Technical Report

Seismic Risk Reduction Strategy for Public School Buildings in Peru

February 2017

Project led by the World Bank, and developed by:

Universidad de los Andes

BANCO MUNDIAL
BIRF • AIF | GRUPO BANCO MUNDIAL

GFDRR
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FOREWORD

In August 2007, an earthquake with a magnitude of 7.8 (M_W) struck the south of Peru with a death toll of 550 people, plus 2,000 people affected and economic losses of around USD 1 billion. With this disaster as a starting point, the World Bank put in motion a new process of support and technical assistance to aid the Government of Peru in the design of policies that would allow to reduce the impact of earthquakes on both the population and the economy. In particular, reducing the seismic vulnerability of critical infrastructure—including buildings from the health, education, transport and government sectors, among others—was set as a priority.

Thus, from 2007 to date, the World Bank and the Government of Peru have underwritten a large number of technical assistance projects and operations which, overall, support three main strands of policy: i) to strengthen planning and resource allocation for disaster risk reduction programs, ii) to enhance vulnerability reduction of critical infrastructure, and iii) to reinforce the capacity of the state to recover after a disaster.

In this context, in 2012 the World Bank financed a study for the seismic risk assessment of 2,000 school facilities in the metropolitan area of Lima and Callao, and trained government officials and university students and professors in the use of the Probabilistic Risk Assessment (CAPRA) platform. The results of this first study allowed, on the one hand, to estimate the damages and losses that may be sustained in case of future earthquakes and, on the other, to highlight the great seismic vulnerability of thousands of school buildings. Between 2013 and 2014, the Ministry of Education of Peru (MINEDU) conducted a School Infrastructure Census (CEI) nationwide. Since 2014, the World Bank has provided technical assistance to the MINEDU for the analysis of such results, the design of a seismic vulnerability reduction program, and the formulation of the National School Infrastructure Plan.

This report presents the seismic risk assessment of the school infrastructure countrywide and a strategy for reducing its vulnerability. It is an integral part of the main results of a program funded by the Government of Japan and the GFDRR (Global Facility for Disaster Reduction and Recovery), the main objective of which is to integrate disaster risk management into infrastructure sectors. For the first time in the history of the country, Peru has a quantitative analysis of the potential damages and losses on the country's school infrastructure network in the event of an earthquake, as well as a risk reduction strategy. Considering the challenge posed to Peru by the need to make interventions in tens of thousands of school buildings, either for structural reinforcement or replacement, this study is an example of the approach, methodology and design of a seismic risk reduction strategy which serves as a model for other countries with similar conditions.

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ACRONYMS

780-POST	780 module or similar built after 1998
780-PRE	780 module built before 1998
A	Adobe structural system
AAL	Average annual loss
CAPRA	Probabilistic Risk Assessment Platform
CIE	School Infrastructure Census
CM	Confined masonry or reinforced concrete masonry
DEM	Digital Elevation Model
DIGEIE	General Directorate for School Infrastructure
FEMA	Federal Emergency Management Agency
GSP	Buildings with good seismic performance
HDP	Buildings with high damage potential
HRC	Buildings with high risk of collapse
INDECI	National Institute of Civil Defense
INEI	National Institute of Statistics and Information
LEC	Loss exceedance curve
LSU	Large school unit
MCF	Moment-resisting concrete frames
MINEDU	Ministry of Education
NA	Not Assigned
NCM	Non-confined masonry
NEHRP	National Earthquake Hazards Reduction Program
NGO	Non-governmental organization
OINFE	School Infrastructure Office
PA	Parents' Association
PC and/or P	Precarious constructions (plywood, *quincha*, mudwall or similar)
PML	Probable maximum loss
PRONIED	National School Infrastructure Program
PROVC and/or PROV	Provisional classrooms
PUCP	Pontificia Universidad Católica de Perú
RCF	Reinforced concrete frames and masonry walls (dual)
RNE	National Building Code
SIFE	Photographic Inspection Software for School Facilities
SIRAD	Resource Information System for Disaster Response
SRTM	Shuttle Radar Topography Mission
SS	Steel structure
STS	Structural System
UGEL	Local Education Management Unit
UNIANDES	Universidad de Los Andes (Bogota, Colombia)
W	Wood structural system (standardized)

GLOSSARY

780 building typology: Typical school module used in Peru with 7.80 m lights fitted in a crosswise direction, which generally has two stories and three classrooms per story. This type of structure was initially built via the National Institute of School Infrastructure (INFES). Later on, this typology was adapted by other state institutions for the construction of school infrastructure. For such reasons, this type of buildings have been built either before the 1998 Code of seismic-resistant design was established (hereinafter, referred to as 780-PRE), in which case they have short columns, or after such code was established (hereinafter, referred to as 780-POST).

AAL (Average annual loss): Sum of the product of the expected losses for a stochastic set of seismic scenarios and the annual frequency of occurrence for each of them. In probabilistic terms, the AAL is the mathematical expectation of annual loss.

Building typology: Groups of buildings that have similar characteristics in their structural systems, both as regards materials and geometry of elements, for the purpose of rating their vulnerability.

Census form: Related to the identification number of the school facilities registered under the School Infrastructure Census (CIE).

Code level: Assessment of the level or degree of compliance with design and construction requirements of the existing building regulations applicable to the buildings under consideration.

Comprehensive reinforcement: Reinforcement of a building in a single stage, during which the overall objectives set out in the design regulations are fully met. It involves a greater economic effort and a longer disruption to the use of the building.

Financial gap: Investment amount required to achieve the objectives set in a given project.

Incremental reinforcement: Reinforcement of a building in order to prevent collapse and protect the occupants' lives. According to the design regulations, more than one stage is necessary to fully meet the overall objectives of seismic retrofitting of buildings.

Loss exceedance probability curve: Probable maximum losses for different return periods considered or annual exceedance frequencies.

Non-structural elements: Elements of the building that are not part of the primary system of vertical or horizontal load resistance. It refers to facades, dividing walls, ceilings, service lines and other facilities of the building. These must be designed to withstand the seismic demand (acceleration, displacement, etc.) of the main structure.

Portfolio of exposure: Database of the assets or components that may be affected by the hazard.

Probabilistic seismic risk assessment: Integration of the hazard and seismic vulnerability of exposed elements so as to obtain the probability of occurrence of different levels of losses associated with seismic events in a given region.

Provisional classrooms: Temporary infrastructure made of detachable materials. They should not be confused with the name given in Lima to the plan of substitution and use of "provisional classrooms", which offer an enhanced seismic performance.

Replacement cost: Value of the exposed element which is equivalent to the cost of replacing it with a new one.

Risk: Probability of damage or loss of the elements exposed to hazard.

School facility: Geographical grouping of several public school buildings in a single plot of land, which includes buildings for various purposes (educational, administrative, restrooms, kitchen, etc.).

School setting: Categorization of the school facilities in different settings, according to the demographic characteristics of the region where the facility is located and its proximity to urban centers. Five possible categories are included: big cities, capital cities, urban centers, connected villages, and scattered communities.

Seismic-resistant building: Building which conforms to all the guidelines under the seismic-resistant construction standard and, therefore, would deliver a good seismic performance.

Seismic hazard: Probability that a potentially harmful natural phenomenon, in this case, a seismic event, will occur.

Seismic microzonation: Hazard study that analyzes the seismic response of different locations in a small region or city by grouping the places with similar features, according to their geological and geo-technical characteristics, into microzones, and specifying in each of them the spectrum of seismic-resistant design for various structural conditions and return periods.

Seismic vulnerability: Susceptibility of specific exposed components to be somehow affected by seismic hazard. It is usually represented by means of seismic vulnerability functions or, alternatively, by fragility functions.

Seismic vulnerability functions: Functions that establish a connection between the expected average damage to an individual structure and the intensity of the seismic event. In this case, the parameter of intensity used is the spectral acceleration at the estimated structural period.

Site effects: Amplification of the spectral response of a seismic signal as a result of the soil characteristics in the area under study.

Structural system: System of elements designed to withstand the loads (vertical or seismic) to which the building will be subjected during its service life.

Substitution: Total demolition and reconstruction of buildings with high risk of collapse.

1. INTRODUCTION

1.1 BACKGROUND

The Ministry of Education of Peru (MINEDU), through the General Directorate for School Infrastructure (DIGEIE), has been working on the drawing up of the National School Infrastructure Plan (PNIE). Within the framework of said effort, it has commissioned the National Institute of Statistics and Information (INEI) with carrying out the School Infrastructure Census (CIE) [1] which started in September 2013 and was delivered in 2014.

The analysis of the results arising from the information gathered by the CIE constitutes the basis for the development of the PNIE in relation to laying down a work baseline, defining the intervention measures to improve the infrastructure at urban and rural levels, and prioritizing the actions in the short, medium, and long term. All this, with the aim of contributing to a better level of planning, efficiencies, and sustainability for the development of school infrastructure in the country.

For this purpose, the MINEDU requested the World Bank's technical assistance for the analysis of the results obtained from the CIE as well as for devising a strategy or program to reduce seismic vulnerability, and drawing up the PNIE. Under this program, different initiatives and studies were developed, including the following:

- Study of school buildings in metropolitan Lima and Callao carried out by the Universidad de Los Andes (Colombia) under the coordination and leadership of the World Bank at the request of MINEDU [2].
- Supplementation and review of the entire CIE database based on the available photographic archives.
- Gathering and documentation of information concerning construction costs, and costs and methodologies for the reinforcement of school structures in different locations of Peru.
- Compilation of reports from similar studies carried out to assess intervention types, and other documentation related to seismic risk reduction in Peru.

Based on this documentation of reference, a nationwide probabilistic seismic risk assessment of school infrastructure was carried out, which constitutes the basis for defining the seismic risk reduction strategy and for setting intervention priorities as key components of the PNIE. This document includes a technical executive summary of the above-mentioned study, which was conducted by the Universidad de Los Andes (Colombia) under the coordination and leadership of the World Bank.

1.2 OBJECTIVES OF THE STUDY

The main objective of the study is to carry out a nationwide seismic risk assessment of the school infrastructure in Peru in order to define risk reduction strategies and to set intervention priorities with a view to optimize future investments that would allow to effectively reduce the vulnerability of the buildings in this sector. The assessment of risk derived from other natural hazards, such as floods or landslides, is beyond the scope of this study.

The specific objectives of the study are as follows:

a) Supplementing the information on hazards so as to consider, in a simplified manner, the site effects produced by expected geo-technical conditions in the different types of soil found in the country.

b) Improving the exposure database on the basis of the information from the 2013 CIE using, to that effect, the photographs compiled by the INEI and the findings from the different field inspections conducted by the Universidad de Los Andes.

c) Improving the classification of building typologies in order to consider the vulnerability of each of them and the potential intervention measures that could be considered.

d) Generating information regarding the seismic risk of the public school infrastructure of the country so as to quantify and understand it, and to become aware of its geographical distribution.

e) Formulating an intervention strategy at the national and regional levels, suggesting optimization criteria, and quantifying the amount of investment required to effectively reduce the vulnerability of the buildings in this sector.

f) Proposing a methodology for the prioritization of interventions in school facilities so as to maximize risk reduction, optimizing the available resources by region.

1.3 SEISMIC RISK REDUCTION STRATEGY OBJECTIVES

The risk reduction strategy for school infrastructure in Peru is designed to meet the following specific objectives and priorities:

1) Reducing the risk of death or injuries in the community resulting from seismic events (maximizing the number of benefited students).

2) Minimizing damages to the infrastructure and protecting the property.

3) Reducing educational services disruption.

As a result, the following priorities related to the direct impact on school infrastructure are defined:

a) Reducing the number of buildings with high probability of collapse.

b) Advancing interventions in those buildings with high damage potential.

1.4 SCOPE AND LIMITATIONS

During the undertaking of this study, the following limitations were encountered:

a) This report was drawn up using the most recent information available about hazards, exposure, and vulnerability of the main typologies which are part of the database for the seismic risk assessment of the country. The analyses are based on the best current expert criteria for the estimation of the required parameters, using the secondary information available for that purpose.

b) The analyses performed allow for the estimation of the expected economic losses arising from potential seismic events and from the vulnerability of the buildings that make up the Peruvian school infrastructure. These outcomes shall only be used for the design of the intervention strategy proposed, and should not be used for any other purposes.

c) The types of interventions—selected on the basis of the known vulnerability of the buildings and their prioritization, which allows to optimize the interventions—allow for the quantification of the total investment amount required for seismic risk reduction and for decision-making as regards the possible number of public school buildings to intervene.

d) The database obtained from the CIE information has some limitations, mainly as regards the accuracy of certain parameters (for example, building areas), classification of structural typologies, and completeness in certain school facilities.

e) The site effects considered for the seismic hazard assessment in the ground surface are determined using simplified indirect methods. This study has not taken into account seismic microzonation studies available for some of the main cities of Peru, since such type of studies are not available for all cities and have neither been validated nor harmonized at national level; therefore, using them would cause significant deviations from the expected outcome.

f) The risk after a possible structural intervention in the school infrastructure has been estimated considering an expected seismic behavior of the buildings according to the type of intervention recommended in the present study.

g) Considering the resolution of the study, the quality of the available information and the associated uncertainties, the subsequent implementation stage should include field inspection campaigns to validate the data and adjust the implementation plan proposed.

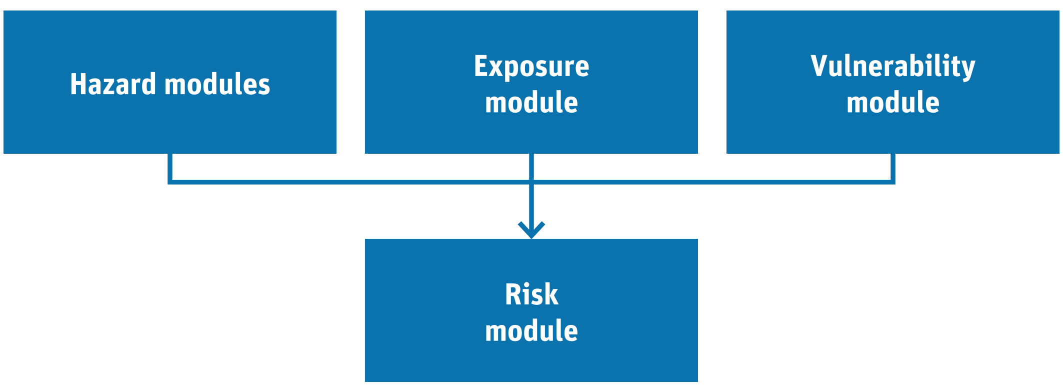
2. SUMMARY OF THE METHODOLOGY

2.1 GENERAL CONSIDERATIONS

This study is focused on the probabilistic seismic risk assessment of the Peruvian public school infrastructure. For this purpose, it is necessary to quantify the seismic hazard in the area under analysis, have a thorough knowledge of the exposed components and their replacement cost, and have detailed information on the seismic vulnerability of the main building typologies.

The probabilistic risk estimation considers the whole range of potential events that may occur in the future. Due to the high uncertainty inherent to the assessment models concerning the severity and frequency of occurrence of events, probabilistic models build such uncertainty into the risk assessment. The probabilistic risk model, which is built on a sequence of components, quantifies potential losses as illustrated in Figure 2-1. Reference 2 presents the detailed methodology for the analysis of risk derived from seismic events.

