 28.000. It began in 2006 and its duration was estimated in three years. This program includes the identification of the schools construction types, the location, the number of floors and occupation. The objective of the program was to identify older buildings and the structural properties required for the vulnerability and risk assessment. There were developed detailed inspections to 250 schools and 10 standard typologies were analyzed trough detailed procedures and were considered as pilot cases. Besides, optimal retrofitting strategies were suggested as well as a guideline for structural and non structural vulnerability reduction (López et al 2008).

In this project, risk indexes were obtained for different seismic scenarios described by a given magnitude and a specific location. The damage grade of each building was estimated by using fragility curves that describes the probability of exceedance of a given damage state for a specific peak ground acceleration (PGA); the PGA at each school site were determined for each seismic event using appropriate attenuation relationships. The reparation costs were obtained as the product of the normalized expected damage grade with the value of the building and the institution, considering its instruction level and social importance. For the evaluation of casualties, in this study is assumed that the seismic events occurs when schools are completely occupied and the number of deaths are estimated by using the mortality rates described in the ATC 13 (López et al 2008).

In Colombia, the educational secretary of Bogotá ordered a vulnerability assessment of the public schools in the City. In 2004 were identified 710 schools; most of them were built before 1960 without seismic previsions. This study showed that 434 have a high vulnerability. Due to high costs that implied vulnerability reduction and relocation for the whole 434 vulnerable schools, the most critical 201 were declared as a priority. In this sense, the project "Improvement and Structural Reinforcement and Risk Management in Public Schools" were formulated and incorporated in the Development Plan of the city denominated "Bogota without indifference" 2004– 2008. In 2004, with the support of the World Bank, a credit for the seismic vulnerability reduction of the schools was approved. The main objective of this project was the seismic retrofitting of the schools in order to achieve the safety standard established in the national building code, as well as to improve the educational infrastructure and to introduce the risk management in the culture (Coca 2006).

From the experiences above mentioned, it is observed that the seismic risk reduction programs requires the participation of managers from the educational sector as well as research groups, risk consultants, teachers, students and the community in general. Those programs include the development of guidelines for vulnerability assessment, as well as different mechanisms for information acquisition in order to collect data about the structural and non structural properties of the schools. Those activities require the planning of personal and economical resources in order to carry out the inspections of the facilities as well as the development of the inventory and database of the schools.

The methods used for seismic risk prioritization of schools on the projects described above rely on the results of specific scenarios. Even if those scenarios are related to the seismic design requisites, the deterministic estimation of the expected losses is only useful and valid for the scenario considered. Therefore, the decisions for risk reduction are observed in a narrow range of possibilities, ignoring the uncertainty that prevails in the seismic risk. Thus, the development of a probabilistic risk assessment should be encouraged.

5 METHODOLOGICAL ASPECTS FOR SEISMIC RISK ASSESSMENT

For seismic risk assessment, seismological and engineering bases are used to develop earthquake forecasting models that allow estimating damages, losses and effects as a result of catastrophic events. Due to the high uncertainties inherent to the models of analysis regarding the severity and frequency of occurrence of the events, the risk model is based on probabilistic formulations incorporating said uncertainty in the risk evaluation. The probabilistic risk model (PRM) constructed as a sequence of modules quantifies the potential losses that arise from a given event, as illustrated in Figure 5-1.

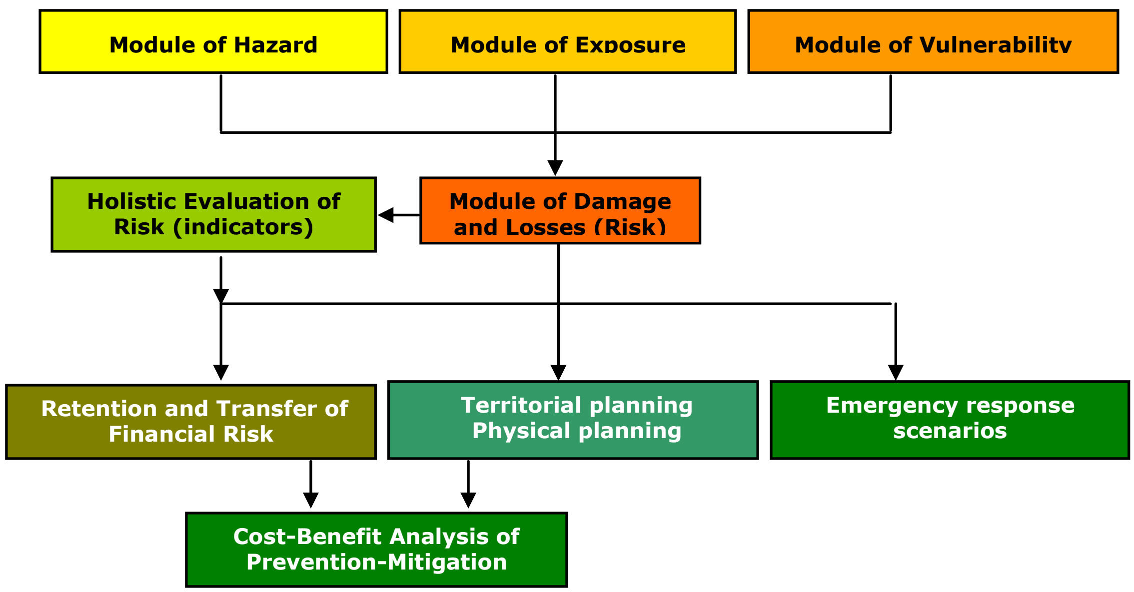

Figure 5-1 General scheme of the probabilistic risk analysis

The suggested analysis modules have the following specific functions:

- Hazards module: This module allows calculating the threat associated to all possible events that could occur, to a group of selected events, or even to a single relevant event. For each type of natural phenomenon, using the module, it is possible to calculate the probable maximum value of the intensity that characterized for different rates of occurrence or return period. In this module is produced for each type of threat, an AME file type (.ame from *amenaza* in Spanish), which include multiple grids, on the studied territory, of the different parameters of intensity of the considered phenomena. Each grid is a scenario of the intensity level obtained from historical or stochastic generated events, with their frequency of occurrence. For this case the parameter of seismic intensity selected is the spectral acceleration.

- Exposure Module: This module deals with the description of the exposed elements or assets that may be affected. It is based on files in "shape" format corresponding to the exposed infrastructure that will be included in the risk analysis. The information required for these files is the following:

    - Identification
    - Location
    - Exposure value
    - Vulnerability function associated to each type of hazard

  In this case the exposure module was developed based on a proxy model or simplified and aggregated description of the exposed assets.

- Vulnerability Module: This module allows the generation of vulnerability functions based on the direct use or modification of existing functions chosen from a library of functions, or by generating new functions from specific information of construction class of the exposed asset o element that has to resist or cope with the phenomenon. The assignment of the vulnerability function to each element is carried out on the shape format file processed in the exposure module.

- Risk Module: This module performs the convolution of the threat with the vulnerability of the exposed elements in order to assess risk or the potential effects or consequences. Risk can be expressed in terms of damage or physical effects, absolute or relative economic loss and / or effects on the population.

Once the expected physical damage has been estimated (average potential value and its dispersion) as a percentage for each of the assets or infrastructure components included in the analysis, one can make estimates of various parameters or metrics useful for the proposed analysis as result of obtaining the Loss Exceedance Curve (LEC). This study focuses, then, in the risk assessment of the school portfolio of each country due to the earthquake hazards, using as measurement the Probable Maximum Loss (PML) for different return periods and the Average Annual Loss (AAL) or technical risk premium. The values of PML and AAL are the main results of this report. These measures are of particular importance for the future design of risk retention (financing) or risk transfer instruments, and therefore they will be a particularly valuable contribution to further studies to define a strategy for financial protection to cover the fiscal liability of the State. In order to establish a reference of the losses, for each country is estimated an index that relates the AAL of the schools portfolio with the national investment in education. This indicator signifies how much from the regular investment in education should be considered for the insurance of the scholar infrastructure.

5.1 SEISMIC HAZARD MODELING

Seismic hazard assessment requires technical and scientific treatment, based on analytical and mathematical models. The theoretical bases of the seismic hazard assessment methodology here presented can be consulted on the CAPRA website (www.ecapra.org). In this study, seismic hazard was performed using CRISIS2007 (Ordaz et. al. 2007). The main steps of the methodology followed are:

1. Definition and characterization of the main seismic sources: the main seismic sources are geometrically defined based on available geological and tectonic information.
2. Seismicity of the main sources: based on the country seismic catalogue, and previous available studies, sources seismicity parameters are assigned, following a Poisson recurrence model.
3. Generation of a set of stochastic events consistent with the regional distribution of location, depth, frequency and magnitude of earthquakes: from the above information, a set of probable seismic events is generated through a recursive geometry division sampling of the sources, and the allocation of seismicity parameters for each segment weighted by its area contribution on the total area. For each segment a series of scenarios is generated whose magnitude depends of the source specific magnitude recurrence curve.
4. Ground motion attenuation model: based on information gathered, previous hazard studies and the state of the art in spectral attenuation functions, an attenuation model is proposed at country level for the appropriate assessment of hazard intensity levels. These results are calibrated to the extent that existing information permits, with those reported in the available previous studies.

5.1.1 SEISMIC PARAMETERS OF SEISMOGENIC SOURCES

The seismicity parameters of the sources are assigned following a Poisson recurrence model, in which the activity of the ith seismic source is specified in terms of the recurrence rate of magnitudes generated by this source. Each of the sources is characterized by a series of seismic parameters which are determined based on the available seismic information:

- *Magnitude recurrence:* represents the average slope of the magnitude recurrence curve (curve of number of events with magnitude greater than *M*, versus seismic magnitude *M*) in the low magnitude zone.
- *Maximum magnitude:* it is estimated based on the maximum probable rupture length of each of the sources, and other morphotectonics characteristics.
- *Recurrence rate for threshold magnitude:* corresponds to the average number of earthquakes per year with magnitude greater than a threshold magnitude value, occurring in a given source. In this study a threshold magnitude of 4.0 was selected.

5.1.2 ATTENUATION OF SEISMIC WAVES

Once the rate of activity of each one of the seismic sources is determined, it is necessary to evaluate the expected impact in terms of ground motion intensity, on a given site of interest. This requires the prediction of the intensity levels presented on the site in question, at bedrock level, if in the ith source occurs an earthquake with a given magnitude. The expressions that relate magnitude, relative position source-site and seismic intensity are known as attenuation laws. Usually, the relative position source-site is specified by the focal (hypocentral) distance. It is considered that the relevant seismic intensities are the ordinates of the acceleration response spectra (for 5% of critical damping), amounts that are approximately proportional to the lateral inertia forces induced in structures during earthquakes. Given the random nature of seismic induced ground movement, seismic intensity is assumed as a random variable with lognormal distribution.

5.1.3 SEISMIC HAZARD

From the seismicity of the sources and seismic wave attenuation patterns, seismic hazard can be calculated considering the sum of the effects of all the seismic sources on a given site. Hazard, expressed in terms of exceedance rates of intensities, can be calculated using the following expression:

$$\nu(a \mid Ro, p) = \sum_{n=1}^{n=N} \int_{Mo}^{Mu} -\frac{\partial \lambda}{\partial M} \Pr(A > a \mid M, Ro)\, dM \qquad \textbf{(Ec. 1)}$$

Where the summation covers all the seismic sources *N*, and Pr (*A*> *a* | *M*, *Ro*) is the probability that the intensity exceeds a certain value, given the magnitude of the earthquake *M*, and the distance between the ith source and the site *Ro*. Function λ is the rate of activity of the seismic source. The integral is performed from *Mo* (threshold magnitude) to *Mu* (maximum magnitude), indicating that takes into account, for each seismic source, the contribution of all possible magnitudes. Since it is assumed that given the magnitude and distance, the intensity has lognormal distribution, the probability Pr (*A*> *a* | *M*, *Ro*) is calculated as follows:

$$\Pr(A > a \mid M, Ro) = \phi\left(\frac{1}{\sigma_{Lna}} \ln \frac{E(A \mid M, R_i)}{a}\right) \qquad \textbf{(Ec. 2)}$$

Where $\phi()$ is the standard normal distribution, *E*(*A* | *M*, *Ro*) is the expected value of the logarithm of the intensity (given by the corresponding attenuation law) and σ_{lna} its corresponding standard deviation.

The seismic hazard is expressed, then, in terms of the exceedance rate of given values of seismic intensity. As mentioned, in this case the seismic intensity is measured by the ordinates of the response spectra of pseudo-accelerations for 5% of critical damping and natural period of vibration of the structure of interest, *T*. Figure 5-2 shows the geographical distribution of the peak ground acceleration (PGA), for a return period of 475 years, in the region under analysis.

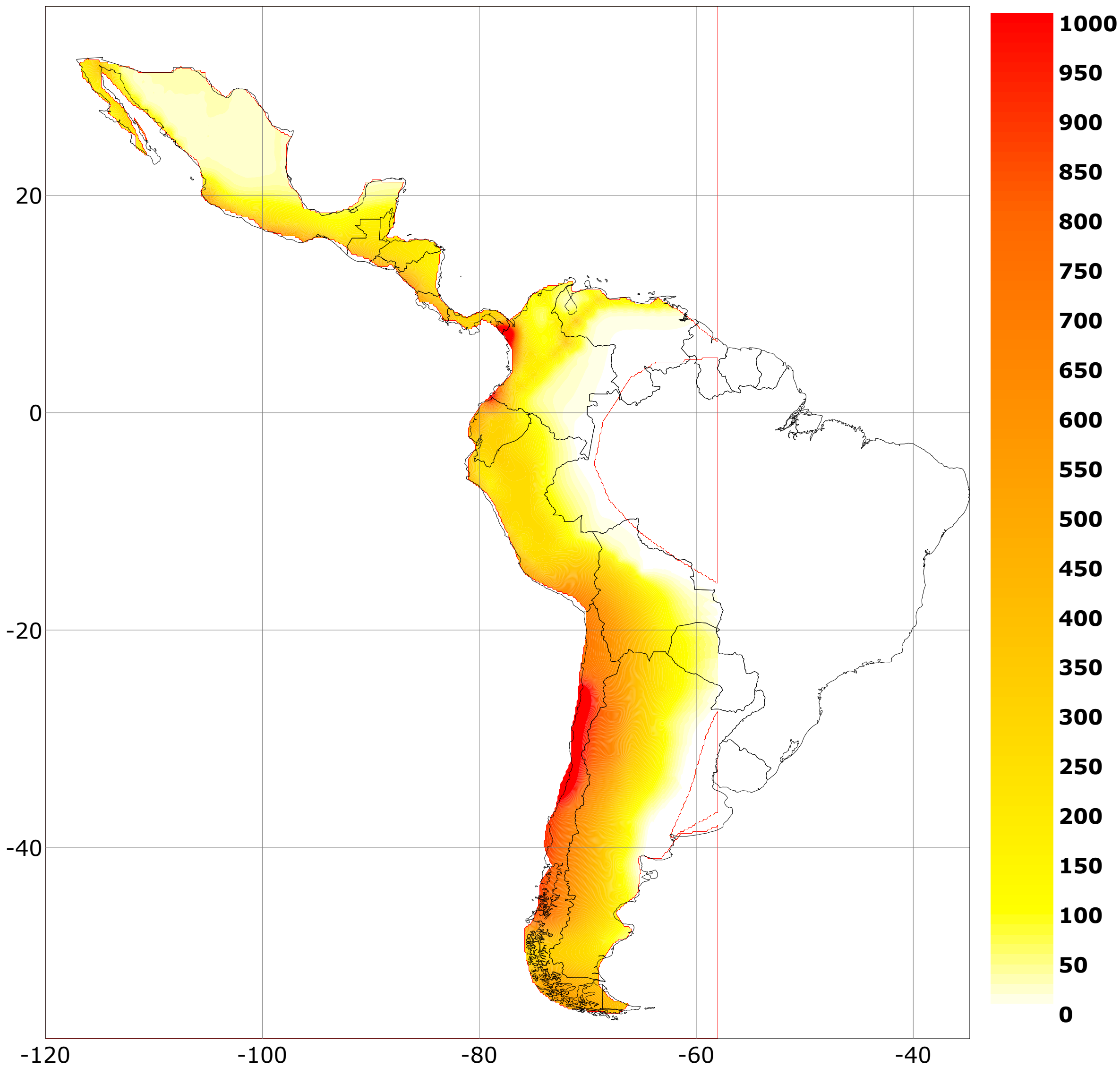

Figure 5-2 PGA [gal] for 475 years return period

5.2 EXPOSURE

The information on exposure to natural events concerns the inventory of buildings and infrastructure that can be affected. This is expressed in terms of assets and population. It is an essential component in the risk analysis or evaluation, and the degree of accuracy of the results depends on its level of resolution and detail. When there is no detailed information available, as in this case, it is necessary to carry out estimations of the exposed inventory of assets based on coarse grain data or on expert opinions. This is referred as the *proxy* exposure model.