Figure 2-1 **General outline of the probabilistic risk analysis**



2.2 RISK ASSESSMENT COMPONENTS

The main components of a probabilistic risk assessment are as follows:

a) Seismic hazard: Represented by means of distribution maps of seismic intensity parameters, such as peak ground acceleration or spectral accelerations for different structural vibration periods, and a specific structural damping. If possible, seismic hazard should include the effects of the dynamic response of soil deposits on each particular location, which may generate significant changes in the maximum ranges, the frequency content, and the duration of the signals. Intensity maps are assessed for a sufficiently complete set of possible events that might occur in the area of influence, taking into account the possible magnitude ranges in the different seismic sources and the relative distances between these and the buildings under analysis. Moreover, every event is characterized by the annual mean frequency of occurrence, which is obtained from the analysis of the historical frequency of events. Hazard information is grouped and handled based on AME-type digital files

(.ame from *amenaza*, i.e. “hazard” in Spanish, in CAPRA [3] modeling software) which contain maps of intensity parameters for each of the defined stochastic scenarios. In this case, the parameter of seismic hazard intensity selected corresponds to the maximum spectral acceleration for a series of structural periods chosen for all geographical locations.

b) Exposure database: It is necessary to create a georeferenced database of the exposed buildings which may sustain damages due to the occurrence of the above mentioned seismic events. The information is stored in “shape” format files, and should contain at least the following fields: ID, geographical location, replacement cost and an associated seismic vulnerability function. Additionally, for the purpose of grading the vulnerability of each component, it is necessary to have information regarding the structural type, height, level of seismic-resistant design, quality of the design and construction, and supplementary information of each school building.

c) Vulnerability information: It is presented by means of functions that connect the damage or loss expected expressed as a percentage with the seismic intensity selected (spectral acceleration for each building). These vulnerability functions represent the expected behavior of the buildings from each particular structural type, so their use is statistically appropriate when there is a wide inventory of exposed assets. Each vulnerability function is defined by a mean value of damage and its variance, which makes it possible to estimate the probability function of the respective losses.

d) Risk module: This module integrates the hazard and vulnerability of the exposed elements to assess risk using different parameters indicating the level of damage, physical impacts, and overall impact on the infrastructure or its occupants. Once the expected physical damage (potential average damage and its dispersion) has been estimated for each of the exposed buildings, whether as a percentage or as an absolute value, it is possible to estimate different parameters or metrics that are useful for the proposed analysis, such as the loss exceedance curve (LEC), the average annual loss (AAL), in absolute or relative terms, and the maximum expected losses, also in absolute or relative terms.

The risk assessment using probabilistic techniques with a CAPRA-type approach is widely documented. References 3, 4, 5 and 6 present in detail the methodological bases of the procedures used in this study.

2.3 APPLICATION OF THE METHODOLOGY TO THE CASE OF PERU

The application of the above mentioned methodology for the risk assessment of school infrastructure in Peru includes the following aspects:

a) Seismic hazard: It is based on the available information and on the assessments carried out in earlier studies (see [2] and [7]), supplemented by rough evaluations of site effects at national level, as shown in Section 3.3.

b) Buildings database: It is based on the information made available by the CEI [1], which includes the following specific information: built area, number of stories, structural system, works executing entity, age of the buildings and geographical location.

c) Analysis of replacement costs: The school infrastructure is evaluated in terms of educational level, geographical location, and bioclimatic zone. This value is an estimate of the replacement cost in case of partial or total loss, and was defined based on the information supplied by local experts.

d) Vulnerability functions: The different building types identified in critical study areas are characterized using a vulnerability function which accounts for the buildings resistance to seismic action in the different events considered. In the case of Peru, preexisting information on the vulnerability of typical building typologies [8] [9] was used, but was modified based on the criteria of the experts in the study so as to take into account the typical construction practices and quality in the country [10]. A vulnerability function is directly assigned to each of the components of the exposure database according to the information of exposure.

e) Risk assessment: The percentage of expected damage is assessed in each of the exposed buildings for each scenario proposed, as well as for the comprehensive probabilistic analysis. In the case of the Peruvian school infrastructure, the risk assessment is expressed in terms of the percentage of physical damage of the buildings reported in the CIE, the AAL for each building, and the probable maximum economic losses (PML) for the building inventory.

3. SEISMIC HAZARD

3.1 AVAILABLE INFORMATION

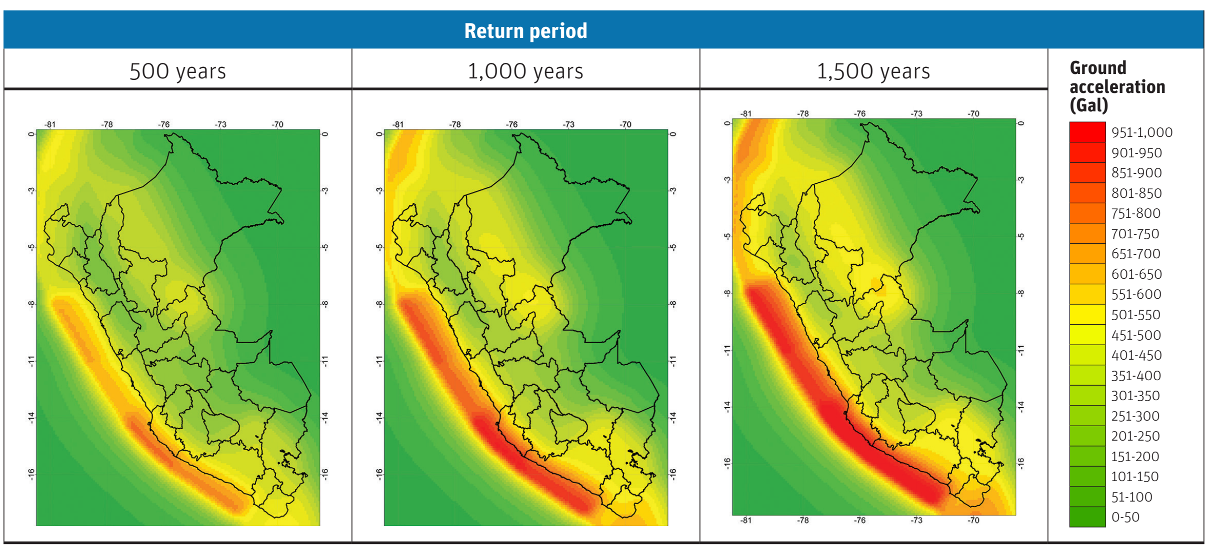
In this study, the seismic hazard is calculated based on the information available from earlier studies [7], and is equivalent to the one used in the previous study of reference [2]. The seismic hazard at national level is represented by an information file with the following characteristics:

- Name: *AME-Nacional 31 intensidades*
- Number of stochastic scenarios: 14,574
- Number of seismogenic sources: 21 seismogenic sources from Peru
- Available intensity parameters: spectral accelerations for the structural vibration periods of 0.1 seconds to 3 seconds in 0.1-second increments

3.2 SEISMIC HAZARD IN FIRM GROUND

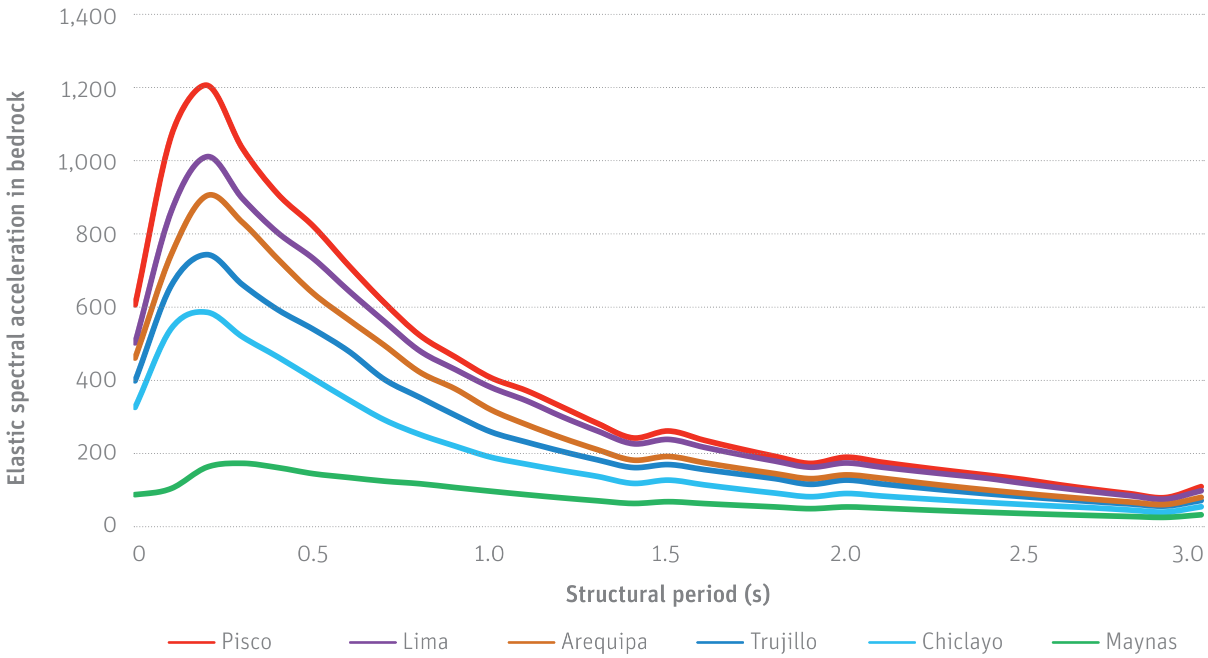
Figure 3-1 shows the probabilistic seismic hazard maps obtained from the previous hazard file. Hazard maps of acceleration in firm ground are presented for return periods of 500 years, 1,000 years and 1,500 years.

Figure 3-1 Probabilistic seismic hazard maps



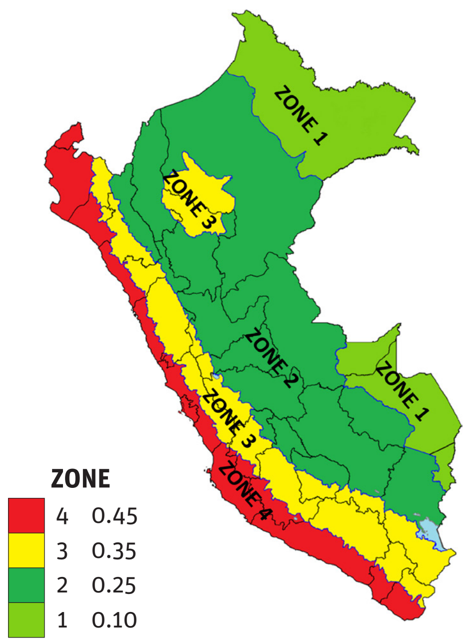
For illustrative purposes, Figure 3-2 shows the response spectrum for a return period of 500 years in representative central locations in the cities of Lima, Arequipa, Trujillo, Chiclayo, Pisco and Iquitos. The spectrum corresponds to a damping of 5% with regard to the critical value.

Figure 3-2 **Representative response spectrum for Lima, Arequipa, Trujillo, Chiclayo, Pisco and Iquitos according to the .AME reference file for a return period of 500 years and a damping of 5% with regard to the critical value**



Furthermore, Figure 3-3 shows the seismic hazard zones defined by the National Building Code (RNE) [11] as updated in the year 2016.

Figure 3-3 **Seismic hazard map, 2016 version**



Note: Taken from the 2016 RNE.

3.3 LOCAL EFFECTS OF THE SOIL

Bedrock hazard, defined in Section 3.2, should be modified to account for the local dynamic response effects caused by dominant soil deposits in each geographical location. In light of the great difficulties that a comprehensive assessment of this type would imply, and bearing in mind the possible impact this consideration may have on the seismic risk assessment of the school building inventory in Peru, it was decided that, for the present study, these effects would be considered through a methodology of approximation that can be applied at country level.

For the zoning of the local seismic response of the various types of soil through simplified models, the methodology proposed in Reference 12 was used. This methodology is based on the estimation of an average shear wave velocity value for the first 30 m of depth of soil deposits (V_{S30}) through a direct relation to the seismicity, topography, and topographic slope of the area. The premise of this methodology is that the topographic slope can be used as a source of baseline information to define the predominant type of soil in the area under study. Thus, once the soil classification is done, it is possible to define an average shear wave velocity value for the first 30 m in any location. This type of simplified analysis is commonly accepted when there are no detailed studies of the site conditions based on geological and geotechnical information.

The proposed methodology is based on the specific Digital Elevation Model (DEM) according to its resolution. For this case, an SRTM (Shuttle Radar Topography Mission) digital elevation model with a resolution of 30 arcsec (1 km x 1 km approximately) was used, in accordance with the recommendations made in specialized literature.

The soil is classified based on the ranges defined in Table 3-1.

Table 3-1 Slope ranges for soil classification according to Wood and Allen (2009)

Type of soil	NEHRP classification	Range of V_{S30} (m/s)	Slope ranges (m/m)	
			Active tectonics	Tectonically stable
1	B	> 760	> 0.14	> 0.025
2	C	620–760	0.10–0.14	0.018–0.025
3		490–620	0.05–0.10	0.013–0.018
4		360–490	0.018–0.05	7.2E-3–0.013
5	D	300–360	0.010–0.018	4E-3–7.2E-3
6		240–300	3.5E-3–0.010	2E-3–4E-3
7		180–240	3E-4–3.5E-3	6E-6–2E-3
8	E	< 180	< 3E-4	< 6E-6

This classification depends on the seismicity type which is representative of each zone: active tectonic region and tectonically stable continental region. In order to classify the areas into one of these two types, the simplified methodology includes the following recommendations:

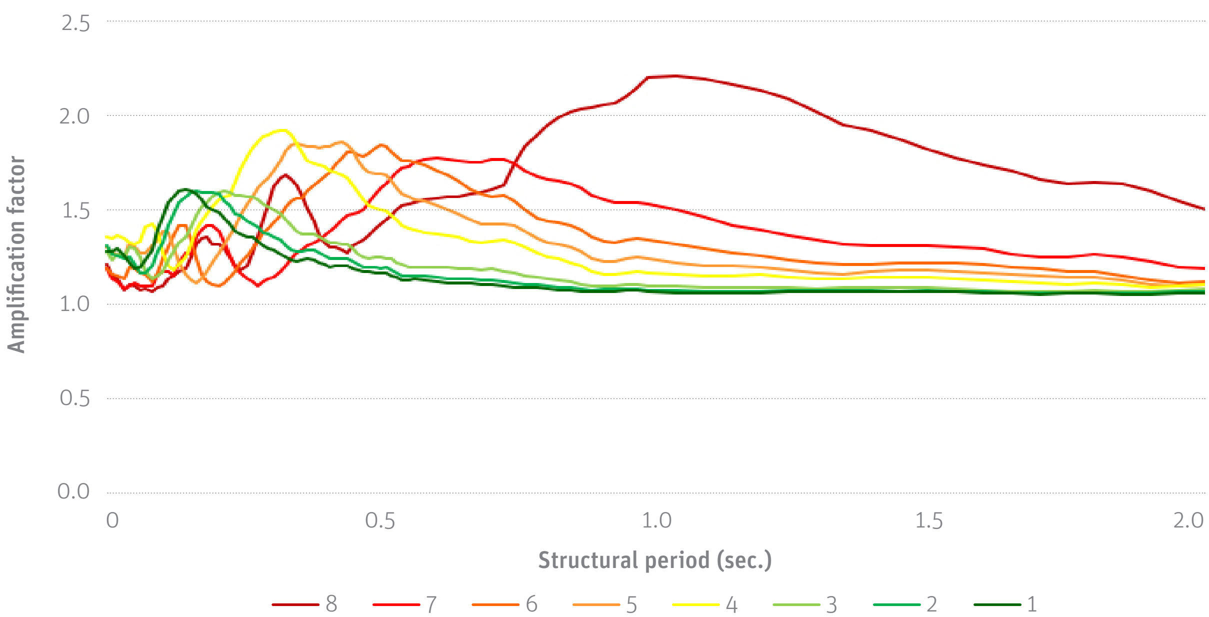
- Active tectonic region: It comprises dynamic topographic relief areas. It is defined on the basis of a mean slope of the region higher than 5%.
- Stable continental region: It comprises areas where the topography is relatively low. It is defined on the basis of a mean slope of the region lower than 5%.