Figure 5-3 shows the general procedure carried out to develop a simplified model of exposed schools at a country level.

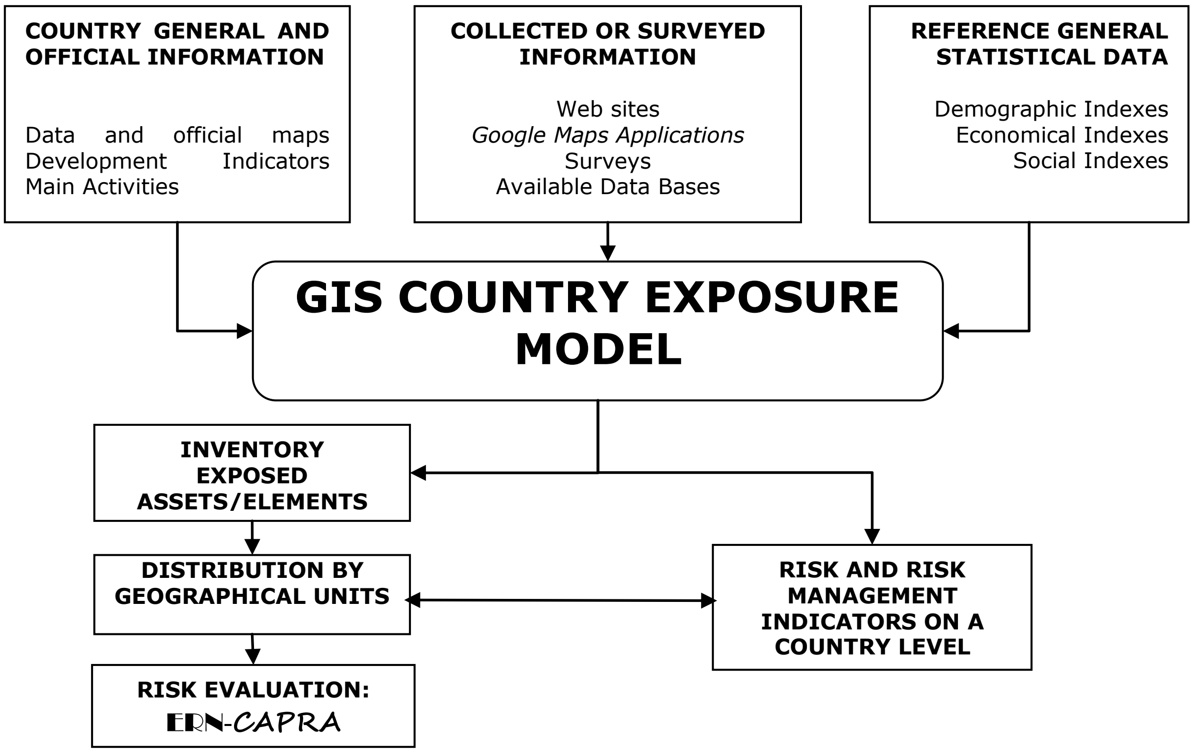

Figure 5-3 Simplified model of the inventory assets for risk evaluation

The objective of the schools' exposure model (*proxy)* at the national level is also to create a suitable distribution for the inventory in terms of geographic national units or political divisions. The bases of exposure estimation are the census databases, indicators related to the human development, welfare and construction prices. The *proxy* exposure model requires the following definitions:

(a) Geographical and political division: the model is presented by means of a categorization in sub national units and municipalities.

(b) To characterize the different urban areas, a zoning assessment is set out in homogeneous zones in terms of infrastructure characteristics, population concentration, economic activity, socioeconomic conditions, amongst others.

More detailed geographical areas can be used if it is required for the analysis; for example, in cities, the suburbs could be included depending on the information available.

In general, it is important to mention that usually for the representation of the exposure it is not possible to have information element by element (for example building by building) because there are not available cadastral data. In most cases a proxy is developed using indirect variables and correlations.

5.2.1 ESTIMATION OF THE BUILT AREA IN EDUCATIONAL FACILITIES

The most reliable parameters for this analysis are the official population reported for each political and administrative sub national unit, as well as the estimated number of students according to the information of the correspondent Education Ministry. For the calculation of building area for education, it is assumed the average built area per student in a school; a value which depends on the level of complexity of each municipality and whether the entity is public or private (See Ec 3). The Table 5-1 shows the range of urban population that is used for each level of complexity.

$$Aedu(m^2) = CE[Est] \times ME\left[{m^2}/{Est}\right] \times PEP[\%] \qquad \textbf{(Ec. 3)}$$

A*edu:* educational built area
CE: number of students of each administrative area
ME: index of average built area per student. It depends on the administrative area complexity level.
PEP: percentage of public education students for each complexity level (see Table 5-1). For private education the PEP is replaced for (1-PEP)

Level of complexity	Population in the urban zone	Public education (%)
High = 1	> 100,000	50
Medium = 2	20,000 a 100,000	80
Low = 3	< 20,000	100

Table 5-1 Population and percentages of public education by levels of complexity

From the revision of a database of the public buildings of Bogotá that were ranked for vulnerability assessment and seismic risk mitigation, it was found that the built area per student in most of the schools is ranged between 0.9 and 2.1 m^2 (See Figure 5-4). Besides, in the Manual for Estimating the Socio-Economic Effects of Natural Disasters, the ECLAC suggests different values for the built area per student; those are presented in Table 5-2 and Table 5-3. In the case of Argentina, the built area per student is near to 6 m^2.

On the other hand, The Educational for All Development Indicator (EDI), shows that Argentina is one of the most advanced countries in the region in terms of achievement of the educational goals (See Figure 5-5). Therefore, by using the indices of built area per student above mentioned and the scale of the EDI, it is possible to estimate this index in the other countries included in the analysis, under the assumption that the better the EDI, the wider the educational areas. The results of the relation between the EDI and the area per student are shown in Table 5-4 and Figure 5-6.

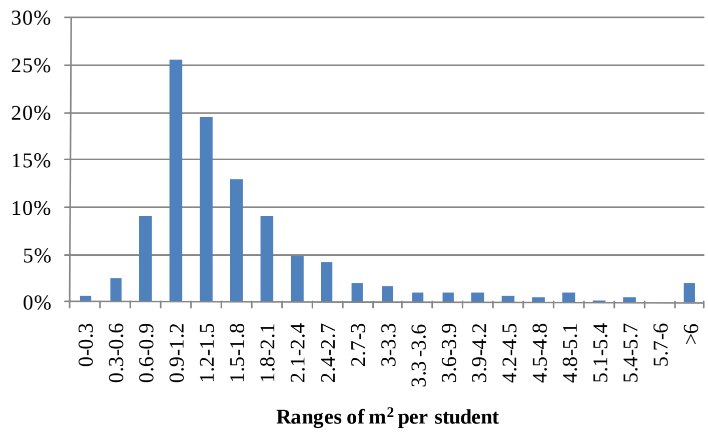

Figure 5-4 Relative frequencies of ranges of m2 per student (Bogota)

Classrooms for basic and secondary education. (m^2 per pupil)		
Overall building area	Argentina	Paraguay
	6	1.2
Classrooms area	Uruguay y Perú	Guyana y Haiti
	1.5	0.9

Table 5-2 Built area per student
Source ECLAC

Other educational services (m^2 per pupil)		
Administrative buildings	Argentina	Bolivia
	0.85	0.05
Laboratories	Ecuador	República Dominicana
	3.8	1.2
Techinical workshops	Ecuador	Uruguay
	5	1.2
Art studios	Paraguay	Uruguay y Perú
	6	1.5
Industrial workshops	Guayana	Guatemala
	9	4.5
Libraries	Brasil	Bolivia
	4.32	0.15
Musical studio	Paraguay	Argentina
	2.7	1.2

Table 5-3 Built area in educational facilities by services
Source ECLAC

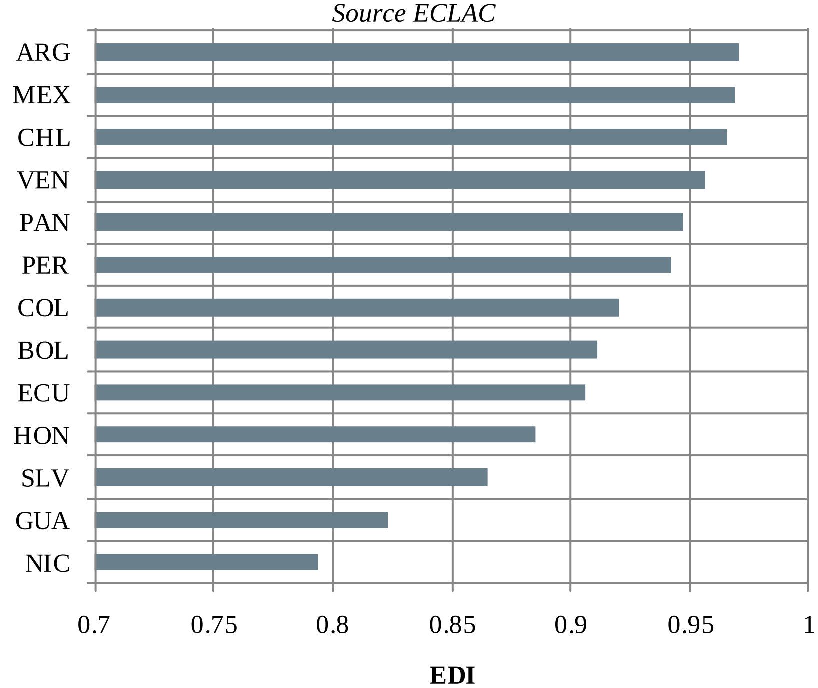

Figure 5-5 EDI
Source UNESCO

Country	EDI	m² per student (estimated)	Level of complexity		
			Low	Medium	High
NIC	0.794	0.78	0.78	0.93	1.09
GUA	0.823	0.84	0.84	1.01	1.18
SLV	0.865	0.91	0.91	1.10	1.28
HON	0.885	1.05	1.05	1.26	1.48
ECU	0.906	1.42	1.42	1.70	1.99
BOL	0.911	1.50	1.50	1.79	2.09
COL	0.92	1.79	1.79	2.15	2.51
PER	0.942	3.02	2.42	3.02	3.63
PAN	0.947	3.31	2.65	3.31	3.97
VEN	0.956	3.77	3.02	3.77	4.53
CHL	0.966	4.25	3.40	4.25	5.10
MEX	0.969	4.40	3.52	4.40	5.28
ARG	0.971	4.52	3.61	4.52	5.42

Table 5-4 m2 per student by countries and level of complexity

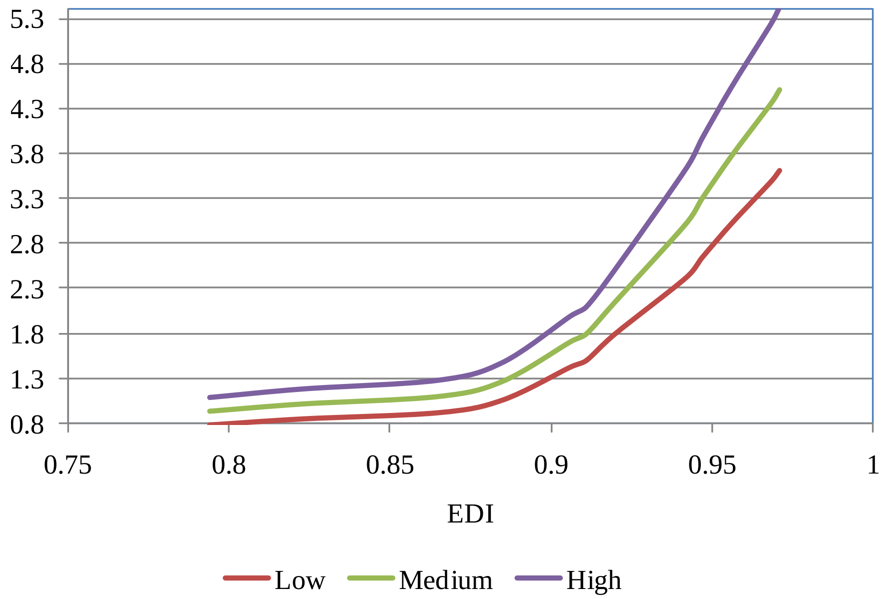

Figure 5-6 m^2 per student by values of the EDI

5.2.2 BUILDINGS COSTS AND EXPOSED VALUES

In order to identify properly the costs of the buildings, prices per m^2 were obtained for different countries from the national centers of statistics. Given the lack of information in some cases, it was necessary to establish a relation among them. Then, the exposed value per student was related to the minimum wage and the GDP per capita. Therefore, the costs per m^2 were adjusted according to those parameters as shown in Figure 5-7.

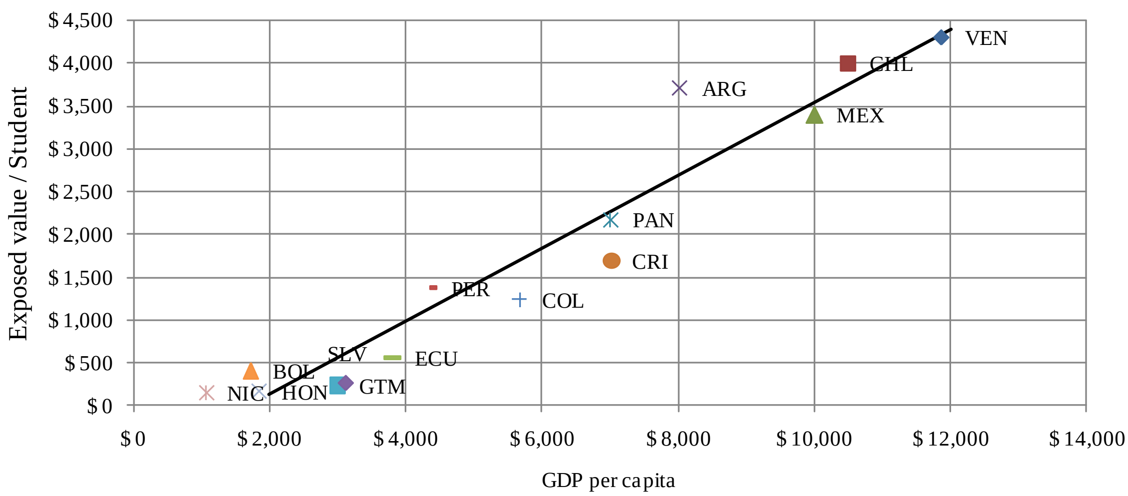

Figure 5-7 Relation between GDP per capita and exposed value per student

An example of the results of the estimation of the schools building area in Nicaragua is shown in Figure 5-8. The results of the exposure module in Colombia are presented in Annex I.