The local amplification effects caused by the soil deposits in the areas under study are specified by a "shape" type file, which defines the areas with a similar seismic behavior and, in each of them, the amplification spectra in the dynamic response for different seismic intensities of analysis which consider the non-linear soil behavior.

Furthermore, in order to define the amplification factors for each of the soil types, a series of non-linear dynamic response analyses of the characteristic stratigraphy have been carried out considering the following parameters as random variables: seismic signals representative of the region under analysis, basement wave velocity, shear wave velocity profile at the ranges specified for the types of soil, and variations in the properties of resistance and damping degradation with the shear deformation of the soils that constitute the stratigraphic profile.

Figure 3-4 shows the spectral amplification factors proposed for each type of soil.

Figure 3-4 **Amplification spectra proposed for the eight types of soil defined**



Note: The numbers in the caption make reference to the related soils included in Table 3-1.

Figure 3-5 shows the Peruvian soil classification map derived from the previously introduced methodology.

With this information, the analysis procedure includes the following steps:

a) Selecting the location of each building.

b) Assessing the seismic intensity in bedrock for such location and for the fundamental vibration period specified for each structure.

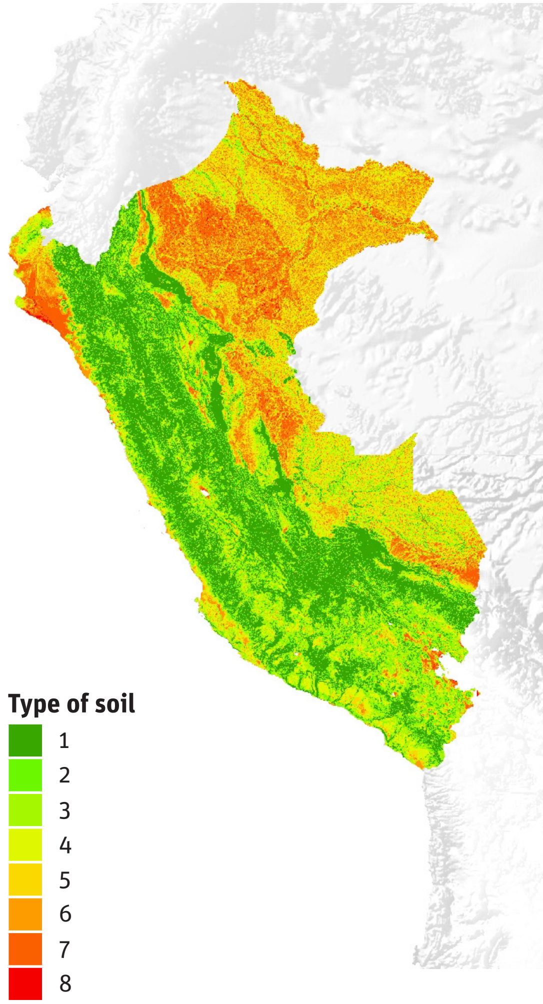
c) Assessing the type of soil on which the building is constructed according to Figure 3-5.

d) For the same structural period specified, and according to the type of soil determined in the previous item, evaluating the seismic amplification factor by site effects using Figure 3-4.

e) Assessing the seismic intensity including local effects by multiplying the spectral acceleration in bedrock by the corresponding amplification factor.

This parameter is used later to assess the economic losses for each component defined in the portfolio of exposure.

Figure 3-5 Classification of Peruvian soils according to methodology V_{S30}



Note: The numbers in the caption make reference to the related types of soil included in the Table 3-1.

4. EXPOSURE AND VULNERABILITY

4.1 INFORMATION CONSISTENCY AND COMPLETENESS

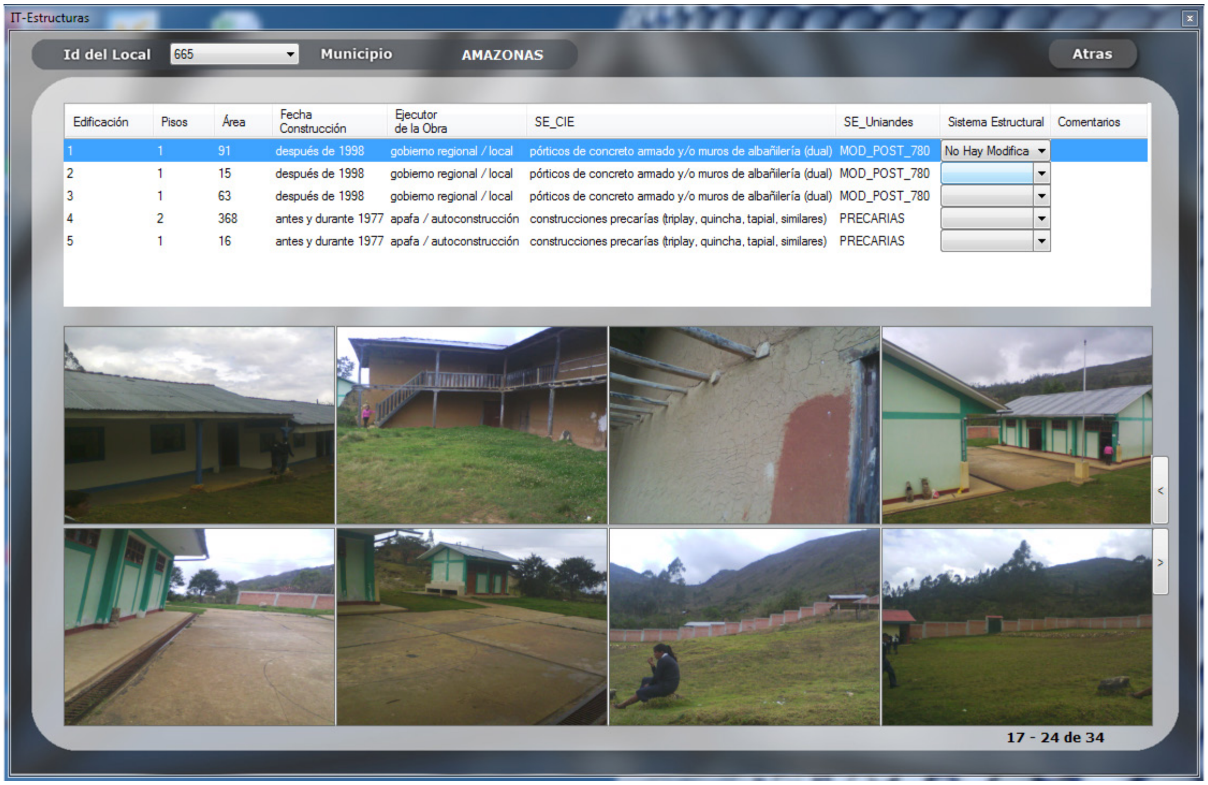
Chapters VI and VII of the CIE [1] include key information used to make up the portfolio of exposure for risk assessment. These chapters introduce the main engineering characteristics of school buildings. Since the number of buildings and of school facilities varies among the different census forms (see Glossary), the criterion adopted was to select the information that would provide the highest level of completeness possible to the reported data. Completeness and consistency analyses were carried out to review the values reported in the CIE.

The review of the information obtained by the CIE allowed for the identification of weaknesses, such as specific empty fields or records, abnormal or inadequate values in some fields and limitations of the census form as regards more detailed structural information. To improve this, non-reliable fields and records were removed, and specific fields with inconsistent information were adjusted.

In order to streamline and optimize the review of information for each school facility, software was developed within the framework of this study for displaying and adjusting the information contained in the database, which mainly uses the inspection of available photographs. This software allows to visually review the data reported for each of the buildings included in a school facility, and the information of the variables relevant for risk assessment. Additionally, it also allows the review of all the photographs contained in the CIE, which ensures the maximum possible consistency between the database and the available information.

Figure 4-1 shows the main interface of the software developed.

Figure 4-1 Main software interface for the visualization and adjustment of the database information



The assumptions stated for the database adjustment take into consideration the expert criteria from different work groups that participated in the study. Once the processes of deleting records and of correcting and supplementing information were completed, a national database was created with the following total records, constituting the exposure database for seismic risk assessment:

• School facility codes: 40,475

• Individual buildings assigned to school facilities: 187,312

The information collected for these 40,475 school facilities is an important baseline corresponding to 92% of the school facilities registered with the Ministry of Education of Peru in 2014.

4.2 EXPOSURE DATABASE

4.2.1 Geographical Location of School Facilities

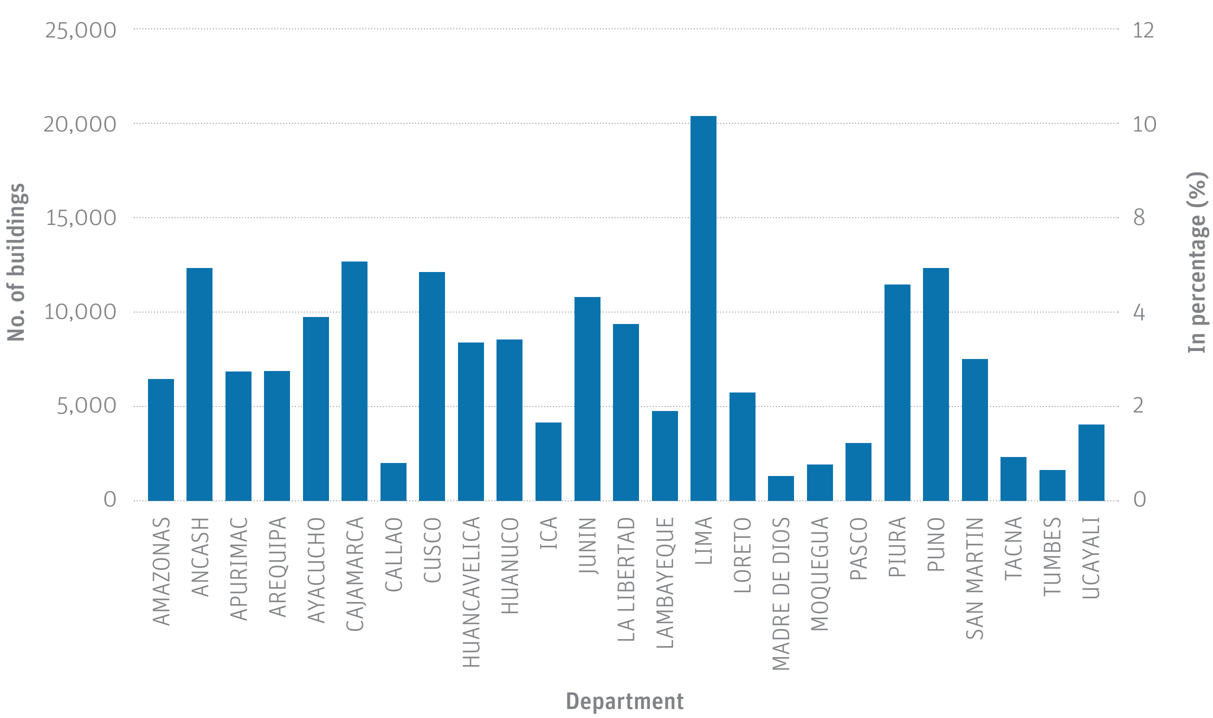
Each school facility has a unique geographical location (longitude, latitude) for all the buildings that compose it. “Latitude” refers to the angle, in degrees, of the line joining one point on the earth's surface with the center of the Earth, measured from the equator. For the purpose of the census form, the latitude of the school facility is measured at the central playground of the facility, or across from it in case there is no access available to the central playground. “Longitude” refers to the angle, in degrees, of the line joining one point on the earth's surface with the center of the Earth, measured from the Greenwich meridian. For the purpose of the census form, the longitude of the school facility is measured at the central playground of the facility, or across from it in case there is no access available to the central playground.

Other location parameters are the department and the province in the reported department where the school facility is located.

Based on the geographical location, additional fields are determined in the exposure database, such as department, school setting, bioclimatic zone and seismic hazard zone.

To quantify and group the results by region, department information for each school facility reported in the CIE was used. Figure 4-2 illustrates the distribution of the total number of buildings by department.

Figure 4-2 Distribution of total number of school buildings by department



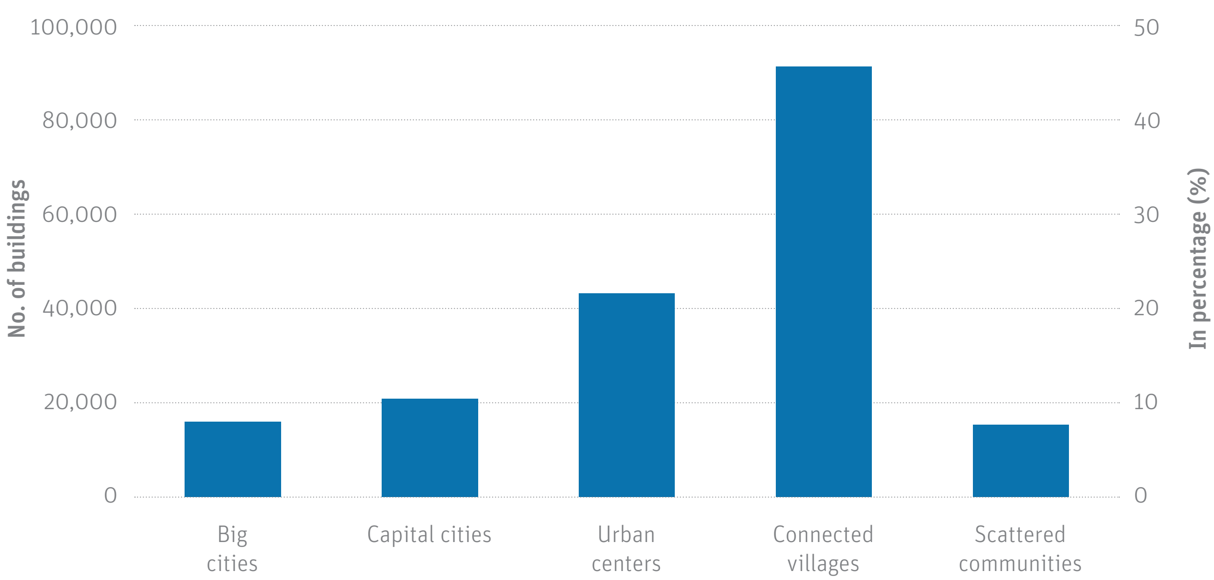
4.2.2 School Setting

"School settings" (Kudó and Székely, 2015) refer to a categorization of the school facilities in different settings, according to the demographic characteristics of the region where the facility is located and its proximity to urban centers. School settings are classified as follows:

- Big cities: Cities with more than 500,000 inhabitants as of 2015 (metropolitan Lima and Callao).
- Capital cities: Urban educational institutions in capital cities and some cities with higher population.
- Urban centers: Urban educational institutions located in other major cities, in province capital cities, less than an hour away from the Local Education Management Unit (UGEL) or in a population center with more than 200 students in an urban area.
- Connected villages: Educational institutions classified as "rural", located in districts that are part of a city or in a population center which is the capital city of a province, or any educational institution (urban or rural) not located in a city or urban center which is less than 5 hours away from the UGEL, has 100 students or more, or is situated in a population center with more than 300 students.
- Scattered communities: Any educational institution which is 5 or more hours away from the UGEL and 2 or more hours away from the municipality, and that is not near a major city or is located in a district with a population density lower than 100 inhabitants per km², or which has less than 100 students and is not connected to or in a city.

Figure 4-3 shows the distribution of school buildings according to the school setting.

Figure 4-3 Distribution of school buildings according to school setting

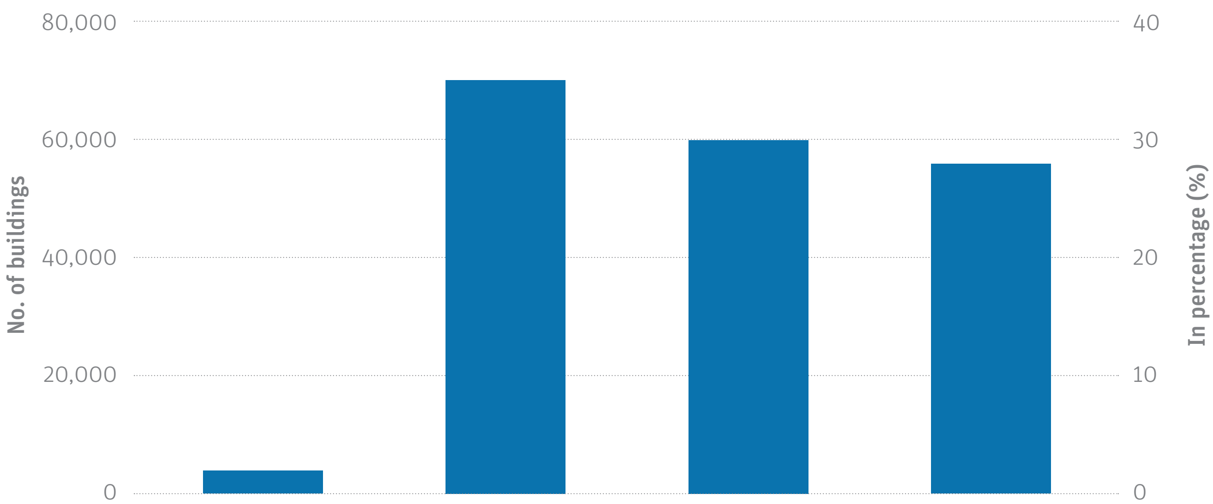


	Big cities	Capital cities	Urban centers	Connected villages	Scattered communities
No.	16,003	20,914	43,318	91,656	15,421
%	9%	11%	23%	49%	8%

4.2.3 Seismic Hazard according to Peruvian Regulations

The Peruvian National Building Code (updated in 2016) [11] considers four seismic hazard zones. The determination of the hazard zone where each school facility is located is done according to the geographical location reported in the CIE. For such purpose, the seismic hazard map shown in Figure 4-3 is used. The final distribution of buildings according to their location in the seismic hazard zones set forth under the regulations is illustrated in Figure 4-4. Based on this figure, it can be concluded that most of the school buildings are located in seismic zones 2, 3 and 4, and that their distribution is fairly even among these three zones.

Figure 4-4 Distribution of school buildings according to seismic hazard zones specified in the standards



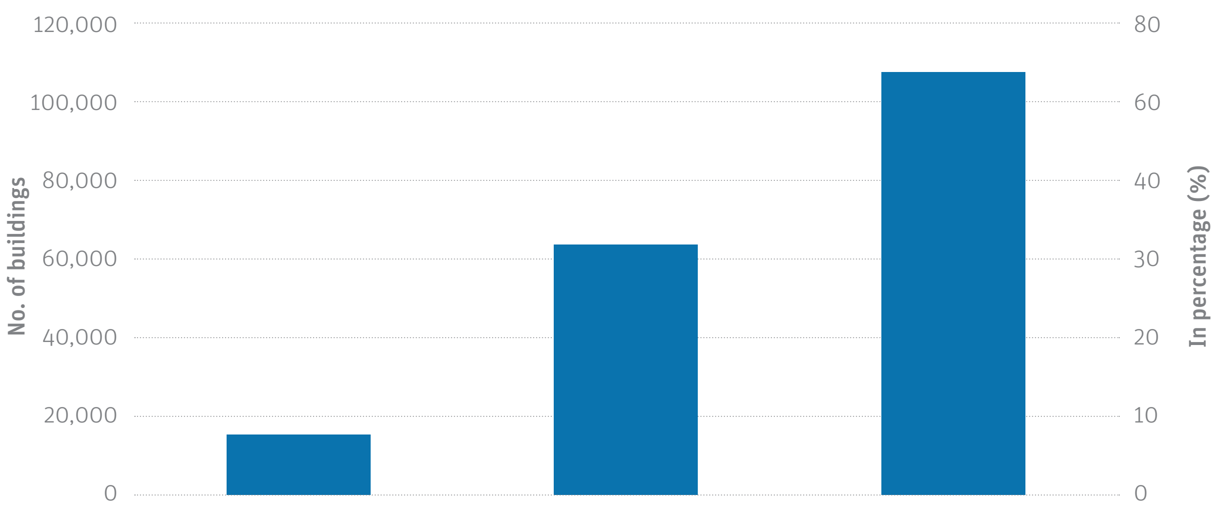
	Zone 1	Zone 2	Zone 3	Zone 4
No.	3,851	69,167	59,132	55,162
%	2.1%	36.9%	31.6%	29.4%

4.2.4 Age of the Construction

The age of the construction is closely related to the type of seismic-resistant design standard applicable at the time it was built and, therefore, it defines the quality of the design and construction. The CIE defines three age levels: “Before or during 1977”, “Between 1977 and 1998”, and “After 1998”. These levels, even though they cover very wide ranges of years, acknowledge the introduction of seismic-resistant design standards in Peru, and their subsequent amendments.

The distribution of the exposed elements in relation to the age of the construction at country level is shown in Figure 4-5. Based on this figure, it can be concluded that most of the buildings were registered in the period after 1998.

Figure 4-5 Distribution of school buildings according to the age reported in the CIE



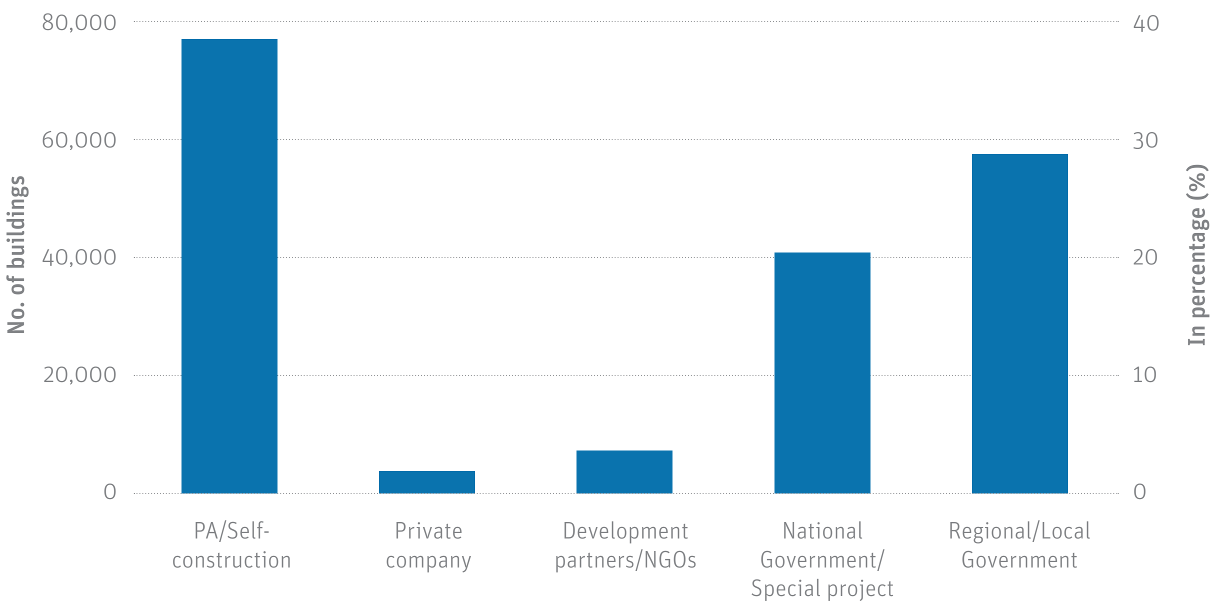
	Before and during 1977	Between 1978 and 1998	After 1998
No.	15,349	63,976	107,987
%	8%	34%	58%

4.2.5 Works Executing Entity

The works executing entity manages the necessary organization to guarantee the process and the final quality of the works underway. This is another important field for the definition of the quality level in the design and construction, because this parameter allows for the identification of those buildings for which the state could have had oversight responsibilities over the design and construction processes. Five possibilities were found for the field "Works Executing Entity": national government and special projects; regional and local government: Parents' Association (PA) and/or self-construction; development partners and NGOs; and private companies.

Figure 4-6 shows the nationwide distribution of the different types of entities in charge of the execution of the works.

Figure 4-6 Distribution of school buildings according to the works executing entity reported in the CIE



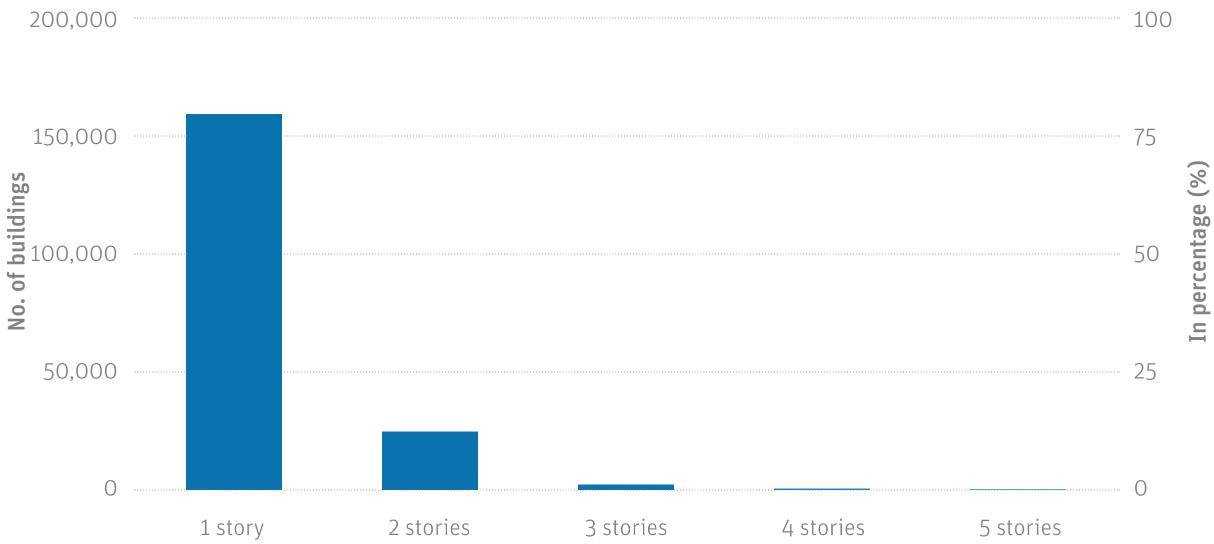
	PA/Self-construction	Private company	Development partners/NGOs	National Government/ Special project	Regional/Local Government
No.	77,377	3,818	7,320	40,983	57,814
%	41%	2%	4%	22%	31%

In this study, it has been considered that the buildings with the best construction quality are those for which the works executing entity has been the local and/or national government. For buildings constructed by the PAs, the quality of the construction is regarded as uncertain.

4.2.6 Building Height

The number of stories allows to differentiate the vulnerability of buildings which have an identical structural system but, due to their height, have a different dynamic behavior. It has been found that most of the buildings in the country are one-story or two-story buildings. The distribution of exposed elements according to the number of stories in the CIE database is shown in Figure 4-7.

Figure 4-7 Distribution of school buildings according to building height reported in the CIE



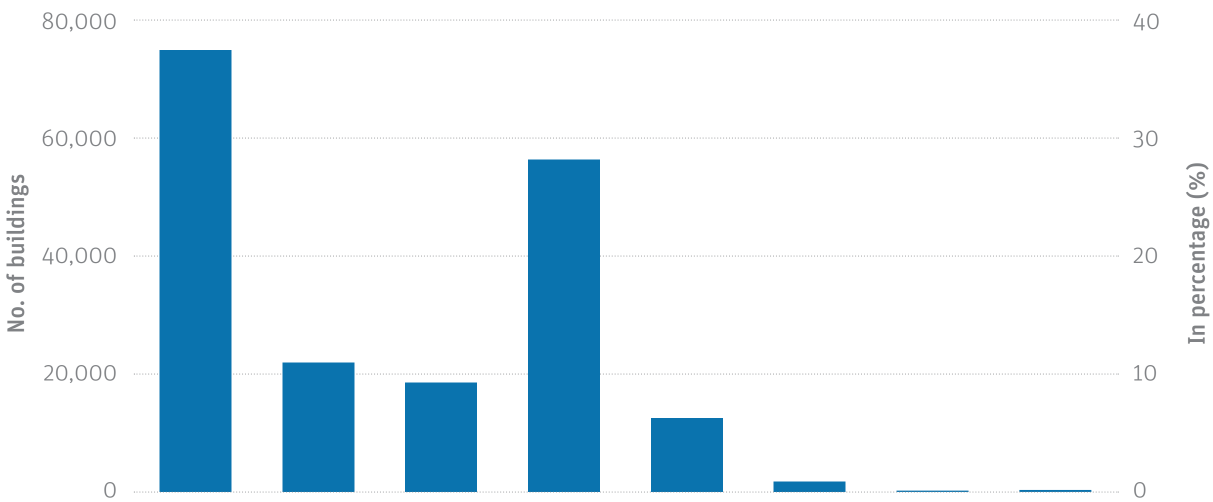
	1 story	2 stories	3 stories	4 stories	5 stories
No.	159,975	24,860	2,329	145	3
%	85.4%	13.3%	1.2%	0.1%	0.0%

4.2.7 Built Area

The built area is obtained based on the “roof area” information reported in the CIE. This area is defined as the area built on the first story of the building, and it is assumed that the structure has the same surface area in any upper stories. Therefore, the total built area is the product of the number of stories by the roof area.