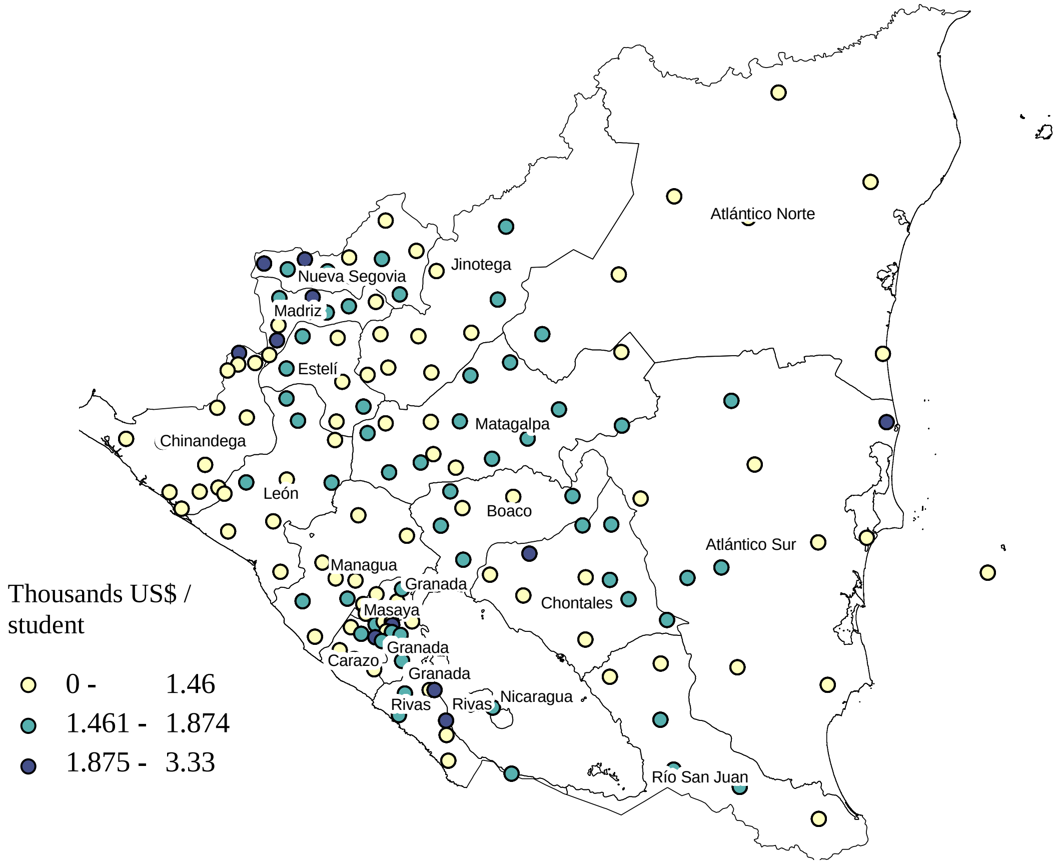

Figure 5-8 Nicaragua. Geographical distribution of the exposed elements

5.3 SEISMIC VULNERABILITY

The seismic vulnerability of buildings is the ratio between any measure of intensity of the phenomenon (acceleration, velocity, displacement or any other, whichever shows the best correlation) and the level of damage of the physical exposed element to such seismic intensity. For example, for the case of several floor building constructions, the seismic intensity that best correlates to the expected damages is the drift or angular distortion between floors (related to the structural deformation due to earthquake forces). For other types of constructions, such as smaller buildings made of masonry or adobe, the maximum ground acceleration is used as correlation parameter regarding damage.

In the analysis, the vulnerability of the buildings is asigned according to the following procedure:

(a) Typifying of the more representing and predominant constructions classes of the portfolio of schools.
(b) Calculation of the vulnerability functions of characteristic construction classes. For this purpose, several analytical models have been developed and some previously published applicable functions have been used, according to preceding national or international experiences.
(c) Assignment of a characteristic construction class and an associated vulnerability function to each element of the exposed inventory of assets.

A summary of the vulnerability functions used for the different exposed elements is presented in the following sections. These curves are based either on the behavior of equivalent typical components obtained from previous studies or from specific analysis on design and construction conditions of the modeled elements.

5.3.1 SEISMIC VULNERABILITY FUNCTIONS

In the analysis are considered typical structural systems such as momentum resistant frames, combined or dual systems, building systems with structural walls, prefabricated systems among others. In general, the damage propensity of this constructions depends on the relative story displacement. The vulnerability functions for these building classes are graphically represented as the *damage percentage vs. the maximum story-drift of the building*.

On the other hand, for construction systems such as masonry structural walls, minor constructions built in adobe, tapia and local materials, the vulnerability functions are best correlated to parameters such as maximum ground acceleration. In this case, the vulnerability functions are best represented as the *percentage of damage vs. the maximum spectral acceleration of the construction*.

The functions of vulnerability are generated in the Vulnerability Module of the **ERN-CAPRA,** based on information available at http://www.ecapra.org/es/ (wiki - vulnerability). The functions are generated in terms of spectral acceleration or in terms of structural drift and are then unified in terms of spectral acceleration, as previously explained. The curves are modified with factors that take into account particular aspects of local construction classes, such as material quality, general condition of constructions, typical design and construction practices and, in general, specific characteristics of predominant structural types. For each country, the representative structural typologies were selected according to the available data in the national census, related to the construction materials and characteristics of the walls, floors and roofs. Besides, it was considered the information about structural types provided by the world housing encyclopedia.[2] Figure 5-9 presents the composition of the built area by structural typologies for each country.

[2] For more information visit http://www.world-housing.net/

In the web site http://www.ecapra.org/es/ (wiki – vulnerability) is available a set of vulnerability functions. Figure 5-10 and Figure 5-11 shows the vulnerability functions used in this report.

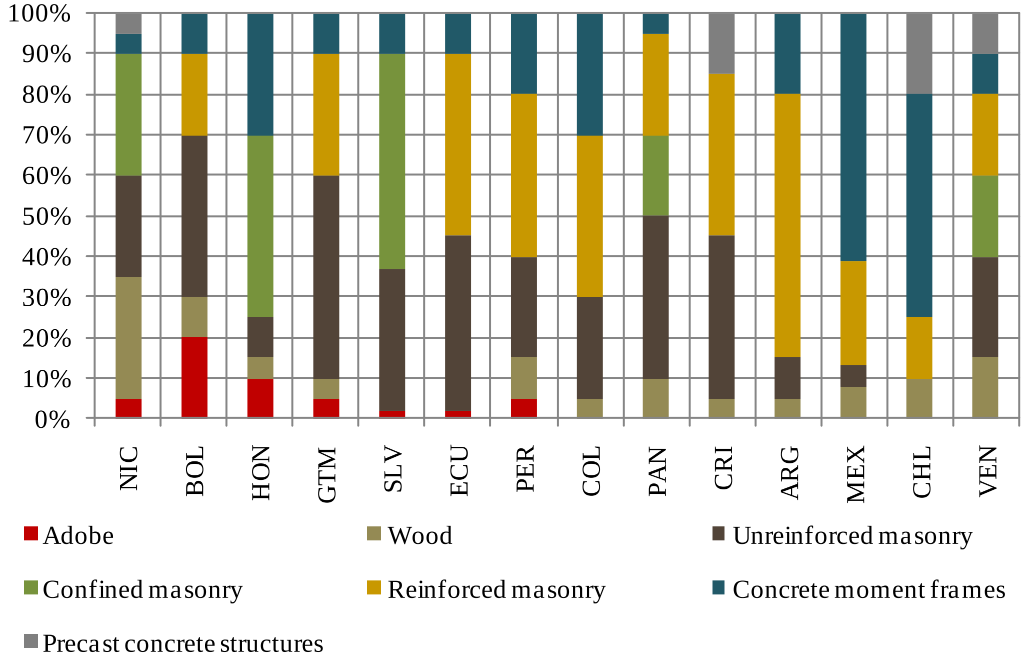

Figure 5-9 Composition of the built area by structural typologies for each country

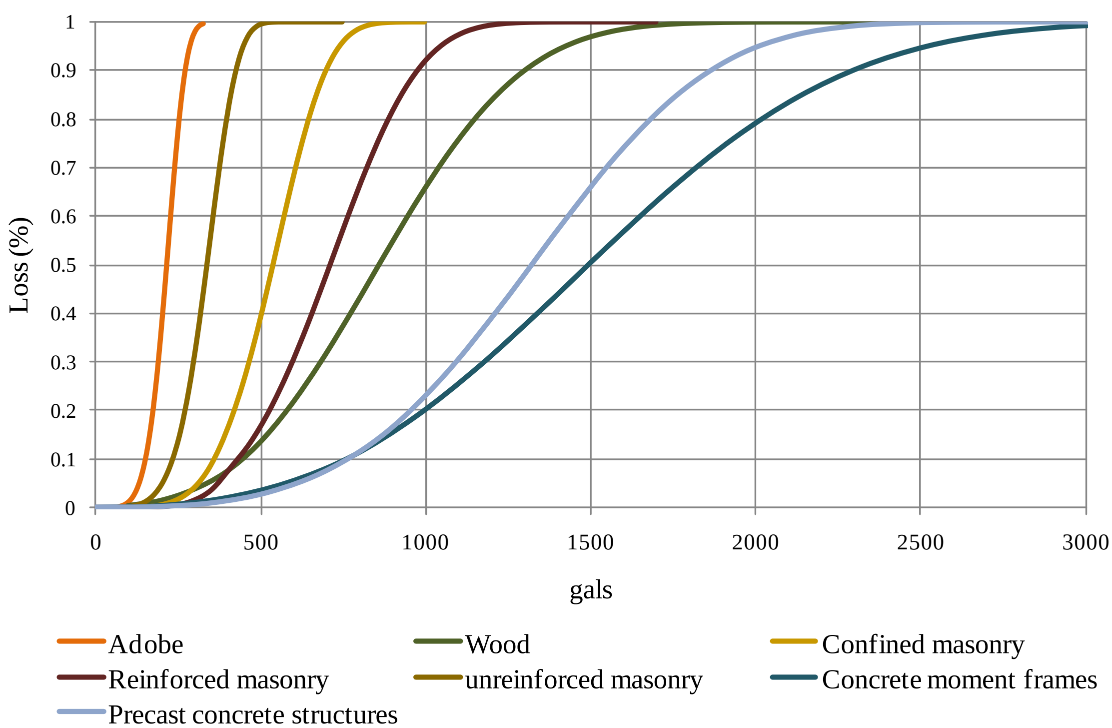

Figure 5-10 Vulnerability curves considered in the current portfolio of schools

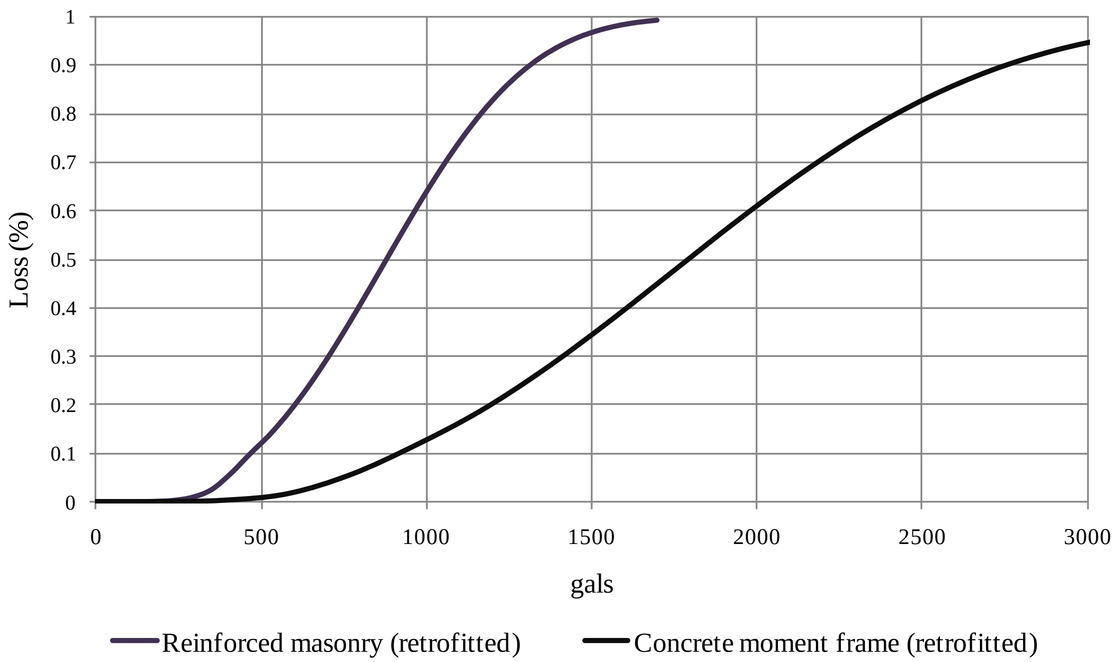

Figure 5-11 Vulnerability curves considered in the retrofitted portfolio of schools

Table 5-5 summarizes the representative structural periods of each structural typology; the assignment of the correspondent seismic intensity in order to estimate the expected loss is based on this parameter.

Vulnerability curve	Structural typology	Structural period (s)
S_A-FPSB-2	Adobe	0.24
S_W-FLFB-2	Wood	0.44
S_MC-RCSB-2	Confined masonry	0.14
S_MR-SLSB-1	Reinforced masonry	0.08
S_MS-SLSB-1	unreinforced masonry	0.08
S_PCR-RLSB-2_0	Concrete moment frames	0.36
S_CP-FLSB-2	Precast concrete structures	0.36
S_MR-SLSB-1_1	Reinforced masonry (retrofitted)	0.08
S_PCR-RLSB-2_1	Concrete moment frame (retrofitted)	0.36

Table 5-5 Types of vulnerability functions, structural types and structural periods

5.4 RISK METRICS

A probabilistic risk analysis of the schools portfolio can be developed at the country level by using the exposed assets inventory, the probabilistic hazard models and the representative vulnerability functions.

As previously explained, the probabilistic risk analysis is done based on a series of hazard scenarios that adequately represent the effects of any event of feasible magnitude that can occur on the area of influence. Each of these scenarios has an associated specific frequency or probability of occurrence. The probabilistic calculation procedure comprises the assessment using appropriate metrics, in this case the economic loss, for each exposed asset considering each of the hazard scenarios with their frequency of occurrence, and the probabilistic integration of the obtained results.

5.4.1 LOSS EXCEEDANCE CURVE

The seismic risk is common described through the loss exceedance curve which specifies the frequencies, usually annually, of the events that may exceed a specific loss value. This frequency is also known as the exceedance rate and is obtained following Ec 4:

$$\nu(p) = \sum_{i=1}^{events} P(P > p \mid i) F_A(i) \quad \textbf{(Ec. 4)}$$

Figure 5-12 shows an example of the loss exceedance curves for a portfolio of exposed elements.

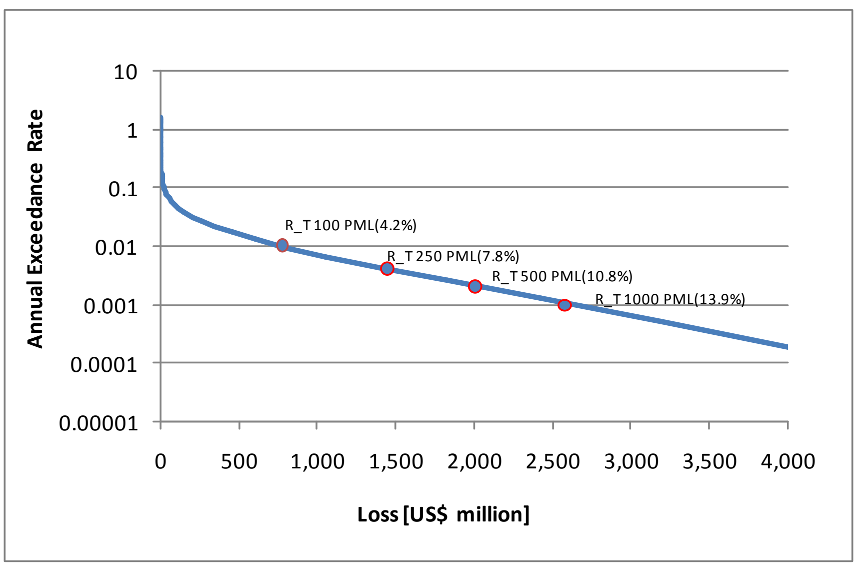

Figure 5-12 Loss exceedance curve for earthquakes

Where $v(p)$ is the exceedance rate of the loss p, $F_A(i)$ is the probability of occurrence of the event i. $P(P>p|i)$ is the probability that the loss is greater than p, given the occurrence of the event i. The exceedance rate is obtained for the sum of all the potential harmful events. The inverse of $v(p)$ is the loss return period.