All the out-of-range values are adjusted using the previous limit values.[1] Figure 4-8 shows the distribution of the roof area values for the buildings under analysis at national level.

Figure 4-8 Distribution of school buildings according to roof area ranges



	10–50 m²	50-75 m²	75-100 m²	100-250 m²	250-500 m²	500-1,000 m²	1,000-1,500 m²	1,500-2,500 m²
No.	75,236	22,005	18,637	56,607	12,576	1,782	203	266
%	40%	12%	10%	30%	7%	1%	0%	0%

1. Upon a thorough review of the roof area, it has been found that the CIE offers inconsistent values, such as null, negative, or disproportionately large areas. Inconsistent values are adjusted by a filter defining a minimum roof area of 10 m² for buildings used for educational and administrative purposes. Also, a maximum roof area value is defined according to the total number of students per school shift. The building with the largest built area is a school facility with only one building and only one shift per day, approximately 3,313 students and a roof area of 2,500 m² in two stories (total built area of around 5,000 m²).

4.2.8 Structural Systems and Building Typologies

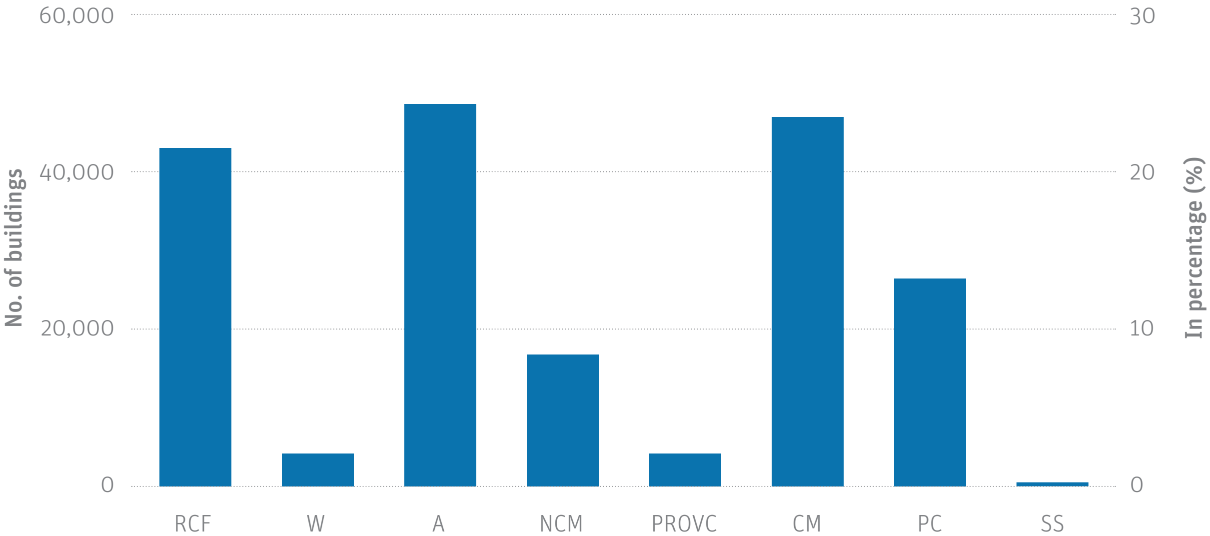
The CIE database includes a general category of "Structural System". These structural systems were verified in the field and through the photographic records taken during the CIE. The structural systems defined by the CIE and the observations about them are included in Table 4-1.

Table 4-1 Structural systems defined in the CIE

Code	Structural system	Description
RCF	Reinforced concrete frames and masonry walls (dual)	There is no clear distinction between buildings with concrete frames and buildings with confined masonry reported in the CIE. In line with this, and considering that this categorization was not made by specialists, the use of vulnerability functions in agreement with the opinion of the project specialists is suggested.
CM	Confined masonry or reinforced concrete masonry	The final classification will require a field inspection. In this sense, buildings classified as made with confined masonry could include buildings which would otherwise be classified as reinforced concrete frames for the purpose of this study.
PROVC and/or PROV	Provisional classrooms	Provisional classrooms built after 1998—unlike the ones built before that date—which have been built by government entities show a good seismic behavior. As to other provisional classrooms, there is high uncertainty as regards their seismic vulnerability. This happens because, in many cases, temporary replacement systems in form of precarious buildings were considered "provisional classrooms".
PC and/or P	Precarious constructions (plywood, *quincha* [cane of bamboo framework covered in mud], mudwall or similar)	Precarious buildings are generally classified as having high seismic vulnerability, since the general recommendation for these is to substitute them by seismic-resistant buildings.
NCM	Non-confined masonry	Buildings made with simple, not reinforced masonry generally show high seismic vulnerability as they have no confinement nor fastening elements in the roof area, which makes them extremely susceptible to damage in the plane perpendicular to the walls.
W	Wood (standardized)	Buildings made of wood and other lightweight materials generally show a low seismic vulnerability. However, after the field inspection of the buildings classified in this category, it has been noted that, in general, these are precarious buildings lacking a clear seismic-resistant system, that they were not designed following any standard or that they are built without any control in the selection of materials or their components, among other problems. Therefore, according to the structural system, an intermediate or high vulnerability level is assigned to these buildings given their highly uncertain behavior.
SS	Steel structure	Structures made of steel in the case of buildings constructed by the government after 1998. However, it can be observed that, in general, these buildings lack a seismic resisting system and have been built without any type of construction and/or structural design control. Therefore, according to the structural system, an intermediate or high vulnerability level is assigned to these buildings given their highly uncertain behavior.
A	Adobe	Adobe buildings show high seismic vulnerability because of their heavy weight and lack of fastening and confinement.
NA	Not Assigned	No structural system assigned to these buildings (i.e., the field is empty).

Figure 4-9 shows the distribution of structural systems according to the information obtained in the CIE.

Figure 4-9 Distribution of school buildings according to the structural system assigned in the CIE



	RCF	W	A	NCM	PROVC	CM	PC	SS
No.	42,261	4,112	47,788	16,437	4,117	46,128	25,969	500
%	23%	2%	26%	9%	2%	25%	14%	0%

For risk assessment, apart from the previous classification, it is necessary to identify the overall building typology, which is assigned using the following parameters:

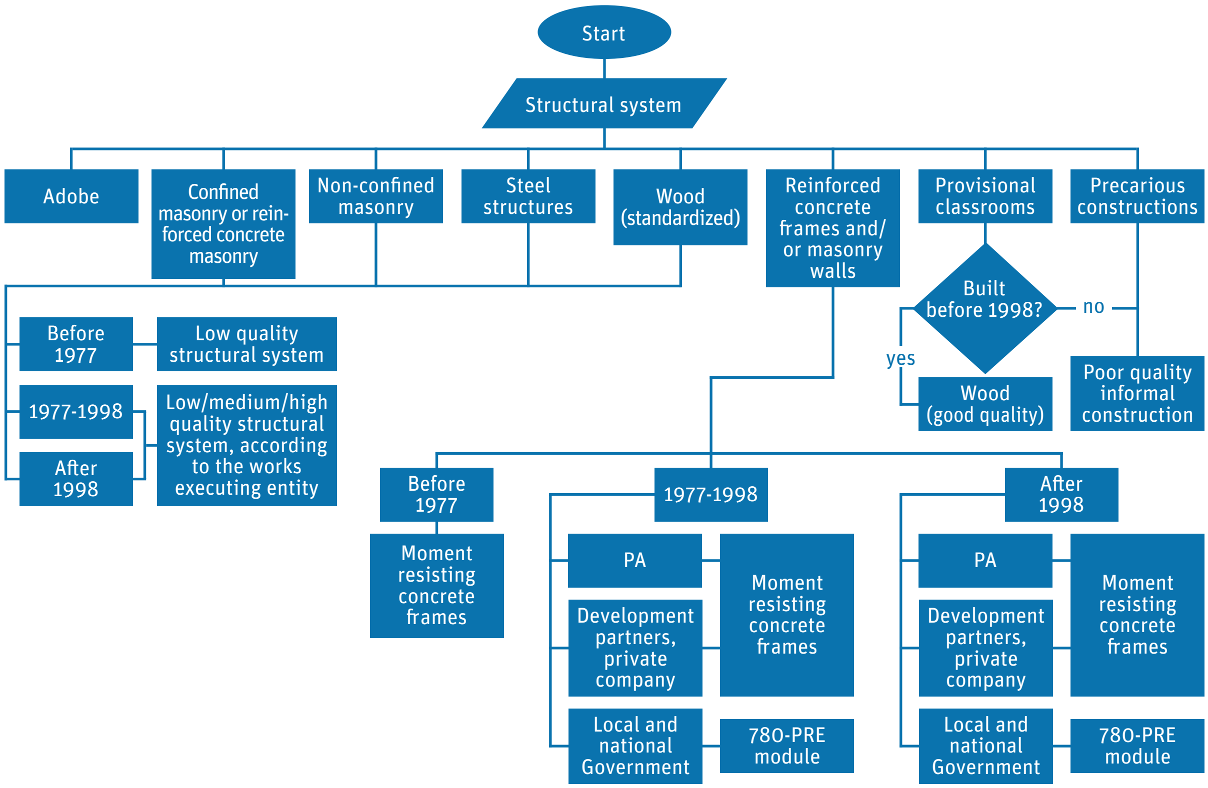
- Structural system
- Main construction material
- Building height
- Quality of the construction or level of design

The building typology is assigned on the basis of a semi-automatic process of parameter assignation which uses the information available in the CIE to determine the aforementioned parameters. In the assignation process, the following supplementary information is also taken into consideration:

- Technical inspection visits by project specialists to different sites.
- The "Technical Evaluator Handbook" (*"Manual del Evaluador Técnico"*) [10], which provides different descriptions regarding the quality of the works, the executing entities and the structural systems considered, among other matters.
- A thorough review of the photographs for the assignation of structural systems, considering the inconsistencies observed in their classification by the CIE, in particular as regards the assignation of the "confined masonry or reinforced concrete masonry" and "reinforced concrete frames and masonry walls (dual)" systems.

Figure 4-10 illustrates the type of algorithm used for such final typology assignation for the analysis.

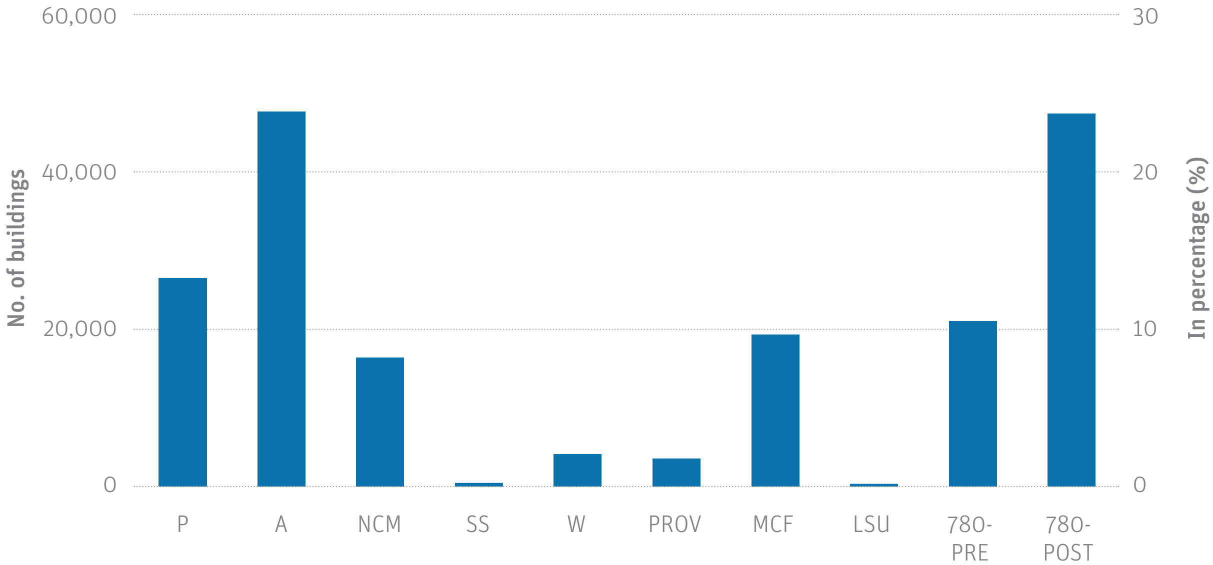
Figure 4-10 **Flowchart for the categorization under the different building typologies**



For additional details regarding the categorization under the different building typologies, see section 4.4.2.

The distribution by final building typologies is shown in Figure 4-11.

Figure 4-11 Distribution of school buildings according to building typologies



	P	A	NCM	SS	W	PROV	MCF	LSU	780-PRE	780-POST
No.	26,559	47,788	16,437	500	4,112	3,527	19,354	351	21,104	47,580
%	14%	26%	9%	0%	2%	2%	10%	0%	11%	25%

4.2.9 Use of the Buildings

The CIE database includes the type of intended use for each building. Table 4-2 shows the different uses reported in the database. This table defines those uses regarded as "educational", which, given their configuration, can host the largest number of students, teachers, and other participants in the school facility and, as a result, represent the group of relevant buildings for intervention.

Table 4-2 Specified uses of buildings in the CIE

List of building uses regarded as "educational"
Regular classrooms
Principal's office
Restrooms for boys and girls (preschool)
Restrooms for students
Restrooms for staff members
Teachers' housing
Vice-principal's office
Library
Students' housing
Break room
Consultancy
Faculty lounge
Diaper change room
Breastfeeding room
Total number of buildings: 152,660

List of building uses regarded as "non-educational"
Pantry
Kitchen
Other
Security
Clinic and Social Services
Print rooms
Security booth
Coffee shop/snack bar
Locker rooms
Cafeteria
Staircases
Educational materials warehouse
Ancillary services room
Cleaning and maintenance
Waiting area
Secretary's office and waiting area
Archive
Elevator
Total number of buildings: 34,652

4.2.10 Number of Benefited Students

In the CIE form, one of the fields is the number of students in each school facility. This parameter will later be used to prioritize the intervention of public school buildings. It allows for the prioritization of those school facilities which may have capacity for a greater number of students than those being served at present. However, it is worth noting that the number of students reported in the CIE in each school facility will be used to quantify the number of benefited students.

4.3 ECONOMIC REPLACEMENT COST OF THE PORTFOLIO

In order to determine the economic replacement cost of the components of the portfolio, a cost model was developed taking into account the geographical location of the school facility, the school setting, the bioclimatic zone and the level of education.

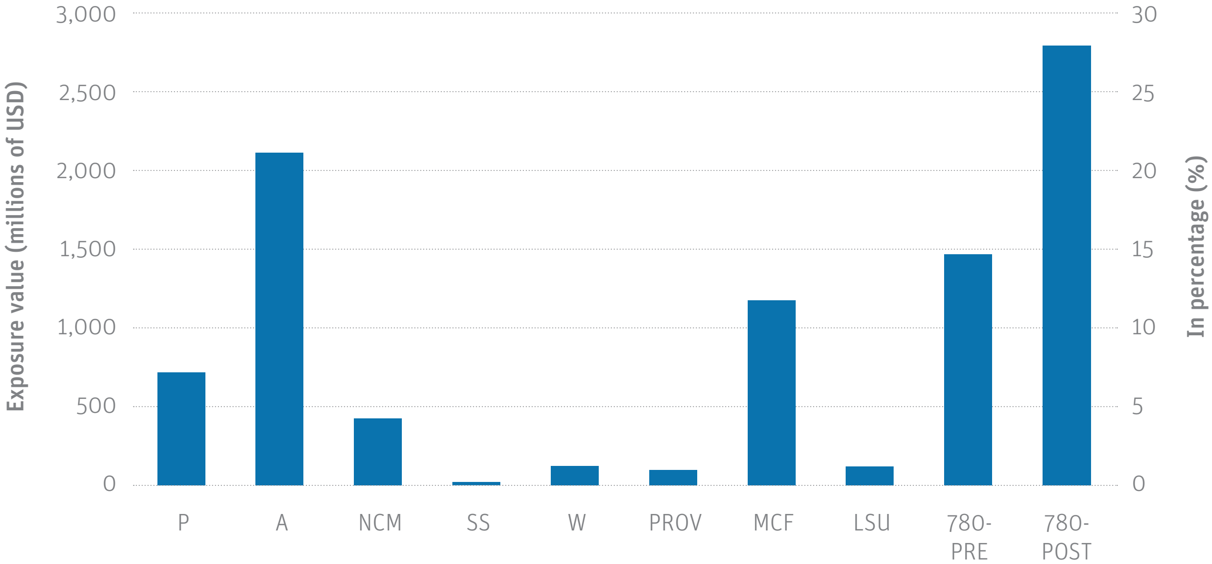
Given it is necessary to roughly quantify the replacement cost of the school facilities, average values for the different school settings are defined. These values correspond to the cost of new construction per square meter built in each of the areas defined. For this calculation, the school setting and the bioclimatic zone have been used. The bioclimatic zone corresponds to the classification of the regions according to the altitude above sea level (in meters), annual rainfall, mean annual temperature and relative humidity. Table 4-3 represents the average value defined for the different possible combinations of school setting and bioclimatic zone, and are shown in United States dollars (USD). To work out the definition of these values, the advise of the MINEDU was sought, as well as that of local and international consultants, and of World Bank specialists.

Table 4-3 Representative average values of school building exposure in Peru (year 2015)

School settings	Bioclimatic zone	Cost of new construction (USD/m²)
Big cities	Coastal desert	303
Capital cities	Coastal desert/Desert	331
	Low inter-Andean/Mid-Andean	339
	High Andean/Mountain	377
	Mountain edge/Humid subtropical/Humid tropical	333
Urban centers	Coastal desert/Desert	353
	Low inter-Andean/Mid-Andean	362
	High Andean/Mountain	399
	Mountain edge/Humid subtropical/Humid tropical	355
Connected villages	Coastal desert/Desert	364
	Low inter-Andean/Mid-Andean	373
	High Andean/Mountain	411
	Mountain edge/Humid subtropical/Humid tropical	366
Scattered communities	Coastal desert/Desert	404
	Low inter-Andean/Mid-Andean	414
	High Andean/Mountain	451
	Mountain edge/Humid subtropical/Humid tropical	407

The expected replacement costs are assigned according to the total built area in each of the buildings included in the database, and they are independent of the structural type of building. Figure 4-12 shows the distribution of the replacement costs by building typology for the complete inventory of buildings. The replacement cost of the entire building inventory amounts to USD 9.1 billion.

Figure 4-12 Replacement cost by building typology



Value (millions of USD)	719	2,121	426	22	122	98	1,181	120	1,474	2,804
%	8%	23%	5%	0%	1%	1%	13%	1%	16%	31%

Note: See description of structural systems in Table 6-1.

The geographical distribution of the building inventory replacement cost by department may be observed in Figure 4-13. In this figure, it can be seen that the department with the highest replacement cost is Lima, followed by some coastal departments. This is worth noting, since the seismic hazard is greater in the coastal area of Peru. In preparing this map, all the exposed buildings in the inventory have been taken into account, irrespectively of their use, seismic zone, or any other parameter.

Figure 4-13 Map of school building replacement costs by department

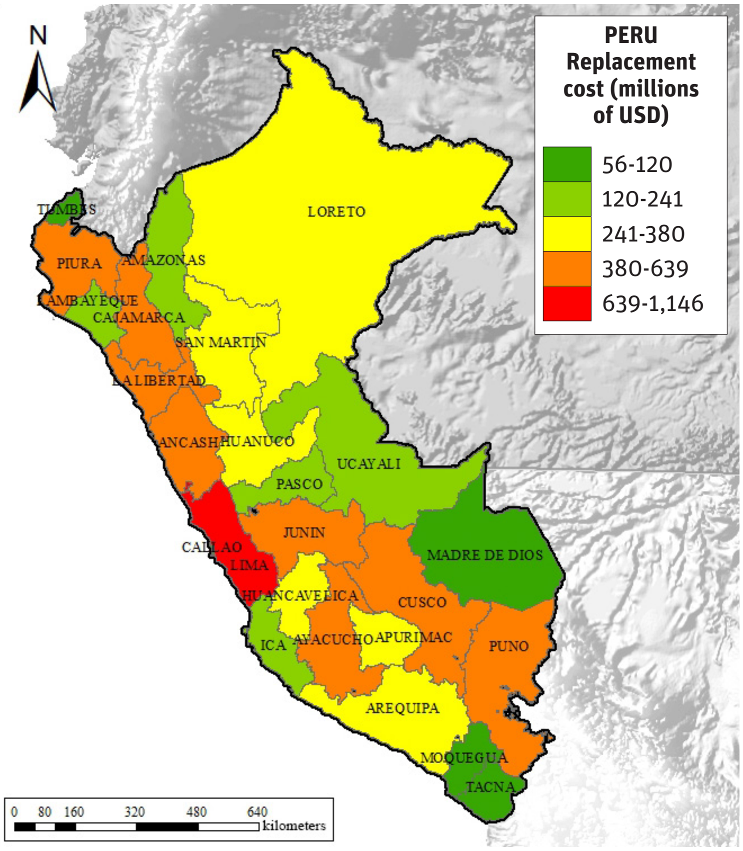


Table 4-4 includes a summary of the main characteristics of the final inventory of school facilities and buildings:

Table 4-4 Summary of portfolio of exposure of school buildings

Characteristics	Value
Number of public school facilities	40,475
Total number of buildings	187,312
Number of buildings for educational use	152,660
Economic valuation of all buildings	USD 9.1 billion
Economic valuation of buildings for educational use	USD 8.4 billion

4.4 VULNERABILITY OF BUILDING TYPOLOGIES

4.4.1 Vulnerability Functions for the Analysis

The vulnerability of the predominant building typologies previously identified and characterized depend on several relevant factors, such as structural systems, main structural materials, height of the construction and its quality—associated to the degree of compliance with the specifications of the seismic-resistant design (seismic code level)—, which define their behavior in specific seismic events. Thus, it is possible to define the level of expected damage both on the main structure of the building and on its non-structural elements. Based on the level of estimated damage for the different seismic events under analysis, it is possible to determine the expected economic loss for each of the buildings considering the set of seismic events that constitute the seismic hazard in the area under study.

In the representation of the vulnerability functions, the seismic intensity of analysis selected in this study is the spectral acceleration for the estimated structural period for each specific building typology. The vulnerability functions used are based on the methodology suggested in references 8 and 13. The vulnerability level for the same construction system and structural material varies according to the number of stories or total height, and to the quality of the construction or seismic code level. For the determination of the code level, the levels of seismic requirements and the applicability of the Peruvian seismic resistance standard were assessed.

The vulnerability functions used for risk analysis are shown in Figure 4-14 and Figure 4-15. Both figures show the differences according to the height of the buildings.

In Table 4-5, column "Seismic code level" makes reference to the degree of compliance with regulations in relation to the level of seismic demand and the lateral deformation capacity for which the building was designed. The selected categories are the following:

- Pre-code (P): It does not comply with any minimum requirement of seismic resistance.
- Low (L): It does not generally comply with the minimum seismic resistance specifications.
- Medium (M): It complies, in general, with seismic resistance specifications.
- High (H): It fully complies with the seismic resistance specifications included in international building seismic design codes in terms of load-bearing capacity and horizontal deformation capacity or ductility for high seismic hazard zones.

Table 4-5 Building typologies and defined vulnerability functions

No.	Structural type	Description	Typical height		Seismic code level			
			Range	No. of stories	P	L	M	H
1	Adobe (A)	Adobe	Low	1+	X	X	–	–
2	Non-confined masonry (NCM)	Load-bearing walls in simple masonry	Low	1-2	X	X	–	–
			Medium	3-5	X	X	–	–
3	Precarious (P)	Informal precarious constructions (plywood, *quincha*, etc.)	Low	1+	X	–	–	–
4	Steel structures (SS)	Steel frames	Low	1-3	X	X	X	–
5	Wood structures (WS)	Wood constructions	Low	1+	X	X	–	–
6	Reinforced concrete frames (RCF)	Concrete structures with concrete frames; highly uncertain seismic behavior	Low	1-3	X	X	X	–
			Medium	4-7	X	X	X	–
7	Large school unit (LSU)	Concrete frames built before the institution of the Peruvian building standards	Low	1-3	–	X	X	–
			Medium	4-7	–	X	–	–
8	780 pre-code (PRE) modules	780 module prior to the 1998 standard; problems related to short columns	Low	1-3	–	X	X	–
9	780 post-code (POST) modules	780 module after the 1998 standard	Low	1-3	–	–	X	X
			Medium	4-7	–	–	X	X
10	Provisional classrooms (PROV)	Provisional classrooms built by the government after the 1998 standard	Low	1-3	–	X	X	–
			Medium	4-7	–	X	X	–

Note: P = pre-code; L = low code; M = medium code; and H = high code.

Figure 4-14 Vulnerability functions for low height buildings

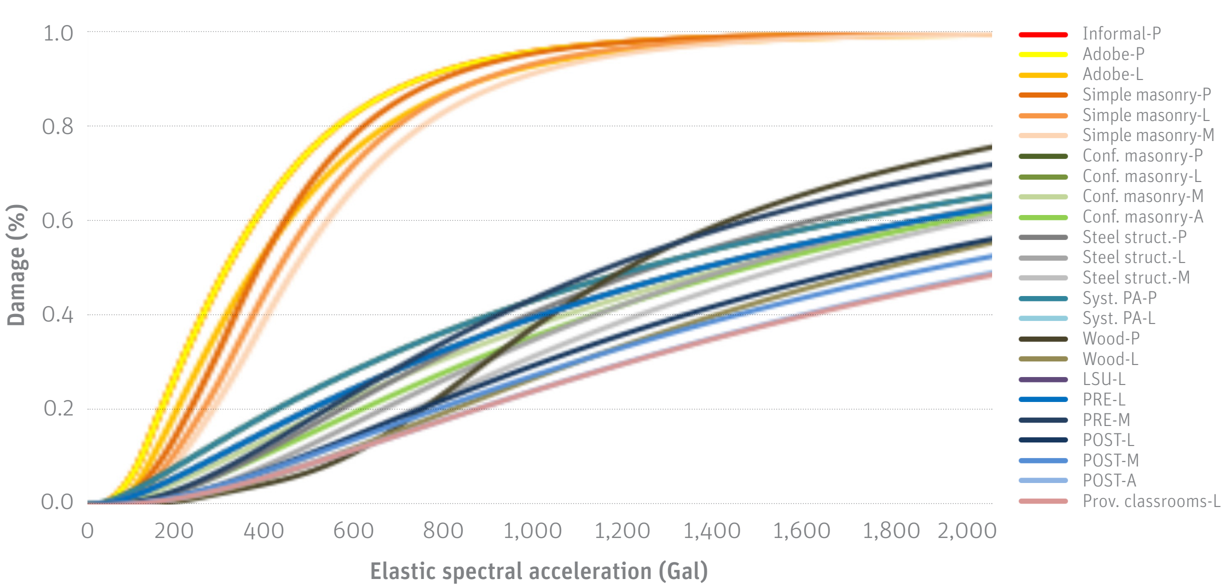
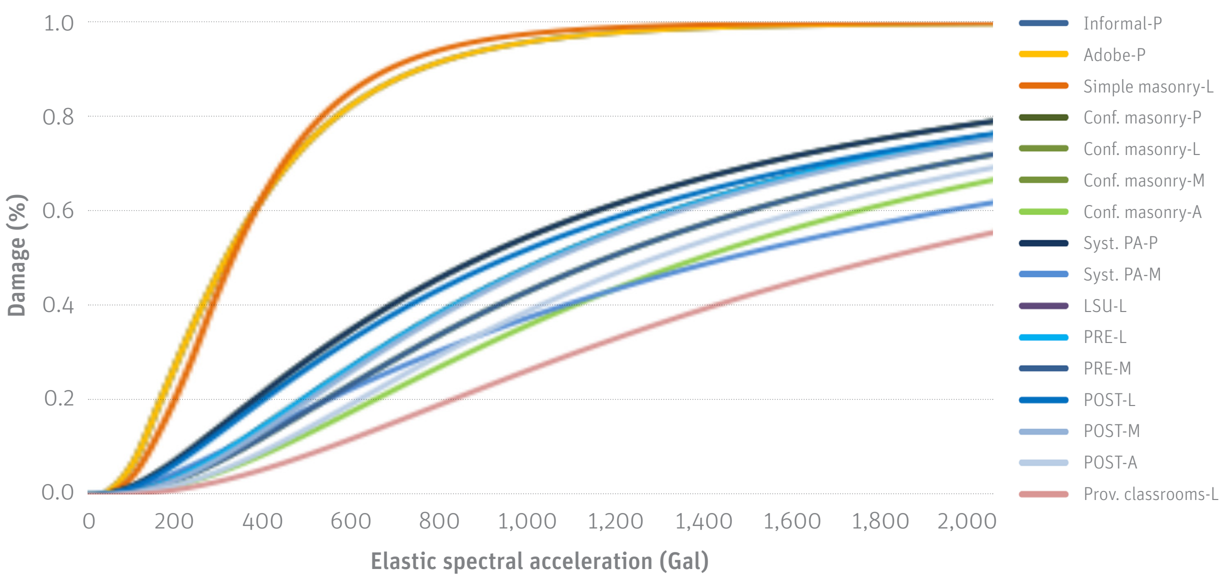


Figure 4-15 Vulnerability functions for medium height buildings



4.4.2 Assignation of Vulnerability Functions to Building Typologies

In order to assign vulnerability functions to the identified building typologies, a number of supplemental criteria related to the quality of the typical systems in Peru are used. The following are some of these considerations:

a) Buildings made with simple, not reinforced masonry generally show high seismic vulnerability as they have no confinement nor fastening elements in the roof area, which makes them extremely susceptible to damage in the plane perpendicular to the walls.

b) Adobe buildings show high seismic vulnerability because of their heavy weight and lack of fastening and confinement.

c) Precarious buildings are generally classified as having high seismic vulnerability.

d) Provisional classrooms built after 1998—unlike the ones built before that date—which have been built by government entities show a good seismic behavior.

e) According to the inspection visits made, there is no clear distinction between buildings with concrete frames and buildings with confined masonry reported in the CIE. In line with this, and considering that this categorization was not made by specialists, the use of vulnerability functions in agreement with the opinion of the project specialists is suggested. The final classification will require a field inspection. In this sense, buildings classified as made with confined masonry could include buildings which would otherwise be classified as reinforced concrete frames.

f) 780 module-type buildings have been classified following the understanding that they include all those buildings reported in the CIE as reinforced concrete frame systems and that have been built by government entities. Although it is acknowledged that these buildings have changed throughout the history of school infrastructure construction, their structural behavior has been similar. The buildings built before 1998 by the government (national or regional) are classified as “780-PRE”, and they show a medium vulnerability level mainly due to the presence of short columns, while the ones built after that year also by the government are classified as “780-POST”. These show a reduced seismic vulnerability as a result of the structural modifications introduced to this system at that time.

g) Buildings classified as “large school units” (LSU) are considered to have intermediate seismic vulnerability due to the presence of short columns. These constructions were built around 1950-1970. There is a broad consensus on the fact that the selection of structural elements was more generous at that time and that the structure itself had greater redundancy than more recent constructions, which grants them a better seismic behavior than, for example, that of the 780-PRE systems. The results of the present report take into consideration the buildings that have already been reinforced and, therefore, should not undergo a new intervention.

h) Buildings made of wood, steel, and other lightweight materials generally show a low seismic vulnerability. However, after the field inspection of the buildings classified in this category, it has been noted that, in general, these are precarious buildings lacking a clear seismic-resistant system, that they were not designed following any standard or that they are built without any control in the selection of materials or their components, among other problems. Therefore, according to the structural system, an intermediate or high vulnerability level is assigned to these buildings given their highly uncertain behavior.

i) “Moment resisting concrete frame (MCF)” constructions are all those buildings categorized as RCF or CM systems according to the CIE that were not built by the government and, thus, have an uncertain level of vulnerability. It is assumed that they generally lack any design or quality control during their construction. For this reason, the vulnerability of these constructions is considered higher than that of equivalent constructions built by the state.