5.4.2 AVERAGE ANNUAL LOSS

The Average Annual Loss (AAL) is the expected value of the annual loss. This metric could be obtained following Ec 5 or by integration of the the ν(p).

$$AAL = \sum_{i=1}^{events} E(P \mid i) F_A(i) \qquad \textbf{(Ec. 5)}$$

In a simple insurance scheme, the Average Annual Loss represents the actuarially fair insurance premium. As an example, Figure 5-13 shows the results of the AAL of the schools on each municipality in Venezuela in the current state (without structural intervention). In Annex I presents specific cases for other countries included in the analysis.

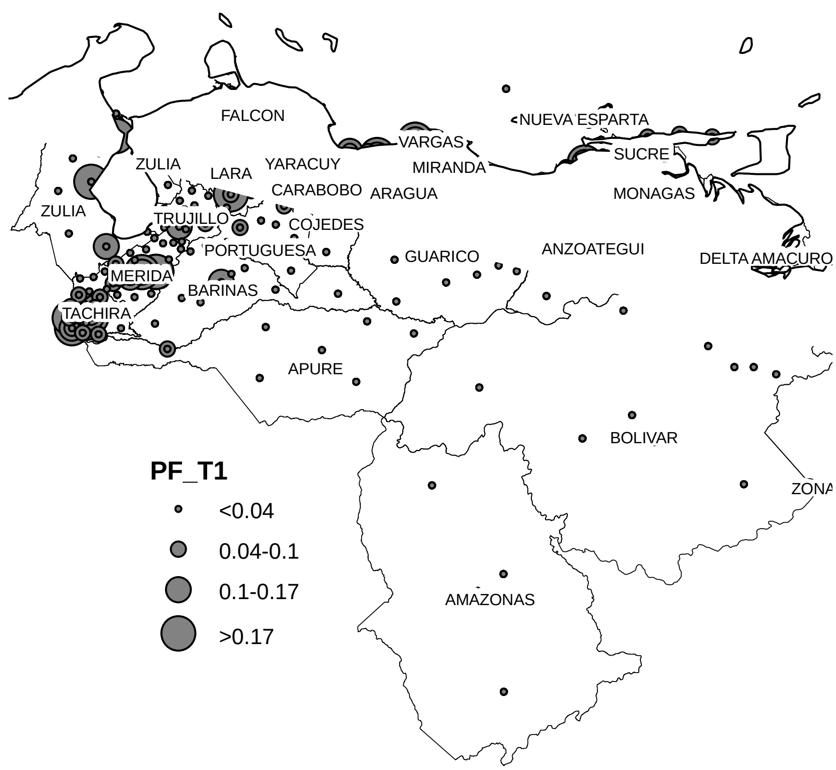

Figure 5-13 Venezuela. Average Annual Loss by municipalities. Current portfolio

5.4.3 PROBABLE MAXIMUM LOSS

The Probable Maximum Loss is referred to losses that may occur with a very low frequency (with a very large return period). There are not universal standards in the definition of this indicator. In fact, the selection of a specific return period is associated to the risk aversion of the agent who bears the risk. In the insurance industry, for example, the return periods used for the PML vary between 200 and 1,500 years at least.

In this report, the metrics described above are estimated using the platform ERN-CAPRA -GIS. More details of the methodology used in this report for seismic risk assessment are described in the link http://www.ecapra.org/es/ (wiki – riesgo).

As an academic example, Table 5-6 and Figure 5-14 presents the probable maximum loss curve, as value and percentage for different return periods. Also, the exceedance probability curves for different PML percentage values for different exposure periods, specifically 20, 50, 100 and 200 years, are presented in Figure 5-14.

Table 5-6 General results of PML for earthquake

Results		
Exposure Value	US$ x10^6	$18,625
Average Annual Loss	US$ x10^6	$30
	‰	1.6
PML		
Return Period	Loss	
Years	US$ x10^6	%
50	$381	2.0%
100	$774	4.2%
250	$1,455	7.8%
500	$2,013	10.8%
1000	$2,583	13.9%

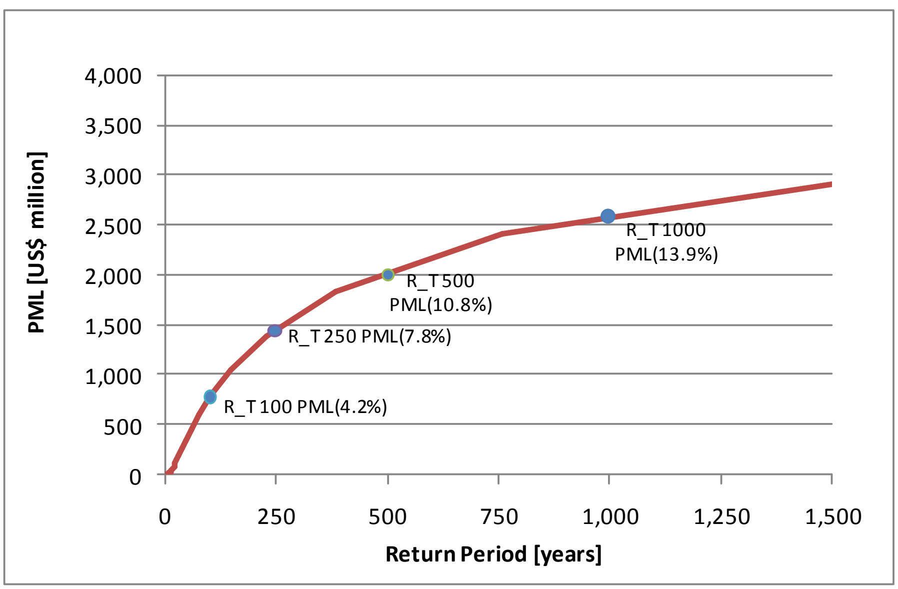

Figure 5-14 PML curve for earthquakes

5.5 PROBABILISTIC BENEFIT COST RATIOS FOR SEISMIC RETROFITTING OF BUILDINGS

Existing infrastructure might be required to be retrofitted in order to maintain an adequate level of the seismic risk to which buildings are exposed. The decision for retrofitting involves different aspects among which the most important is the cost effectiveness of retrofitting. Once estimated the seismic risk in both the current state and in the retrofitted state, it is possible to develop an analysis of benefit cost of risk mitigation. Mora et al (2009) presents an innovative methodology for this analysis from a probabilistic approach which is briefly described in this section.

These authors develop an analytical solution for the probability distribution of the net present value of losses. Those results are verified by using Monte Carlo simulation techniques and present a complete case study for three groups of public buildings in the city of Bogota, Colombia, corresponding to the educational, health and administrative sectors. The analysis permits to obtain the probability distribution for the net present value of the losses, for both the non retrofitted and the retrofitted conditions of the structures, thus allowing the determination of the probability that the net present value of savings (net present value for losses for the non retrofitted structure minus equivalent losses for the retrofitted state) is greater than the cost of retrofitting the structure at the present conditions. The methodology finally allows a rational analysis of different rehabilitations alternatives in order to have analytical parameters for final decision making (Mora et al 2009).

In the traditional approach, the best retrofitting alternative would be the one with the highest expected savings per dollar invested, that is, the maximum expected benefit-cost ratio. However, it has been recognized that, due to its stochastic nature, the net present value of the earthquake losses is an extremely uncertain quantity, so rational decisions cannot be reached by looking only to its expected value, thus disregarding its associated uncertainty. Rather, it has been proposed to compute the probability of having a benefit-cost ratio greater than unity, and choosing the alternative for which this probability is maximum (Mora et al 2009).

Thus, the authors develop an expression of the probability distribution of a general cost-benefit ratio, Q, which is defined as follows:

$$Q = (L_U - L_R)/R \qquad \textbf{(Ec. 6)}$$

where L_U is the net present value of the losses due to all future earthquakes for the present structural condition, L_R is the net present value of the losses due to all future earthquakes for the retrofitted structural condition, and R is the initial cost of structural retrofitting, which is deterministic and is generally evaluated based on previous similar retrofitting projects. The value of R varies depending on the degree of intervention on the structure.

Retrofitting usually involves additional costs related to replacement or repair of non-structural elements such as windows, ceilings, floors, old pipes and also general maintenance of the structure. Also, some retrofitting processes are usually associated to a general upgrading of the construction or even a complete renovation, including a new architectonic upgrade. In those cases, and in order to make a fare evaluation, only the direct structural retrofitting costs should be considered in the proposed analysis.

Other costs may be associated to the functionality loss and the opportunity costs of the investments in education that must be related to the welfare of the communities and the school attending children.

5.5.1 RETROFITTING COSTS

Retrofitting costs are associated to the necessary structural interventions in order to guarantee a pre defined level of safety of the structure. Therefore, it depends on the structural system of the buildings and its seismic design. For this consultancy, the costs of the seismic upgrading of schools are assumed as standard costs for each typology in all countries. Those costs were related to the data available about seismic risk reduction projects of schools in Latin America.

For this purpose, two experiences are available and were used as reference of the estimated costs of retrofitting. The first one is the seismic upgrading of schools in Quito (See GeoHazards International 1995). The value of the structural interventions as well as the structural deficiencies and retrofitting alternatives are shown in Table 5-9 and Table 5-10.

Additional information was acquired from the program of seismic vulnerability reduction of schools in Bogotá. According to Coca (2006), the total investment in the structural retrofitting and improvement of the schools has been about US$ 162.7 million dollars. The total area of buildings with structural interventions (retrofitting, replacement) was about 680,000 m^2; this includes 172 structural reinforced schools, 326 non structural improved schools, and 54 enlarger schools. From this information, the costs of the structural intervention was about 240 US$ per m^2. Examples of the schools considered in this project are presented in Table 5-7.

School	Results of the project
Rodrigo Lara Bonilla	Capacity: 3.200 students. Built area 8,425 m^2. 34 classrooms, 4 laboratories, 6 informatics rooms, a library, two administrative areas
Colegio San Carlos Sede B	Capacity: 1.280 students. Built area 2.767 m^2, 32 classrooms, 5 administrative areas, 4 laboratories, 4 informatics rooms, 4 bathrooms, a coliseum and a cafeteria.
Colegio Luis López de Mesa	Capacity: 2,000 students. Built area 4,206 m^2. Reinforcement costs upon 3.800 millions of COP. 25 Classrooms, 30 bathrooms, 6 administrative areas, 2 technology rooms..
Colegio Alfonso López Pumarejo-Sede A	Capacity: 2,352 students. Investment of more than 4.000 millions of COP. 28 classrooms, a technology room, a sciences room, 2 chemistry laboratories,3 informatics rooms and an administrative area..
Colegio distrital	The cost of the Project was superior to 5.700 millions of COP. 38

School	Results of the project
Marruecos y Molinos	classrooms, 4 laboratories, 4 administrative areas, a library and other services such as of nursery, parking, among others.
Colegio Atanasio Girardot	Capacity 2,240 students. Overall rebuilt. The cost of the project was superior to 7.000 millions of COP. 24 classrooms, 3 laboratories, informatics room, 3 administrative areas and other services such as nursery, meetings room, among others.

Table 5-7 Examples of the results of the seismic risk reduction of schools in Bogotá.
Source: Educational Secretary of Bogotá[3]

Considering the information available on the experiences above mentioned, the retrofitting costs were assumed for each construction material as is shown in Table 5-8.

Construction material	Retrofitting costs (US$/m^2)
Adobe	50
Wood	200
Unreinforced masonry	250
Confined masonry	100
Reinforced masonry	200
Reinforced concrete moment frames	300
Precast concrete structures	300

Table 5-8 Retrofitting costs considered in the analysis

[3] http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=436
http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=417
http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=327
http://www.sedbogota.edu.co//index.php?option=com_content&task=view&id=224

School name	Number of buildings	Construction material	Year of construction	Educational level	Number of stories	Built area (m^2)	Retrofitting costs	
							US$	US$ /m^2 (1995)
Ana Paredes de Alfaro	1	Reinforced concrete	1956	Pre primary	1	540	14,000	25.93
Experimental Sucre	4	Reinforced concrete	1952-1959	Primary	3-4	3,080	57,000	18.51
José de Antepara	1	Adobe	1940	Pre primary and primary		900	11,000	12.22
República de Argentina	1	Unreinforced masonry	1953	Primary	2	700	Not available	
República de Chile	4	Reinforced concrete	1945 / 1994	Primary and secondary	2	2,570	244,000	94.94
Río Amazonas	3	Reinforced concrete	1978	Secondary	2-3	1,600	39,000	24.38
11 de Marzo	1	Steel moment frame	Unknown	Secondary		380	7,700	20.26
Dirección Nacional de Construcciones Escolares, Módulo I	Many	Reinforced concrete				Not available	160,000	63.00
Dirección Nacional de Construcciones Escolares, Módulo II	Many	Steel moment frame				Not available	33,000	13.00

Table 5-9 General description of the schools analyzed and retrofitting costs

(Source: GeoHazards International 1995)

School	Structural deficiencies	Retrofitting alternatives
Ana Paredes de Alfaro	Beams and columns with insufficient reinforcement. Several cracks in the building	Retrofitting of reinforced concrete column-to-beam connections
Experimental Sucre	Beams and columns with insufficient reinforcement, Short columns; soft story, seismic pounding risk	Addition of shear walls in order to reduce the soft story problem. Addition of separation joints between the walls and the columns in order to reduce the short column effect.
José de Antepara	Flexible walls without previsions for lateral loads. Risk of collapse of the roof. Flexible diaphragm.	Addition of confined walls in the transversal direction. Addition of rigid reinforced concrete frames in the transversal direction. Rehabilitation of the trusses and bracing of the roof.
República de Argentina	Short columns. Weak wall to beam connections.	Modification of the walls openings in order to reduce the short column effect. Upgrading of the in –plane stiffness of the walls
República de Chile	Low quality of conservation. Degradation of the properties of the concrete. Disruption of the vertical elements of the structure. Excessive long spans.	Given the insufficient seismic requirements in the design of the school, three of the buildings were heavily modified. Given the low quality of the materials and the poor seismic design of one of the buildings, it was decided to demolish it and built another one.
Río Amazonas	Building designed without previsions for lateral forces. Seismic pounding risk. Short columns. Excessive deflections in the stairs modules.	Upgrading of the lateral stiffness of the buildings through the addition of reinforced masonry walls or steel grids. Addition of separation joints between the walls and the columns in order to reduce the short column effect.
11 de Marzo	Insufficient stiffness of the beam column nodes. Corrosion of the steel bar reinforcement.	Addition of separation joints between the walls and the columns. Reinforcement of the beam-column nodes. Protection of the steel elements with anticorrosive painting.
Dirección Nacional de Construcciones Escolares, Módulo I	Short column; soft story.	Stiffness upgrading of the longitudinal walls. Modification of the walls openings in order to reduce the short column effect
Dirección Nacional de Construcciones Escolares, Módulo II	Short column. Corrosion of steel elements.	Upgrading of the lateral resistance of the structure. Addition of separation joints between the walls and the columns in order to reduce the short column effect.

Table 5-10 General description of the structural deficiencies and retrofitting alternatives

6 SEISMIC RISK IN SCHOOLS OF THE ANDEAN REGION AND CENTRAL AMERICA

In this chapter, it is presented a course-grain disaster risk analysis (the potential damage and loss) of the portfolio of schools by country in the Andean area of South America and in Central America using a proxy of the schools built area and their physical vulnerability. With the information available and the methods used for exposure, hazard, vulnerability and risk modeling, it is possible to estimate the Loss Exceedance Curve and the Average Annual Loss for both the current and the retrofitted schools portfolio. In Annex I, it is developed a country profile of the schools at risk in Colombia. It is organized in two parts: The first present the context of the country: the exposure model (a geographical distribution of the schools proxy) and a seismic hazard map of a return period of 475 years in order to identify at a first glace the areas of high density of exposed elements as well as the zones of higher intensities of the seismic hazard. In the second one, it is shown the summary of the exceedance loss curve of the schools portfolio of each country in the current state and in the case of structural intervention. Besides, it is presented a geographical distribution of the estimated relative physical losses.

6.1 REGIONAL EDUCATIONAL CONTEXT

The assessment of the seismic risk at schools is a reference of the level of safety of these facilities and it is useful for vulnerability reduction programs and communities resilience improvement. Nevertheless, the outcomes of risk assessment, for a better understanding, must be related with the description of the socioeconomic context and the performance of the educational sector in the region of the study. This is important in order to understand the meaning of the losses for the community who face them.

Thus, in this section is presented a brief commentary about the performance of the educational sector in Latin America, in order to identify the countries in which the expected losses of the educational infrastructure may have a greater impact, as well as a general view of the countries limitations in post disaster situations.

The Education for All (EFA) movement is a global commitment to provide quality basic education for all children, youth and adults. The movement was launched at the "*World Conference on Education for All"* in 1990 by UNESCO, UNDP, UNFPA, UNICEF and the World Bank. For monitoring the progress of the EFA program, UNESCO suggests the EFA Development Index (EDI) which is a composite indicator that evaluates the goals on primary education, adult literacy, gender parity and equality and quality. It falls between 0 and 1, with 1 representing full achievement of Education for All (UNESCO 2010)

In the case of Latin America, Argentina, Aruba, Cuba and Uruguay have achieved the goals; Chile, Mexico, Saint Lucia, Trinidad and Tobago and Venezuela, are close to achieving the four EFA goals and have a EDI between 0.95 and 0.96. Sixteen countries rank in an intermediate position, with EDI values ranging from 0.80 to 0.94. In this situation are Bahamas, Barbados, Belize, Bolivia, Brazil, Colombia, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Panama, Paraguay, Peru, Saint Vincent and the Grenadines, and Suriname. These countries have a mixed progress report; while school participation is often high, indicators for adult literacy and quality (as measured by survival to grade 5) are less impressive. Finally, only Nicaragua (with an EDI just under 0.80) is considered to be far from achieving EFA (UNESCO 2010).

As a complement of the information of the EDI, in Figure 6-1 it is presented the literacy rate for different countries in Latin America. The Human Development Index is presented in Figure 6-2 and Figure 6-3 shows the public expenditure in education. In those Figures, the countries included in this consultancy are highlighted.

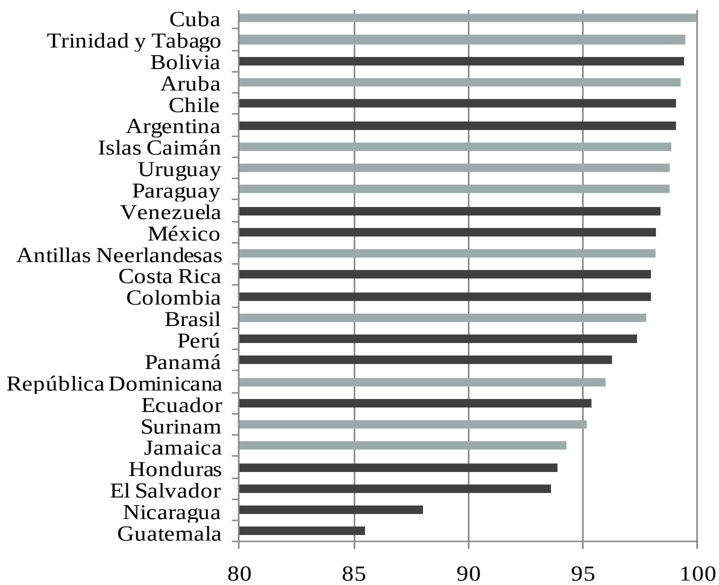

Figure 6-1 Literacy rate

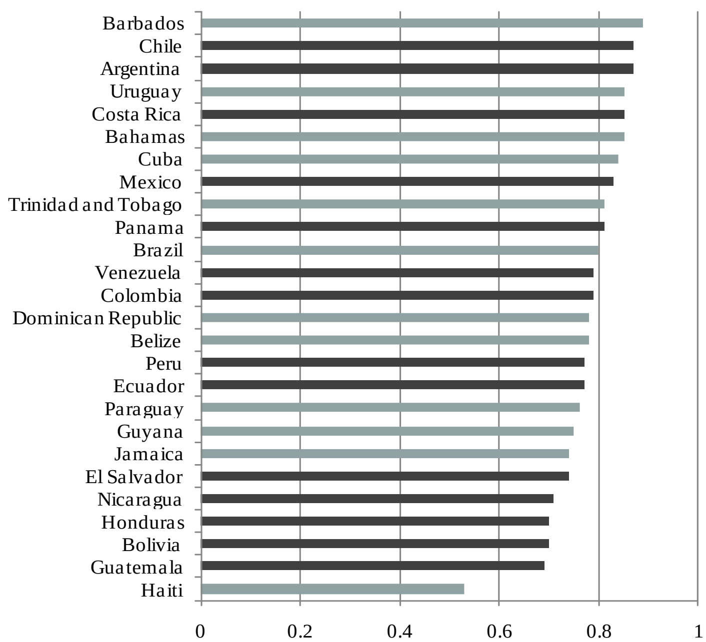

Figure 6-2 Human Development Index 2005

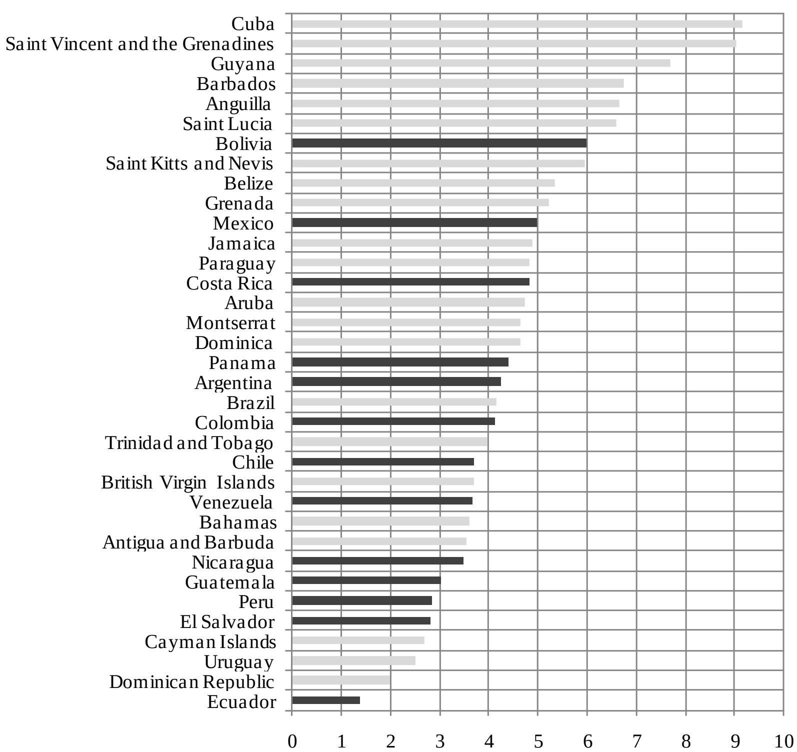

Figure 6-3 Public expenditure on education as percentage of GDP

6.2 SUMMARY OF RESULTS

By using the exposed assets inventory, the probabilistic hazard models and the representative vulnerability functions, it is possible to obtain a probabilistic risk analysis of the schools portfolio at the country level. For this purpose, the platform **ERN**-*CAPRA – GIS* was used in order to estimate the Exceedace Loss Curve for both the current and retrofitted portfolio of schools, as well as the Average Annual Loss at each administrative unit considered for each country.

In order to establish a context of the results, Table 6-1presents general information of the economy of the country, the number of inhabitants and students, the investment in education as percentage of the GDP and the Educational for All development Index (EDI). On the other hand, Table 6-2 shows the estimated exposed values in terms of students, built area and its economic value.

The assessment of seismic risk of the schools is expressed in terms of the Average Annual Loss at a country level. (See Table 6-3 and Figure 6-4). Based on the Loss Exceedance Curve obtained for the school portfolio of each country and considering the estimated costs of structural interventions presented in section 5.5.1, a probabilistic benefit cost ratio is obtained following the methodology described in section 5.5. The results of the Benefit Cost Analysis are presented in Table 6-4.

From Figure 6-4 and Table 6-3, it is possible to identify 3 categories of countries according to the estimates of the AAL of the current portfolio of schools. The lower values of the AAL (lower than 1 ‰) are found in Argentina, Venezuela and Mexico. In general, these results reflects a lower concentration of buildings in zones of relative high seismic hazard (in the case of Argentina) as well as the composition of the schools portfolio by structural typologies of relative low vulnerability such as reinforced concrete and reinforced masonry.

The highest values of the AAL (greater than 10 ‰) are estimated for Peru, Ecuador, El Salvador, Nicaragua, Costa Rica and Guatemala. These results reflect the composition of the school portfolio by structural typologies of relative high vulnerability such as unreinforced masonry and adobe, located in zones of relative high seismic hazard. The estimates of the AAL for these countries are considerable

Bolivia, Panamá, Chile, Honduras and Colombia have an estimate of the AAL between 1‰ and 10‰. Those results are also related with the seismic hazard model developed for each country and the structural typologies considered relevant for each schools portfolio. In the case of Chile, the seismic hazard is relative high meanwhile the school portfolio is composed by structural typologies of relative low vulnerability such as reinforced concrete and reinforced masonry. In the case of Honduras Panamá and Colombia, the concentration of exposed values in zones of relative high seismic hazard is moderate.

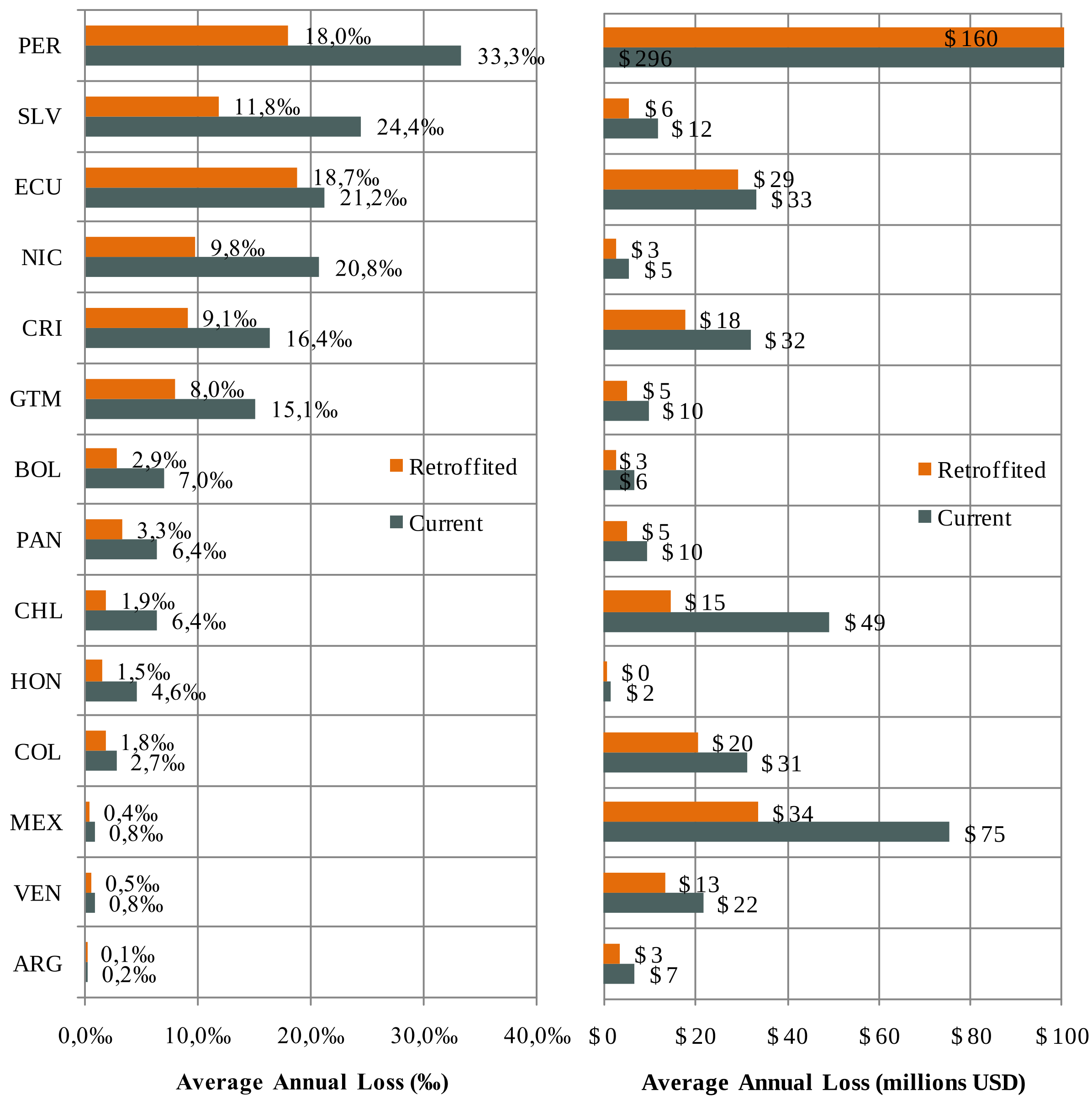

Figure 6-4 Average Annual Loss of the educational sector by country

Country	Inhabitants	Students	Minimum wage	GDP (millions $US)	GDP per capita ($US)	Investment in education (% GDP)	Investment in education (% GDP per capita	EDI
ARG	40,482,764	8,038,308	$ 388	$ 324,920	$ 8,026	4.26	14.47	0.971
BOL	9,602,224	2,286,652	$ 90	$ 16,578	$ 1,726	5.99	16.23	0.911
CHL	16,455,612	1,929,800	$ 316	$ 172,795	$ 10,501	3.71	13.86	0.966
COL	43,144,945	9,170,199	$ 265	$ 244,829	$ 5,675	4.12	15.47	0.92
CRI	4,200,576	1,153,291	$ 339	$ 29,502	$ 7,023	4.83	19.76	No data
ECU	14,354,942	2,817,108	$ 210	$ 54,686	$ 3,810	1.37	13.982	0.906
SLV	7,073,129	1,803,495	$ 185	$ 22,115	$ 3,127	2.82	9.25	0.865
GTM	13,003,021	2,760,358	$ 194	$ 39,099	$ 3,007	3.02	10.11	0.823
HON	7,675,455	2,022,766	$ 291	$ 14,222	$ 1,853	No data	No data	0.885
MEX	109,766,036	26,225,836	$ 138	$ 1,097,960	$ 10,003	4.97	16.28	0.969
NIC	5,791,049	1,743,900	$ 266	$ 6,245	$ 1,078	3.48	13.982	0.794
PAN	3,310,067	682,940	$ 377	$ 23,184	$ 7,004	4.38	16.13	0.947
PER	29,165,807	6,483,956	$ 176	$ 126,789	$ 4,347	2.83	8.26	0.942
VEN	26,412,620	5,932,654	$ 410	$ 313,361	$ 11,864	3.66	13.982	0.956