5 SEISMIC RISK ASSESSMENT

5.1 INTRODUCTION

The probabilistic seismic risk assessment of the Peruvian school building inventory was carried out on the basis of the seismic hazard information (Chapter 3), the portfolio of exposure of school facilities and buildings, and the vulnerability of the dominant building typologies (Chapter 4). The risk is expressed through direct economic losses in terms of absolute or relative economic value as regards the replacement cost associated with each building. In the latter case, this parameter shows the degree or level of damage or disruption that may be associated with the direct physical impact. This analysis does not consider the economic losses related to building content nor the indirect losses resulting from the disruption to the educational service, such as impacts on third parties, on the economy or on the level of development of a region or the entire country.

The main risk metrics used in the present analysis are the following:

- Average annual loss (AAL): The AAL is estimated for each of the exposed components and for the total of them as the sum of the product between the loss expectancy for a given setting and the annual frequency of occurrence of the event in question, and for all the stochastic events considered. In probabilistic terms, the AAL is the mathematical expectation of annual loss.
- Probable Maximum Loss (PML): The PML represents the loss value for a given level of exceedance. It corresponds to the probable maximum loss for the different return periods under consideration, and is obtained from the loss exceedance curve, which may be estimated based on the loss associated with all the possible events, according to its return period.
- Loss expectancy for a critical setting: A critical setting may be defined as that with the greatest share in the AAL, or that which represents the highest intensity earthquake or the highest expected damage in the area under analysis considering both the economic loss and the annual frequency of occurrence of each of the events. Once the critical setting is chosen, the percentages of expected loss and economic loss associated with each of the exposed elements of the inventory under study may be determined.

5.2 RISK ASSESSMENT BASIC RESULTS

Table 5-1 and Figure 5-1 present a summary of the results of the probabilistic analysis in terms of loss expectancy and probable maximum loss.

Table 5-1 Average annual loss and probable maximum loss for the national portfolio of exposure

Results		
Exposed value	USD $x10^6$	9,087
Average annual loss	USD $x10^6$	190.0
	‰	20.91
PML		
Return period	**Loss**	
Years	**USD x106**	**%**
100	308	3.4
250	408	4.5
500	497	5.5
1,000	590	6.5

Figure 5-1 Probable maximum loss curve for the national portfolio of exposure

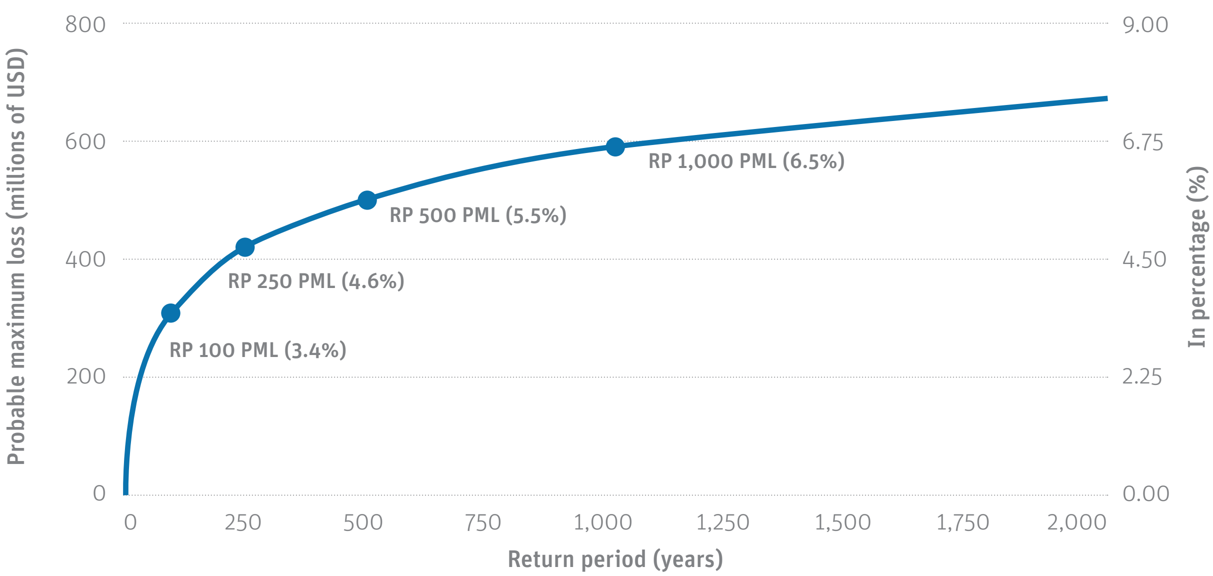


Table 5-2 shows the AAL values for the critical school facilities (the ones with the highest absolute loss expectancy), including ID, number of buildings, structural types included and replacement cost of the whole school facility. In Reference 14, the results for the total of buildings grouped by school facilities are shown.

Table 5-2 Average annual loss of critical school facilities in the national portfolio of exposure

Facility ID	Longitude	Latitude	VALFIS (USD)	AAL (USD)	AAL VALFIS (‰)	No. of buildings in school facility by structural type: P	A	NCM	SS	W	PROV	MCF	LSU	780-PRE	780-POST	TOTAL
68212	-72.494	-16.078	9,317,777	275,591	30	0	0	0	0	0	0	1	0	8	1	10
315279	-77.066	-12.099	8,109,391	666,873	82	2	26	2	0	7	0	6	0	3	0	46
65770	-71.517	-16.42	3,437,026	205,040	60	3	0	5	0	0	0	28	0	0	5	41
462166	-69.355	-15.49	12,616,816	334,024	26	1	12	1	0	0	0	0	0	0	2	16
400079	-71.339	-17.615	3,193,694	124,223	39	5	0	0	0	0	1	18	0	0	10	34
68924	-72.164	-14.996	4,167,556	145,400	35	1	2	1	0	0	0	0	0	1	1	6
59241	-71.544	-16.361	2,447,697	149,725	61	0	0	0	0	0	1	20	0	0	0	21
55460	-71.544	-16.396	2,464,667	148,986	60	0	0	0	0	0	0	9	0	0	0	9
58859	-71.549	-16.388	2,146,317	134,311	63	0	0	1	0	0	1	12	0	0	0	14
288370	-77.056	-12.043	2,543,819	26,130	10	1	0	1	0	0	0	3	0	0	4	9

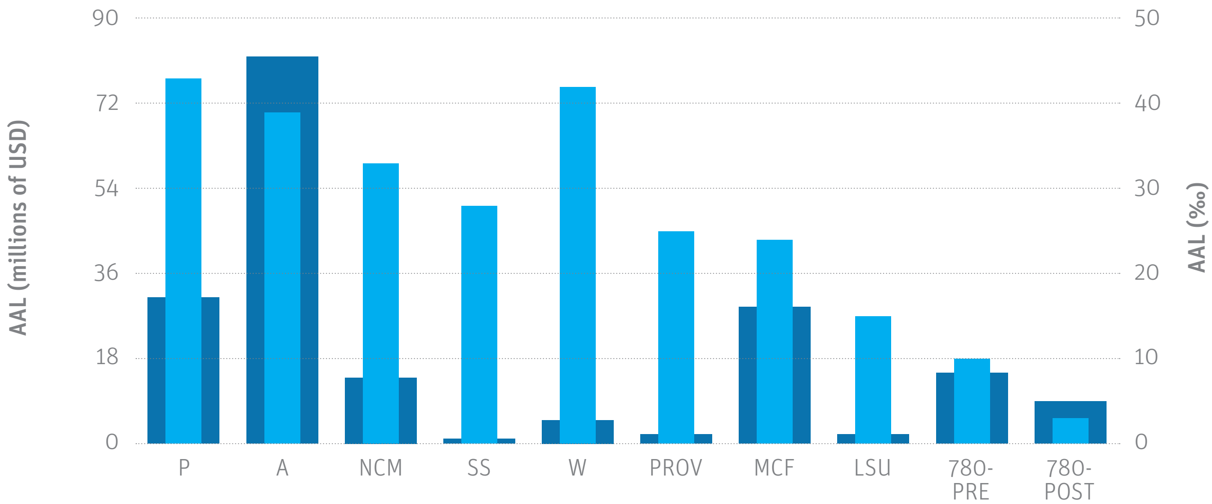
Note:
Facility ID: School facility identifying code.
Latitude, Longitude: Geographic coordinates.
VALFIS: Total exposed value by school facility.
AAL: Average annual loss for the school facility.
AAL/VALFIS: Average annual relative loss for the school facility.
Structural types: Those indicated in Table 4-5.

Table 5-3 and Figure 5-2 include the AAL values for the total building inventory grouped by building typology. The table allows for the determination of the degree of relative risk for each of the typologies, and is relevant for the definition of a structural intervention strategy.

Table 5-3 Average annual loss by building typology for the national portfolio of exposure

Structural type	Exposed value (USD)	Total exposed percentage (%)	Average annual loss (USD)	Percentage loss in relation to total loss (%)	Average annual loss (‰)
Adobe (A)	2,121,032,365	23.3%	82,380,845	43.4%	39
Non-confined masonry (NCM)	426,105,389	4.7%	14,179,890	7.5%	33
Precarious (P)	719,472,341	7.9%	30,936,713	16.3%	43
Steel structures (SS)	22,261,436	0.2%	612,315	0.3%	28
Wood structures (WS)	121,622,702	1.3%	5,157,853	2.7%	42
Reinforced concrete frames (RCF)	1,181,068,616	13.0%	28,729,096	15.1%	24
Large school unit (LSU)	119,948,968	1.3%	1,811,792	1.0%	15
780 pre-code (PRE) modules	1,473,738,383	16.2%	15,116,499	8.0%	10
780 post-code (POST) modules	2,803,627,701	30.9%	8,616,630	4.5%	3
Provisional classrooms (PROV)	98,090,886	1.1%	2,431,430	1.3%	25
Total	9,086,968,786	100%	189,973,063	100%	21

Figure 5-2 Total and percentage average annual loss by building typology for the national portfolio of exposure



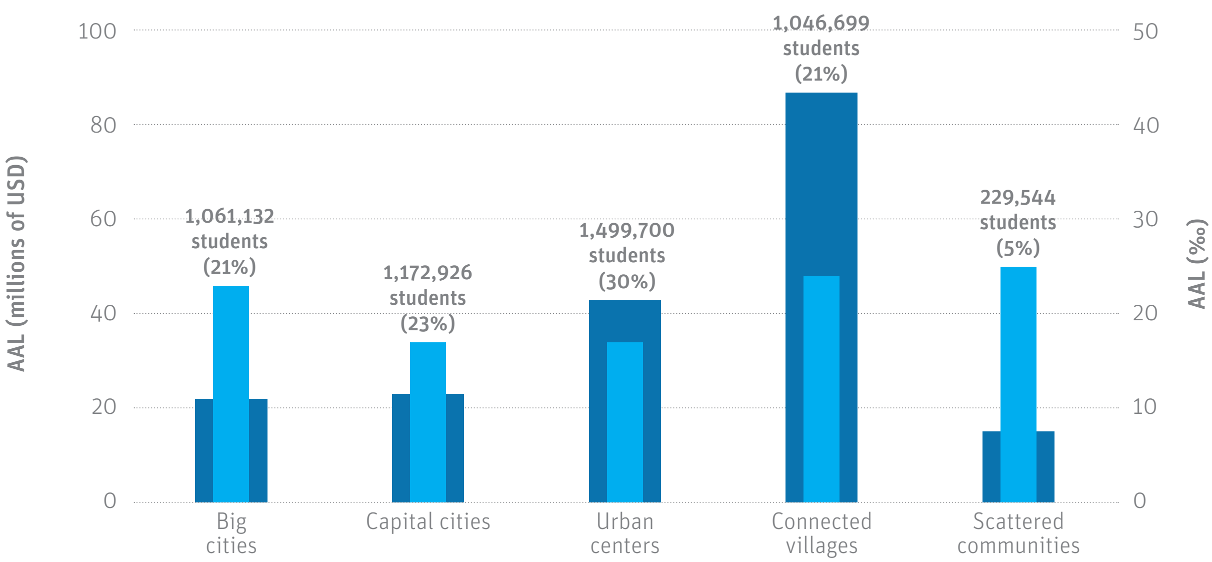
	P	A	NCM	SS	W	PROV	MCF	LSU	780-PRE	780-POST
AAL (millions of USD)	31	82	14	1	5	2	29	2	15	9
AAL (‰)	43	39	33	28	42	25	24	15	10	3

Structural system

Note: See description of building typologies in Table 4-5.

The results of risk classified by school setting are also shown. Figure 5-3 shows the AAL results in millions of USD.

Figure 5-3 Average annual loss by school setting



	Big cities	Capital cities	Urban centers	Connected villages	Scattered communities
AAL (millions of USD)	22	23	43	87	15
AAL (‰)	23	17	17	24	25

School setting

Figure 5-4 shows the AAL for each of the regions of the country. Figure 5-5 shows the geographical distribution of the physical losses expressed as AAL in each department, in absolute and percentage values.