Table 6-1 General information of the country and the educational sector

Country	Build area (m^2 x 10^3)	Build area / Student (m^2)	Exposed value (millions $US)	Exposed value / Student	Exposed value (% GDP)	Exposed value / Build area ($US/$m^2$)
ARG	42,768	5.3	$ 29,793	$ 3,706	9%	$ 697
BOL	4,953	2.2	$ 929	$ 406	6%	$ 187
CHL	9,999	5.2	$ 7,716	$ 3,998	4%	$ 772
COL	20,710	2.3	$ 11,327	$ 1,235	5%	$ 547
CRI	3,159	2.7	$ 1,952	$ 1,692	7%	$ 618
ECU	4,146	1.5	$ 1,572	$ 558	3%	$ 379
SLV	1,535	0.9	$ 475	$ 263	2%	$ 309
GTM	2,204	0.8	$ 640	$ 232	2%	$ 291
HON	1,993	1.0	$ 332	$ 164	2%	$ 166
MEX	122,785	4.7	$ 89,116	$ 3,398	8%	$ 726
NIC	1,909	1.1	$ 263	$ 151	4%	$ 138
PAN	2,170	3.2	$ 1,483	$ 2,172	6%	$ 684
PER	18,194	2.8	$ 8,881	$ 1,370	7%	$ 488
VEN	28,131	4.7	$ 25,519	$ 4,301	8%	$ 907

Table 6-2 Exposed values estimated in the educational sector

Country	AAL				PML (500)			
	Current		Retrofitted		Current		Retrofitted	
	(Millions US)	(‰)	(Millions US)	(‰)	(Millions US)	(%)	(Millions US)	(%)
ARG	$ 7	0.2	$ 3	0.1	$ 171	0.6	$ 135	0.5
BOL	$ 6	7.0	$ 3	2.9	$ 79	8.5	$ 51	5.5
CHL	$ 49	6.4	$ 15	1.9	$ 470	6.1	$ 286	3.7
COL	$ 31	2.7	$ 20	1.8	$ 580	5.1	$ 528	4.7
CRI	$ 32	16.4	$ 18	9.1	$ 470	24.1	$ 369	18.9
ECU	$ 33	21.2	$ 29	18.7	$ 256	16.3	$ 249	15.8
SLV	$ 12	24.4	$ 6	11.8	$ 153	32.2	$ 101	21.4
GTM	$ 10	15.1	$ 5	8.0	$ 122	19.1	$ 99	15.4
HON	$ 2	4.6	$ 0	1.5	$ 28	8.5	$ 14	4.2
MEX	$ 75	0.8	$ 34	0.4	$ 965	1.1	$ 716	0.8
NIC	$ 5	20.8	$ 3	9.8	$ 70	26.7	$ 45	17.1
PAN	$ 10	6.4	$ 5	3.3	$ 239	16.1	$ 151	10.2
PER	$ 296	33.3	$ 160	18.0	$ 1,406	15.8	$ 1,269	14.3
VEN	$ 22	0.8	$ 13	0.5	$ 633	2.5	$ 444	1.7

Table 6-3 Average Annual Loss and PML (Tr 500 years) for both current and retrofitted portfolios

Table 6-4 presents the results of the probabilistic Cost-Benefit Analysis; E(L) refers to the expected value of the AAL for both the non retrofitted (current) and the retrofitted portfolio. VAR(L) is the variance of the AAL and r and θ are the parameters of the gamma cumulative distribution function of the Cost Benefit Ratio. This table includes the retrofitting costs estimated for each country, the expected value of the Cost Benefit ratio, E(Q), and the probability that the Cost Benefit Ratio is greater than 1, P(Q>1).

In order to obtain a more detailed description of the estimated losses, the AAL was estimated for each structural typology considered in the analysis. Therefore, for each country and construction material, the AAL is presented in Table 6-5 to Table 6-11.

Country	Current				Retrofitted				Cost-Benefit		
	E(L)	VAR(L)	r	θ	E(L)	VAR(L)	r	θ	Retrofitting costs	E(Q)	Pr(Q>1)
ARG	221	5,330	24	9	108	3,415	32	3	9,623	0.01	0.6%
BOL	218	1,546	7	31	90	528	6	15	991	0.13	0.0%
CHL	1,658	50,524	30	54	479	16,641	35	14	2,750	0.43	0.0%
COL	1,047	67,283	64	16	686	53,021	77	9	5,022	0.07	0.0%
CRI	1,078	63,959	59	18	599	30,995	52	12	742	0.64	92.1%
ECU	1,123	24,355	22	52	994	23,297	23	42	947	0.14	87.3%
SLV	392	7,277	19	21	189	2,584	14	14	263	0.77	94.9%
GTM	326	4,444	14	24	172	2,244	13	13	501	0.31	1.0%
HON	52	174	3	15	16	40	2	7	349	0.10	0.0%
MEX	2,537	304,391	120	21	1,117	157,436	141	8	32,354	0.04	0.0%
NIC	184	1,381	7	25	87	471	5	16	353	0.28	0.0%
PAN	321	11,286	35	9	165	4,515	27	6	445	0.35	12.6%
PER	9,991	695,700	70	143	5,391	483,296	90	60	4,094	1.12	100%
VEN	726	81,969	112.9	6.4	445	41,884	94.1	4.7	5978	0.05	0.0%

Table 6-4 Probabilistic Cost Benefit Analysis

Country	Adobe					
	Built area (m^2 x10^3)	Exposed value (US$ millions)	AAL Current		AAL retrofitted	
			$US	‰	$US	‰
ARG	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
BOL	991	$ 186	$ 3	15.1‰	$ 1	4.3‰
CHL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
COL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
CRI	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
ECU	83	$ 32	$ 5	161.2‰	$ 2	57.4‰
SLV	31	$ 10	$ 1	77.4‰	$ 0	29.9‰
GTM	110	$ 32	$ 2	47.3‰	$ 1	18.4‰
HON	199	$ 33	$ 0	13.9‰	$ 0	4.8‰
MEX	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
NIC	95	$ 13	$ 1	60.0‰	$ 0	23.1‰
PAN	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
PER	910	$ 444	$ 72	162.4‰	$ 25	57.0‰
VEN	0	$ 0	$ 0	0.0‰	$ 0	0.0‰

Table 6-5 Average Annual Loss of adobe buildings

Country	Wood					
	Built area (m^2 x10^3)	Exposed value (US$ millions)	AAL Current		AAL retrofittted	
			$US	‰	$US	‰
ARG	2,138	$ 1,490	$ 2	1.1‰	$ 1	0.6‰
BOL	495	$ 93	$ 2	25.4‰	$ 1	13.4‰
CHL	1,000	$ 772	$ 17	22.0‰	$ 8	10.3‰
COL	1,035	$ 566	$ 5	8.8‰	$ 3	4.5‰
CRI	158	$ 98	$ 2	21.0‰	$ 1	10.1‰
ECU	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
SLV	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
GTM	110	$ 32	$ 1	17.6‰	$ 0	8.6‰
HON	100	$ 17	$ 0	9.6‰	$ 0	5.0‰
MEX	9,823	$ 7,129	$ 16	2.2‰	$ 8	1.1‰
NIC	573	$ 79	$ 2	20.9‰	$ 1	10.0‰
PAN	217	$ 148	$ 1	8.0‰	$ 1	4.0‰
PER	1,819	$ 888	$ 88	99.4‰	$ 43	47.9‰
VEN	4,220	$ 3,828	$ 6	1.5‰	$ 3	0.7‰

Table 6-6 Average Annual Loss of wood buildings

Country	Unreinforced masonry					
	Built area (m^2 x10^3)	Exposed value (US$ millions)	AAL Current		AAL retrofitted	
			$US	‰	$US	‰
ARG	4,277	$ 2,979	$ 1	0.3‰	$ 1	0.3‰
BOL	1,981	$ 372	$ 0	1.1‰	$ 1	1.6‰
CHL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
COL	5,177	$ 2,832	$ 10	3.7‰	$ 12	4.3‰
CRI	1,264	$ 781	$ 23	29.0‰	$ 12	15.6‰
ECU	1,783	$ 676	$ 19	27.9‰	$ 23	34.6‰
SLV	537	$ 166	$ 6	33.1‰	$ 3	17.8‰
GTM	1,102	$ 320	$ 6	19.2‰	$ 3	10.9‰
HON	199	$ 33	$ 0	4.0‰	$ 0	2.1‰
MEX	6,139	$ 4,456	$ 7	1.6‰	$ 8	1.8‰
NIC	477	$ 66	$ 2	25.7‰	$ 1	13.8‰
PAN	868	$ 593	$ 6	9.4‰	$ 3	4.7‰
PER	4,548	$ 2,220	$ 57	25.6‰	$ 72	32.5‰
VEN	7,033	$ 6,380	$ 6	1.0‰	$ 7	1.1‰

Table 6-7 Average Annual Loss of unreinforced masonry buildings

Country	Confined masonry					
	Built area (m^2 x10^3)	Exposed value (US$ millions)	AAL Current		AAL retrofitted	
			$US	‰	$US	‰
ARG	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
BOL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
CHL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
COL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
CRI	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
ECU	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
SLV	814	$ 252	$ 5	19.8‰	$ 2	9.2‰
GTM	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
HON	897	$ 149	$ 0	2.6‰	$ 0	1.1‰
MEX	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
NIC	573	$ 79	$ 1	15.3‰	$ 1	7.1‰
PAN	434	$ 297	$ 2	5.3‰	$ 1	2.7‰
PER	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
VEN	5,626	$ 5,104	$ 6	1.2‰	$ 2	0.3‰

Table 6-8 Average Annual Loss of confined masonry buildings

Country	Reinforced masonry					
	Built area (m^2 x10^3)	Exposed value (US$ millions)	AAL Current		AAL retrofitted	
			$US	‰	$US	‰
ARG	27,799	$ 19,365	$ 2	0.1‰	$ 1	0.1‰
BOL	991	$ 186	$ 0	0.3‰	$ 0	0.2‰
CHL	1,500	$ 1,157	$ 3	3.0‰	$ 2	2.1‰
COL	8,284	$ 4,531	$ 6	1.3‰	$ 4	1.0‰
CRI	1,264	$ 781	$ 6	8.1‰	$ 4	5.6‰
ECU	1,866	$ 707	$ 6	8.0‰	$ 4	5.6‰
SLV	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
GTM	661	$ 192	$ 1	5.4‰	$ 1	3.8‰
HON	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
MEX	31,924	$ 23,170	$ 13	0.6‰	$ 10	0.4‰
NIC	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
PAN	543	$ 371	$ 1	2.7‰	$ 1	1.9‰
PER	7,278	$ 3,553	$ 25	6.9‰	$ 17	4.8‰
VEN	5,626	$ 5,104	$ 2	0.3‰	$ 1	0.2‰

Table 6-9 Average Annual Loss of reinforced masonry buildings

Country	Concrete moment frames					
	Built area (m^2 x10^3)	Exposed value (US$ millions)	AAL Current		AAL retrofitted	
			$US	‰	$US	‰
ARG	8,554	$ 5,959	$ 2	0.4‰	$ 0	0.0‰
BOL	495	$ 93	$ 1	9.1‰	$ 0	0.3‰
CHL	5,499	$ 4,244	$ 25	5.8‰	$ 3	0.7‰
COL	6,213	$ 3,398	$ 10	2.9‰	$ 1	0.3‰
CRI	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
ECU	415	$ 157	$ 4	23.4‰	$ 0	1.7‰
SLV	154	$ 47	$ 0	8.1‰	$ 0	0.8‰
GTM	220	$ 64	$ 0	6.0‰	$ 0	0.5‰
HON	598	$ 99	$ 0	4.0‰	$ 0	0.2‰
MEX	74,900	$ 54,361	$ 39	0.7‰	$ 7	0.1‰
NIC	95	$ 13	$ 0	7.1‰	$ 0	0.5‰
PAN	109	$ 74	$ 0	3.1‰	$ 0	0.2‰
PER	3,639	$ 1,776	$ 54	30.4‰	$ 3	1.7‰
VEN	2,813	$ 2,552	$ 1	0.5‰	$ 0	0.0‰

Table 6-10 Average Annual Loss of concrete moment frame buildings

Country	Precast concrete structures					
	Built area (m^2 x10^3)	Exposed value (US$ millions)	AAL Current		AAL retrofitted	
			$US	‰	$US	‰
ARG	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
BOL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
CHL	2,000	$ 1,543	$ 4	2.6‰	$ 1	0.7‰
COL	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
CRI	474	$ 293	$ 1	3.0‰	$ 0	0.7‰
ECU	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
SLV	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
GTM	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
HON	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
MEX	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
NIC	95	$ 13	$ 0	2.7‰	$ 0	0.5‰
PAN	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
PER	0	$ 0	$ 0	0.0‰	$ 0	0.0‰
VEN	2,813	$ 2,552	$ 1	0.2‰	$ 0	0.0‰

Table 6-11 Average Annual Loss of precast concrete structures

It has been recognized that the potential damages that may suffer the infrastructure of the educational sector due to the occurrence of seismic events must be reduced in order to preserve the life of children and to guarantee both the safety of the investments in education and the development process of this sector. The first consideration is a moral commitment, universally accepted. Meanwhile, the others are related / restricted to the context of the community who face the risk, considering the ability to prevent potential crisis and to recover from disasters, as well as the progress achieved in education. In other words, the seismic risk of schools must be observed in a context, identifying the potential losses (infrastructure, lives, and opportunities) and the capacity to protect the exposed values and to replace them.

A reference of the progress in education at a country level is presented in the Educational for All Index (EDI). Through the comparison between the estimates of the AAL and the EDI, the seismic risk assessment of schools has different meanings. It is possible to identify four different categories: I) countries with large AAL and notable advances in education. II); countries with notable advances in education and low estimates of the AAL; III) countries with low progress in education and low estimates of the AAL and IV) countries with low progress in education and high estimates of the AAL.

For the first two groups, the seismic risk represents the probability of disruption of the educational services at the current level. Further, on these countries, the achievement of the current progress in education is probably associated to continued programs and investments oriented to the improvement of the coverage and quality of the education. Thus, the seismic risk represents the opportunity costs of those investments. For the remaining groups, the seismic risk represents a limitation to obtain the required educational infrastructure that satisfies educational goals related to the coverage and quality.

In Figure 6-5 it is possible to classify the countries included in this analysis as follows:

- Group I: Peru, Costa Rica,
- Group II Mexico, Venezuela, Panamá, Colombia, Bolivia and Chile.
- Group III: Honduras, Colombia, Bolivia
- Group IV: Nicaragua, Guatemala, El Salvador.

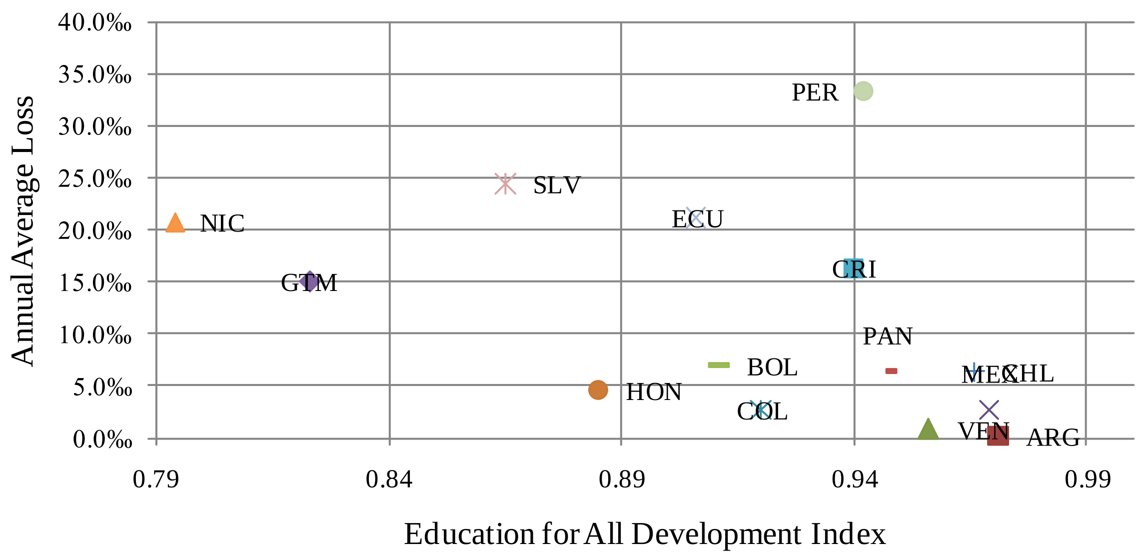

Figure 6-5 Average Annual Loss and Education for All Development Index

A similar procedure is also performed in order to analyze the ability to recover from disasters. A reference of the resourcefulness of the educational sector at a country level is described in terms of the investment in education as a percentage of the GDP per capita. Through the comparison between the estimates of the AAL and this index, it is possible to identify four different categories: I) countries with large AAL estimates and high investments in education. II) Countries with high investments in education and low estimates of the AAL. III) Countries with low investments in education and low estimates of the AAL, and IV) Countries with low investments in education and high estimates of the AAL.

Countries belonging to the first groups are considered as those with more resources available for post disaster recovery projects, under the assumption that part of the recovery funding is obtained from the budgetary reallocation of the educational sector. In contrast, the remaining groups represent countries that may have limited resources for disaster recovery. Depending on the resilience of each country, the recovery of the pre disaster educational standards would postpone the achievement of more advanced educational objectives.

In Figure 6-6 it is possible to classify the countries included in this analysis as follows:

- Group I: Costa Rica, Nicaragua, Ecuador
- Group II Bolivia, Venezuela, Panamá, Chile, Mexico, Colombia, Argentina
- Group III: none
- Group IV: Peru, Guatemala, El Salvador.

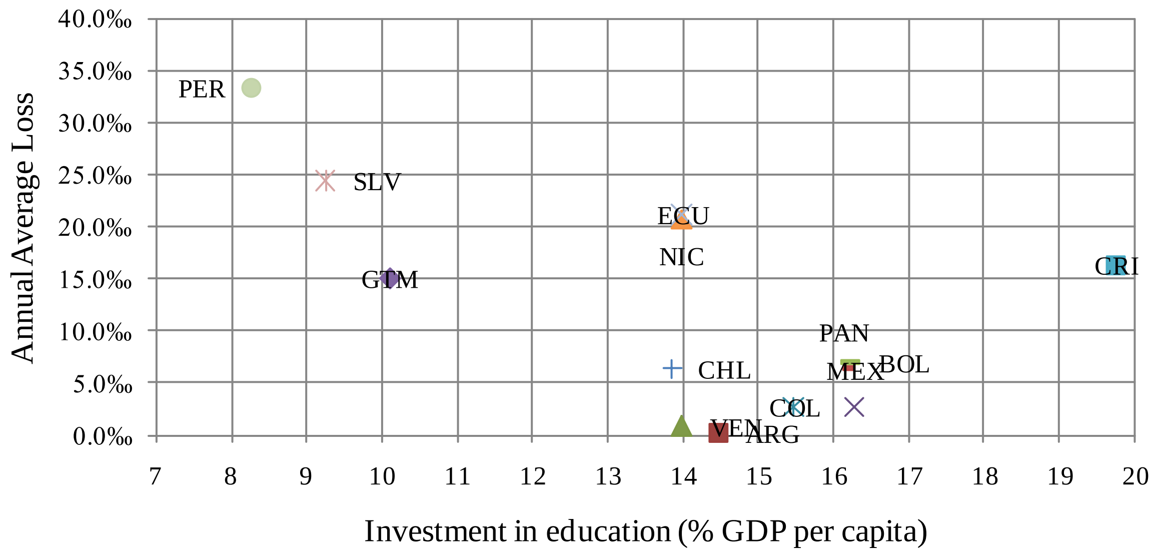

Figure 6-6 Average Annual Loss and investment in education (% GDP per capita)

In addition to the commentaries about the estimated AAL of the schools portfolio of each country, it is necessary to include general observations of the probabilistic cost benefit ratios obtained in this report. From the list of countries included in this analysis, only in Ecuador, El Salvador, Costa Rica and Peru the probability that the net present value of savings (net present value for losses for the non retrofitted portfolio minus equivalent losses for the retrofitted state) is greater than the cost of retrofitting the portfolio at the present conditions. This result depends on the vulnerability of the structural typologies, the economic appraisal of the buildings, the geographical distribution and concentration of exposed values, the discount rate of the AAL, the retrofitting costs and the seismicity of the region of interest.

If the schools portfolio is composed by structural typologies of low capacity /high vulnerability, the retrofitting costs may be as high as the replacement value of the infrastructure. In this case, the demolish/rebuild option is preferred to the structural intervention. On the other hand, if the seismic upgrading of the buildings reflects a slight reduction of the AAL which is not significant to the retrofitting costs, the seismic upgrading of the portfolio is not considered to be profitable from a financial perspective.

The geographical distribution and concentration of the exposed elements is also relevant in order to define the benefit cost ratio of the structural intervention of the schools. If a considerable proportion of the exposed elements are located at areas of relative low seismicity, at the national level, the benefits of the structural intervention cannot be discerned.

The discount rate used to convert costs (losses) due to future earthquakes into present (monetary) value is relevant in the decision of the seismic upgrading of buildings. As this rate decreases, future benefits increase and so do the benefit/cost ratios. In the case of Thessaloniki (Greece), Andreas et al (2008) applied a discount rate of 4% in the analysis of feasibility of pre earthquake strengthening of buildings in a life cycle cost analysis. The Federal Emergency Management Agency, in the Benefit-Cost Model for the assessment of Seismic Rehabilitation of Federal Buildings (FEMA 1992) suggests rational values for the discount rate ranging from 3 to 6%. Under these considerations, the discount rate used in order to estimate the present value of the losses is 3%.

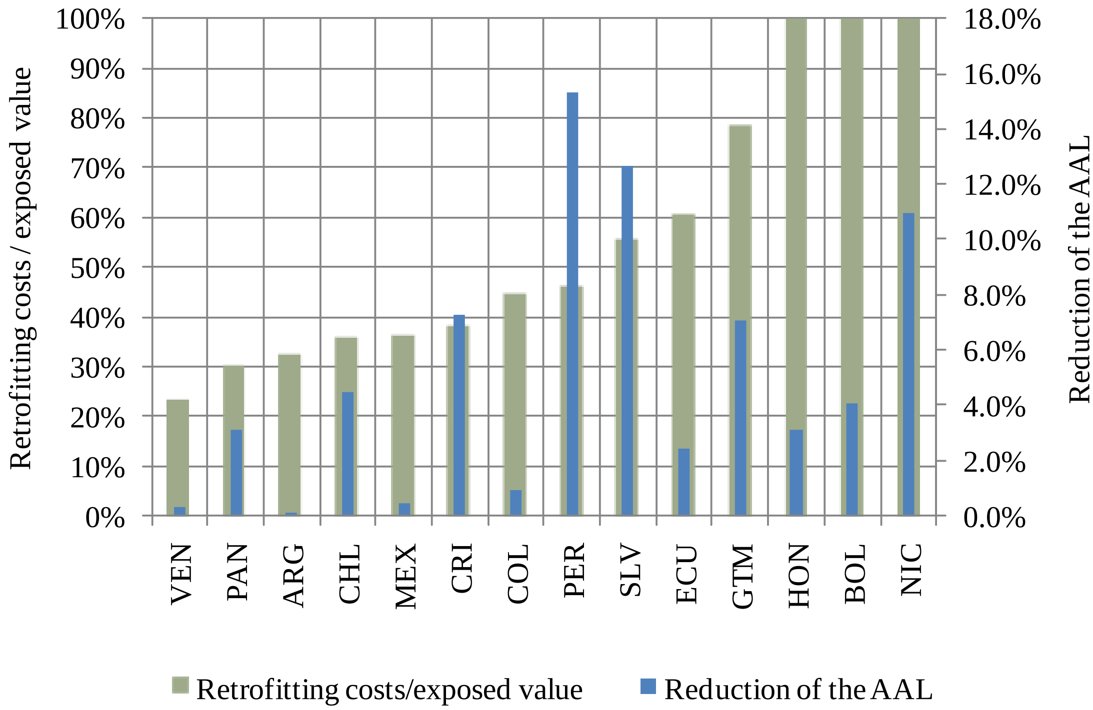

Figure 6-7 Retrofitting costs / exposed value

Figure 6-7 presents the retrofitting costs in terms of the exposed value for each country. From this Figure it is possible to identify the cases above mentioned. For Honduras, Bolivia and Nicaragua, the retrofitting costs are greater than the replacement value, therefore, the Cost Benefit Ratio is lower than 1. In the model developed for this consultancy, for these countries, the percentage of vulnerable structures such as masonry and adobe buildings is high (see Figure 5-9), then, the structural intervention should require a significant investment, comparable with the replacement of the infrastructure.

On the other hand, the difference of the AAL between the current and the retrofitted portfolio in the case of Venezuela, Panamá, Argentina, Chile. Colombia and México is not significant compared with the retrofitting costs (see Figure 6-4), then, from a financial perspective, the seismic upgrading of the school portfolio is not attractive. This result is also related with the structural typologies considered representative for those countries. From Figure 5-9 it is possible to observe a higher percentage of reinforced concrete and reinforced masonry buildings. For those structures, the reduction of its vulnerability due to the seismic retrofitting is low compared with the reduction of the vulnerability of the remaining structural types (see Figure 5-10 and Figure 5-11).

Between those extremes, Ecuador, Peru, Costa Rica and El Salvador has a better chance to develop a feasible seismic upgrading of the schools portfolio, given the expected reduction of the AAL and the estimated costs of the structural intervention.

It must be remarked that those results represents a rough estimate of the seismic risk at a country level. The model used for this analysis is based on general information of prices, retrofitting costs and estimates of the exposed values and considerations on its vulnerability; therefore these results should not be considered in order to define specific programs of seismic risk reduction. Given the scope and limitations of the model, the concentration of expected losses at sub national levels is not distinguishable in this report, then, the feasibility of seismic upgrading of schools in cities, as in the Case of Bogotá, or Quito, cannot be observed neither discussed from this analysis.

The results obtained from this consultancy are useful in order to develop comparisons among countries. From Figure 6-4 it is possible to identify that the countries that have a wider composition of the most vulnerable structural typologies (adobe, wood, unreinforced masonry) have the greater values of the AAL. This assumption is confirmed in the estimation of the AAL by structural typology. From Table 6-5 to Table 6-11 it is possible to observe that the most vulnerable structural types have higher values of the AAL. Those results reflect the need on the intervention of these buildings in order to guarantee the safety of the children and the investments in education.

More detailed results of the seismic risk of the schools in the case of Colombia are presented in the country profiles included in the Annex I. This profile is useful as a first step, as a ranking procedure, for a national seismic reduction program. The development of risk mitigation strategies should be based on more detailed information. Those profiles may include information about the number of teachers as well as references of the capacity of the educational sector and the government to manage the expected losses. Those aspects are outside of the scope of this consultancy but are suggested for further works.

7 COMMENTS ON SEISMIC REDUCTION OF EDUCATIONAL FACILITIES

There are several evidences of the damages in schools during earthquakes. Understanding that the seismic risk may be reduced by the intervention of the physical vulnerability, it is necessary to promote and develop national programs of risk identification and mitigation of this infrastructure. Efforts on identifying successfully recovery processes may be not as interesting and effective as those oriented to the reduction of potential crisis and negative effects to the educational sector. Schools are not only shelters and alternative facilities for emergency management; those infrastructures has a primary object related to the formation of human capital and the improvement of the welfare and well being of communities, thus, its safety must be a priority in the national development plans.

According to Dasgupta & Weale (1992), life quality is related to the determinants of well-being in terms of the availability of food, clothing, potable water, education facilities, health care and income. Therefore, the loss of the school coverage and educational services due to seismic events, represents a reduction of the life quality of the community who face them.

From the empirical analysis on a panel of 19 OECD countries observed from 1971 to 1998, Beraldo et al (2009) have found a robust positive correlation between expenditures on health and education and GDP growth. The estimated positive impact is stronger for health than for education. Also, these authors have found some evidence that public expenditures influence GDP growth more than private expenditures. In particular, their estimates shows that a 1% increase in total educational expenditure growth rate would increase the per-capita GDP growth rate by about 0.03%, with most of this effect coming from public expenditure.

Then, taking into account the effects of education in welfare, well being and economic growth, as well as the requisites on the children's safety and the protection of the public investments, the reduction of the seismic vulnerability of educational facilities must be promoted in national plans, with adequate schedules, information and funding.

Identifying good practices in the post disaster reconstruction of schools is a great effort and its outcomes are highly divulged in order to coordinate recovery plans and resources on potential crisis. Nevertheless, there is a greater opportunity on improving the safety of the children and protecting the investments in education from a prospective risk management of the schools portfolio. This challenge includes the identification of the potential losses, the design of possible alternatives of structural and non structural vulnerability reduction, the design of a retrofitting program, the assignment of priorities to the interventions, and the project funding.

From this perspective, the objectives of the collaboration extended by ILO/CRISIS to the UNISDR secretariat in the implementation of the "Hyogo Framework for Action 2005-2015, represent a partial risk management strategy only based on corrective actions. Therefore, this collaboration should include other items related to risk identification, prevention and mitigation. The feasibility of the seismic upgrading of schools must be evaluated within an interdisciplinary framework where the safety of the children, the improvement of the scholar infrastructure and the resilience of the communities cannot be rejected by the economical benefits derived from the reduction of the expected losses.

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ANNEX I COUNTRY PROFILE

8.1 COLOMBIA

Table 8-1 shows general indicators of investment in education, school age population, youth literacy and the estimate of scholar buildings area. Table 8-2 shows the number of students of public schools by departments in Colombia. This information was obtained from the Ministry of Education and it is related to the enrolment of pupils on all levels in 2007. The population in 2008 was estimated by using a growth rate of 1.3% according to CEPAL. The composition of the schools portfolio by structural typologies is presented in Figure 8-1. The geographical distribution of the exposed elements is presented in Figure 8-2.

General Indicators	
GDP (billions US$)	244,828.8
Investment in education as % of GDP (ten years average)	4.12
Investment in education per pupil as % of GDP per capita (ten years average)	15.47
School age population pre primary	2,657,734
School age population primary	4,409,221
School age population low secondary	3,525,446
School age population secondary	5,268,571
School age population upper secondary	1,743,125
Youth literacy	97.99
EFA development index	0.92
Total area estimated of schools buildings (m^2)	20,710

Table 8-1 Colombia. General educational indicators

Department	Number of municipalities	Students (Census 2007)
Amazonas	10	18,894
Antioquia	125	1,239,029
Arauca	7	56,638
Atlántico	23	400,734
Bogotá	1	1,011,615
Bolívar	45	486,393
Boyacá	123	271,535
Caldas	27	195,150
Caquetá	16	118,017
Casanare	19	84,206
Cauca	41	300,870
Cesar	25	251,069
Choco	31	128,369
Córdoba	28	400,912
Cundinamarca	116	458,159
Guainía	6	9,275
Guaviare	4	22,843
Huila	37	253,680

Department	Number of municipalities	Students (Census 2007)
La Guajira	15	154,366
Magdalena	30	338,292
Meta	29	178,272
Nariño	64	378,817
Norte De Santander	40	301,389
Putumayo	13	95,082
Quindío	12	114,633
Risaralda	14	190,741
San Andrés, Providencia Y Santa Catalina	2	11,286
Santander	87	410,181
Sucre	26	242,002
Tolima	47	304,454
Valle Del Cauca	42	717,208
Vaupés	5	8,918
Vichada	4	17,170
Total	1,114	9,170,199

Table 8-2 Students of public education by department

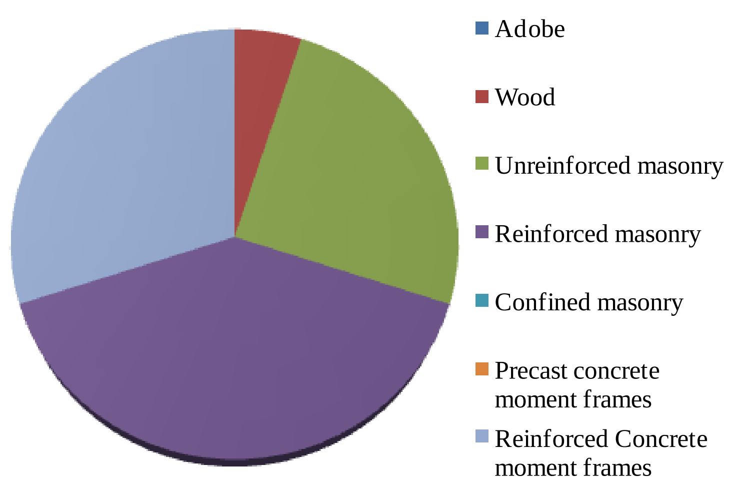


Figure 8-1 Colombia. Composition of the schools portfolio by structural typologies

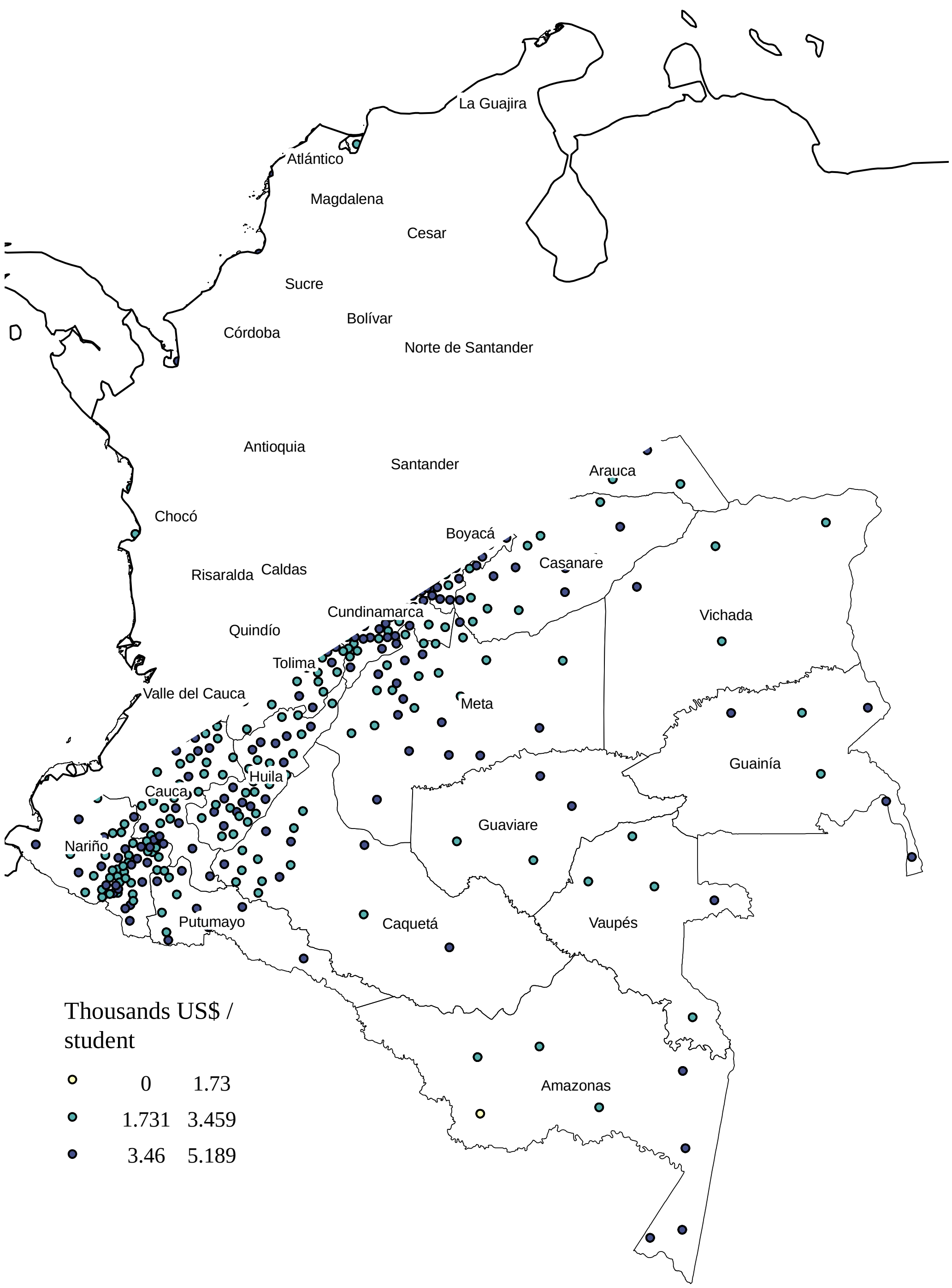


Figure 8-2 Colombia. Geographical distribution of the exposed values

Figure 8-3 shows a seismic hazard map for a return period of 475 years in the country. By using the exposure, hazard, vulnerability and risk modules presented in Section 5, the Loss Exceedance Curve has been estimated for the current and retrofitted portfolio of schools. Those results are summarized in Table 8-3 and Figure 8-4. A geographical distribution of the AAL is presented in Figure 8-5 and Figure 8-6.

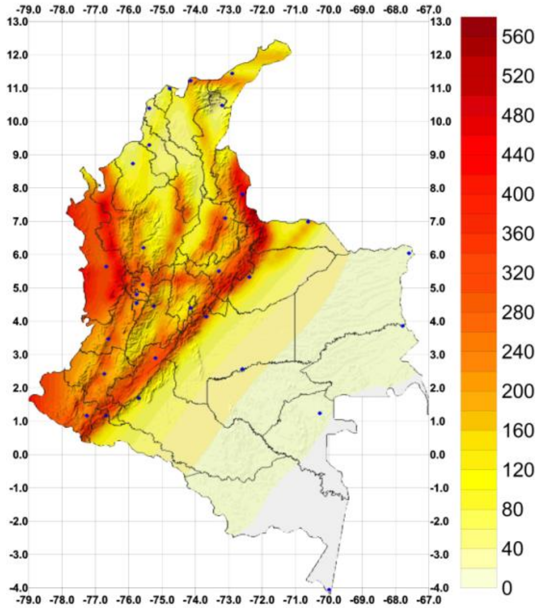


Figure 8-3 Seismic hazard map (Tr 475 years)

Exposed value (Millions US$)	11,327			
Average Annual Loss (AAL)	Current portfolio		Retrofitted portfolio	
	(Millions US$)	(‰)	(Millions US$)	(‰)
	31.15	2.7	20.46	1.8
Probable Maximum Loss	Current portfolio		Retrofitted portfolio	
Return period	US$	%	US$	%
50	137	1.21%	135	1.19%
100	242	2.14%	234	2.07%
250	411	3.63%	418	3.69%
500	595	5.25%	528	4.66%
1000	770	6.80%	680	6.00%

Table 8-3. Colombia Summary of losses. Current state

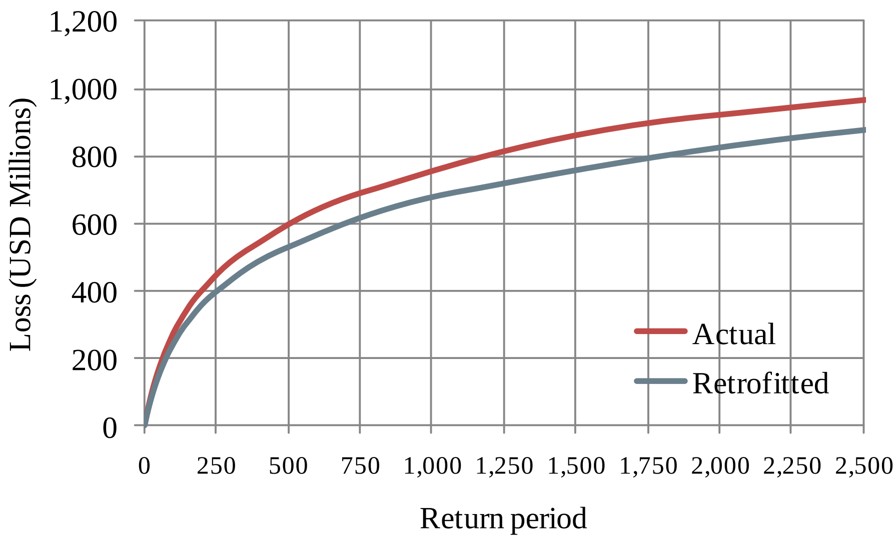


Figure 8-4 Colombia. Probable Maximum Loss Curves

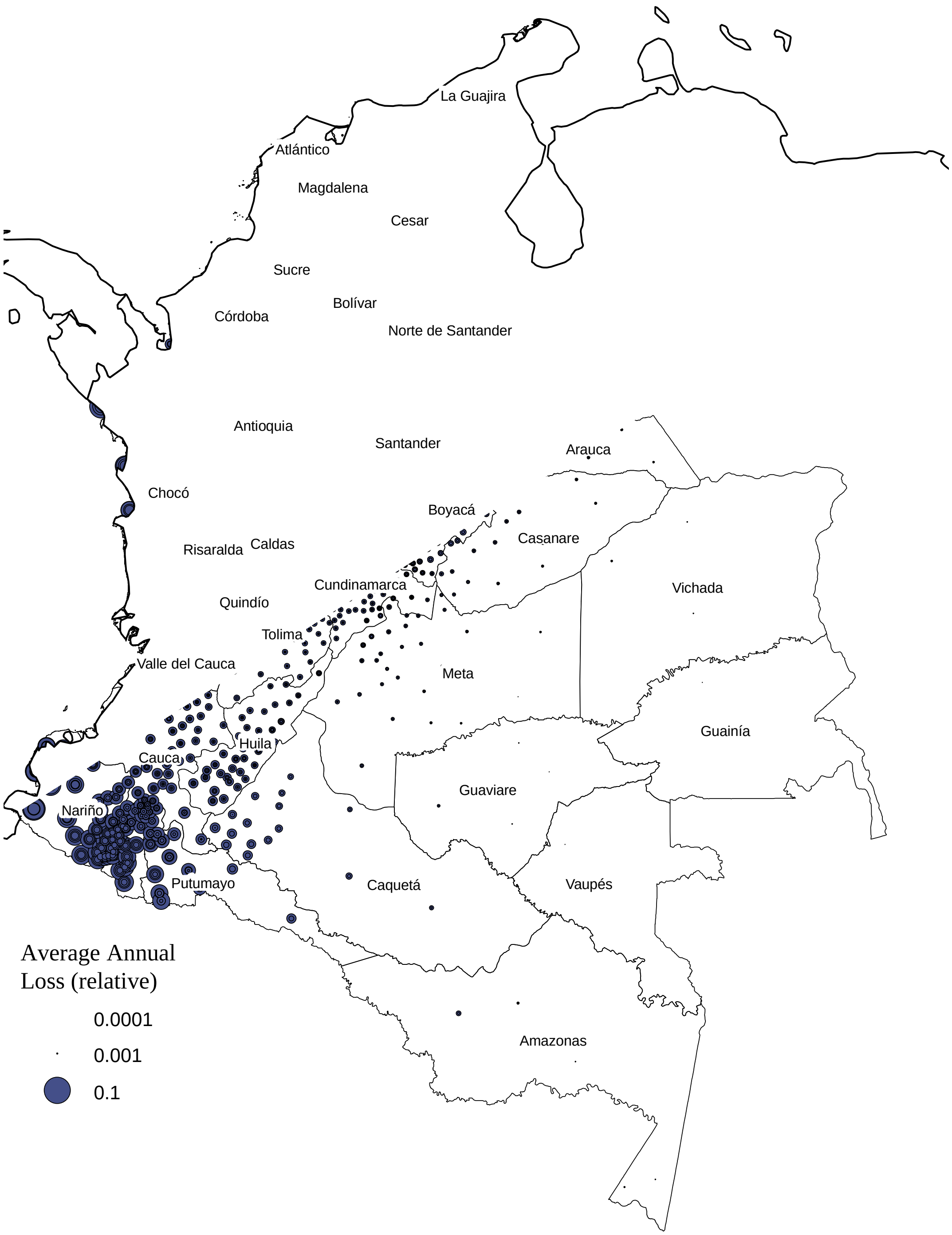
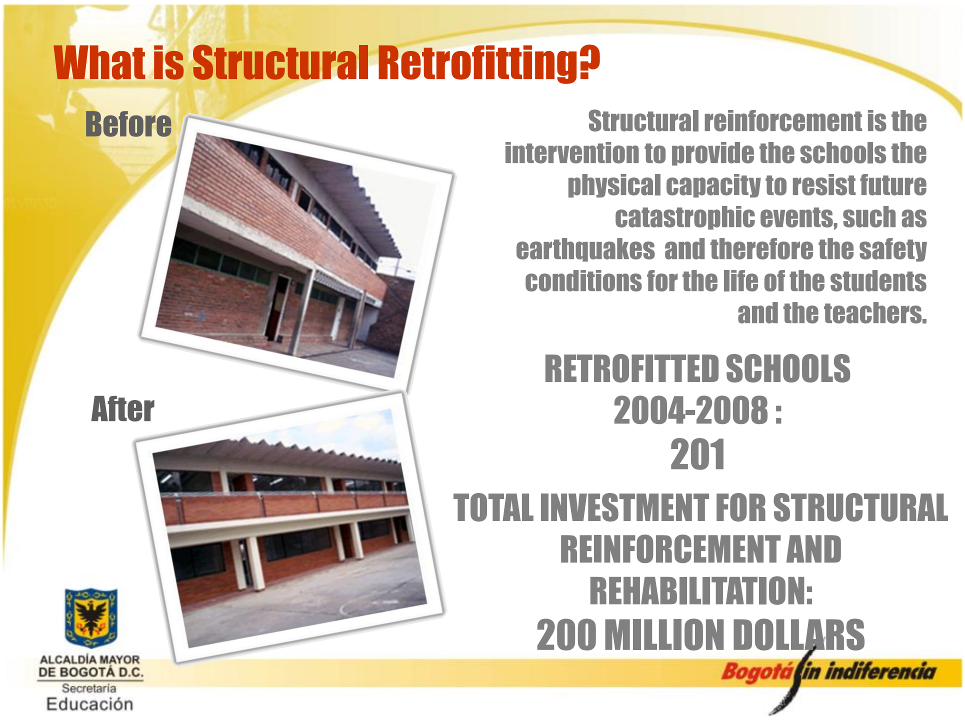


Figure 8-5 Colombia. Average Annual Loss (Relative) Current state

Figure 8-6 Average Annual Loss. Current state



Benefit Cost Analysis of seismic risk reduction of schools in Latina America

The case of Bogota

Bogota, reinforces its schools – A historic program for the city

Benefit Cost Analysis of seismic risk reduction of schools in Latina America

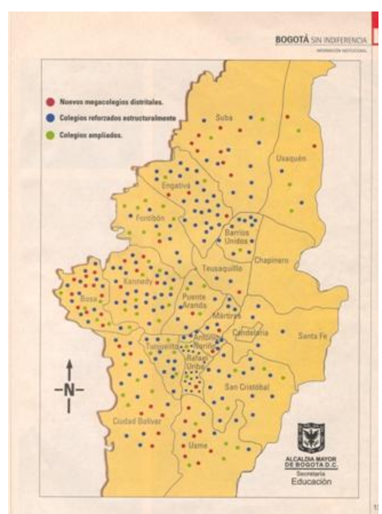
THE CASE OF BOGOTA

Bogota, reinforces its schools – How they were and how they are now

Benefit Cost Analysis of seismic risk reduction of schools in Latina America

THE CASE OF BOGOTA

Number of schools by district : New : Reinforced : Enhanced



Benefit Cost Analysis of seismic risk reduction of schools in Latina America

THE CASE OF BOGOTA

New mega-schools : In some cases it was better than reinforce the old buildings

Benefit Cost Analysis of seismic risk reduction of schools in Latina America

THE CASE OF BOGOTA

New campaign: Evaluation of seismic risk to 2,700 private schools

ESTRUCTURAS TENDRÁN QUE REFORZARSE

Examen de riesgo sísmico a 2.700 colegios privados

Antes del 2019 todos los colegios de Bogotá tendrán que cumplir con condiciones de sismorresistencia y de calidad estructural para seguir funcionando. Distrito dará plazos para ajustarse a estas exigencias.

EL INVENTARIO SE HARÁ EN TRES MESES