Figure 5-4 **Geographical distribution of direct physical average annual loss by department**

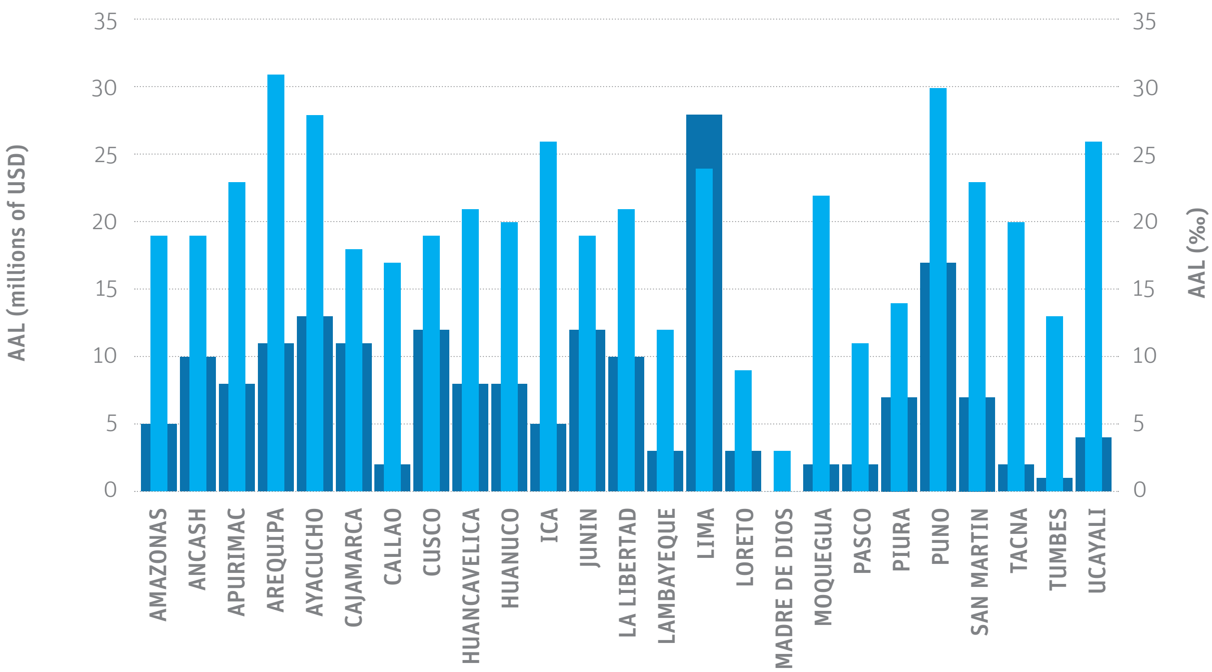
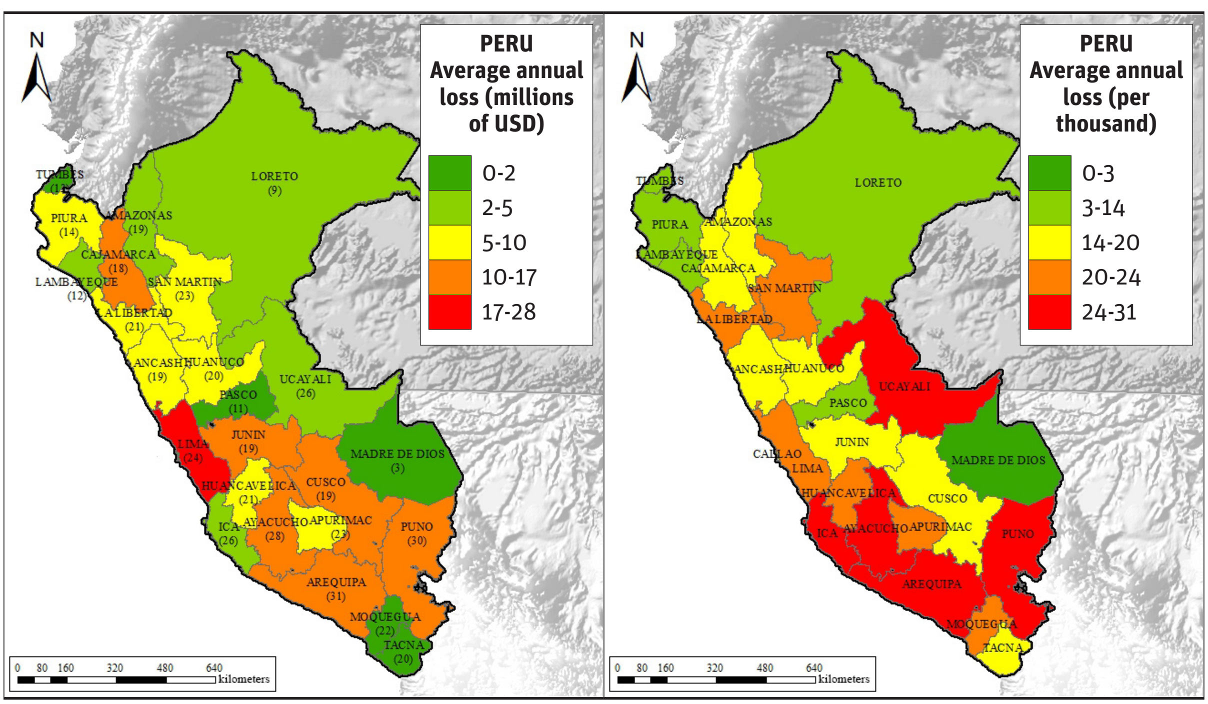


Figure 5-5 **Geographical distribution of average annual loss by department**



5.3 CATEGORIZATION OF BUILDING TYPOLOGIES BY LEVEL OF RISK

The results of the risk analysis allow to establish the following categorization of building typologies:

a) **Buildings with high risk of collapse (HRC):** Buildings that frequently show a poor seismic behavior and, as a result, their prospective intervention would imply major technical difficulties, high costs and few guarantees of functionality. This category includes: precarious buildings, provisional classrooms, adobe and non-confined masonry.

b) **Buildings with high damage potential (HDP):** Buildings that show a poor seismic behavior in medium/high magnitude seismic events; however, they show technical, functional and economic feasibility for intervention. This category includes the following structural systems: large school units, moment resisting concrete frames and 780-PRE modules.

c) **Buildings with good seismic performance (GSP) expectancy:** Buildings designed and built following seismic-resistant criteria; according to the objectives of the program, it is considered they do not require any type of intervention. This category only includes the building typology identified as 780-POST modules.

This categorization of building typologies according to their level of risk is subsequently used as part of the proposed intervention strategy.

6. SEISMIC RISK REDUCTION STRATEGY

6.1 PROCESS TO DEFINE THE STRATEGY

The design of the seismic risk reduction strategy includes the following process:

1. Definition of the interventions by identified building typologies according to their level of risk
2. Estimation of the intervention cost for the total inventory of public school buildings in the country
3. Prioritization of interventions and estimation of costs for a 10-year period
4. Optimization of the intervention strategy and prioritization of the intervention subprograms
5. Disaggregation of interventions by region

6.2 DEFINITION OF INTERVENTIONS ACCORDING TO BUILDING TYPOLOGIES

The intervention of school buildings is aimed at correcting possible structural defects and at providing the structure with an appropriate combination of rigidity, resistance and ductility which may ensure its good behavior in future seismic events under the terms established in the E030 Standard of the Peruvian National Building Code. Four main intervention lines are defined:

- **Conventional reinforcement:** The reinforcement intervention is made in a single phase and in such a way that the school building reaches the level of seismic behavior established in the E030 Standard [11].
- **Incremental reinforcement:** The structural intervention is made in two or more phases marked by predefined levels of performance that should be achieved in each of them. The levels of performance are defined for each structural typology according to Reference 15. In the last phase, the school building reaches the level of seismic behavior established in the E030 Standard.
- **Substitution of school buildings for new seismic-resistant buildings:** It is applied when there is no technical and/or financial feasibility for structural reinforcement. It involves the demolition of the existing building, the installation of temporary classrooms, and the design and construction of the new building.
- **Contingent intervention to prevent collapse:** It is a type of reinforcement of the adobe walls made with welded wire mesh, wood elements, or any other approved technique that is implemented to prevent collapse, as the substitution of those buildings would be complex and would take a long time.

For each one of the categories of building typologies according to the level of risk (see Section 5.3), the following possible lines of intervention are defined:

a) **Buildings with high risk of collapse (HRC):** Building substitution and/or contingent intervention is recommended.

b) **Buildings with high damage potential (HDP):** Two options are defined: incremental reinforcement for 780-PRE type school buildings, and conventional reinforcement for other structural typologies.

c) **Buildings with good seismic performance (GSP):** No type of intervention is considered according to the scope and objectives set in the present project.

Table 6-1 summarizes the types of intervention proposed in line with the building typologies.

Table 6-1 Possible types of structural intervention

Types of intervention	Buildings with high risk of collapse (HRC)	Buildings with high damage potential (HDP)	Buildings with good seismic performance
Definition and characteristics	Poor seismic behavior; their intervention implies major technical difficulties, high costs, and few guarantees of functionality.	Regular seismic behavior in medium/ high magnitude seismic events. Technical, functional, and economic feasibility for intervention.	Seismic-resistant buildings
Structural typology including	• Adobe (A) • Non-confined masonry (NCM) • Precarious (P) • Provisional (PROV)	• Large school units (LSU) • Moment resisting concrete frames (MCF) • 780-PRE modules	• 780-POST modules
Intervention options	a) Substitution for seismic-resistant buildings. b) Substitution for provisional classrooms (in the short term) while modular alternatives are defined. c) Contingent intervention to prevent collapse.	a) Incremental reinforcement with gradual interventions and in stages; compliance with the essential requirements of the regulations should be achieved at the initial stage. b) Conventional reinforcement with a single stage intervention to achieve total compliance with the regulations. c) Contingent intervention in buildings located in medium and low hazard zones.	Not required

6.3 ESTIMATION OF THE INTERVENTION COST

6.3.1 Estimated Total Cost

Based on the groups of structural typologies previously defined and the associated lines of intervention, intervention subprograms and their approximate cost were determined as explained below:

a) **Intervention subprogram No. 1: Substitution.** It includes all buildings with high risk of collapse (HRC) located in high or intermediate seismic hazard zones. The estimate of the intervention cost is made with the following equation:

Substitution cost = [300,450] USD/m² + 25% (reusable provisional classrooms) + 10% (demolition)

b) **Intervention subprogram No. 2: Conventional Reinforcement.** It includes all buildings with high damage potential (HDP) located in high or intermediate seismic hazard zones. The estimate of the intervention cost is made with the following equation:

Comprehensive reinforcement cost = 50% of replacement cost

c) **Intervention subprogram No. 3: Buildings in low seismic hazard zones.** It includes all the HRC and HDP buildings located in low seismic hazard zones for which a contingent intervention is suggested so as to prevent total or partial collapse. In these cases, the estimate of the intervention cost is made with the following equation:

Contingent intervention cost = 15% of replacement cost

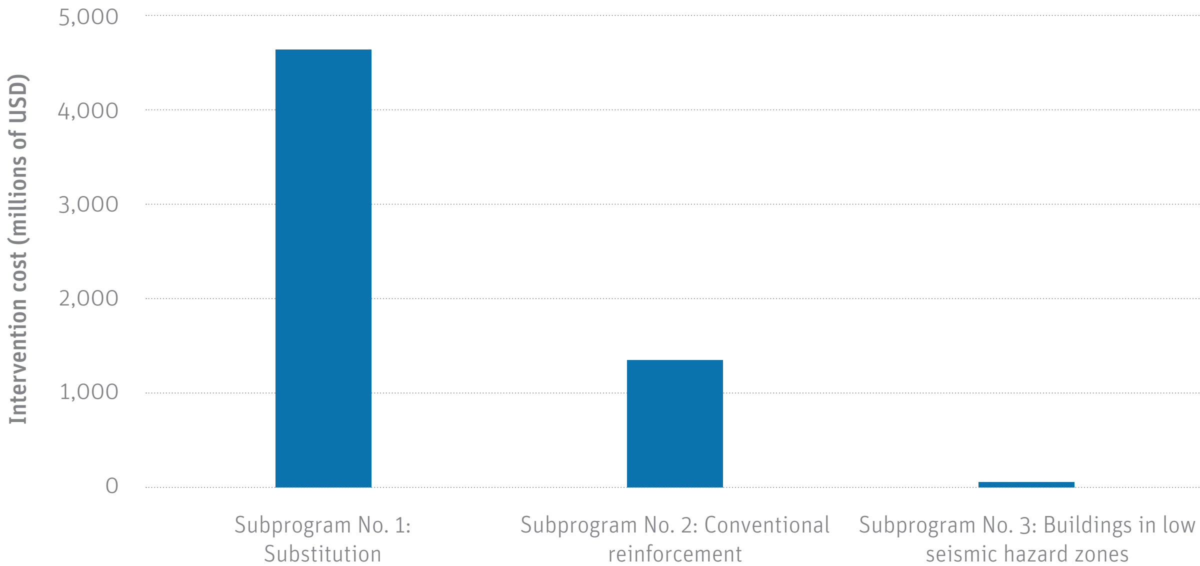
The intervention costs associated with each of them have been calculated as percentages of the replacement cost based on statistical data from existing projects. As it was mentioned in section 6.3, the replacement cost takes into account value variations according to the geographical location of the facility and the school setting. The costs associated with substitutions take into account the need to relocate students in provisional classrooms while the construction of the new building is carried out. The approximate value for the demolition of the existing building is also included. The value of the incremental reinforcement is conservative, and its assessment is shown with greater detail in references 14 and 16.

Based on previous intervention subprograms, the structural type and the replacement cost of each building, as well as the financing procedures defined, the total cost of the interventions was estimated as shown in Table 6-2 and Figure 6-1.

Table 6-2 Summary of total cost of interventions

	No. of buildings	Total cost in millions of USD
Program for seismic vulnerability reduction in school infrastructure	139,732	6,032
Cost by subprogram		
Subprogram No. 1: Substitution	97,110	4,660
Subprogram No. 2: Conventional reinforcement	39,933	1,353
Subprogram No. 3: Buildings in low seismic hazard areas	2,689	19

Figure 6-1 Total gap by subprogram



	Subprogram No. 1: Substitution	Subprogram No. 2: Conventional reinforcement	Subprogram No. 3: Buildings in low seismic hazard zones
Total gap (millions of USD)	4,660	1,353	19

Type of intervention

6.3.2 Intervention Cost for a 10-Year Seismic Risk Reduction Program

As the PNIE was drawn up for a 10-year period, a risk reduction program was defined for the same period.

In order to optimize the resources for this program, only the buildings classified according to their educational use as common classrooms, restrooms for boys and girls, students and staff, libraries, faculty lounges, and principal's offices, among others, are included. Based on this, the following are considered second priority buildings:

- Buildings with non-educational specific uses, such as pantries, kitchens, cafeterias, waiting areas, educational material warehouses, staircases, print rooms, security and security booths, among others
- Buildings with good seismic performance expectancy (GSP)
- Buildings located in low seismic hazard zones

Based on this, the statistics for the 10-year program are obtained, which are included in Table 6-3.

Table 6-3 Summary of portfolio of exposure of school buildings

Characteristics	Value
Number of public school facilities	40,475
Total number of buildings	187,312
Number of buildings with good performance	44,031
Number of excluded buildings	34,652
Total number of buildings to be intervened	108,629
Total value of the inventory to be intervened	USD 8,435 millions

6.4 10-YEAR PRIORITIZED INTERVENTION STRATEGY

The criteria used in the 10-year program are as follows:

a) School buildings located in intermediate and high seismic hazard zones are prioritized. In this group, those buildings with uses involving high-occupancy take priority.

b) Each building is assigned a single level of intervention according to its location and its structural typology.

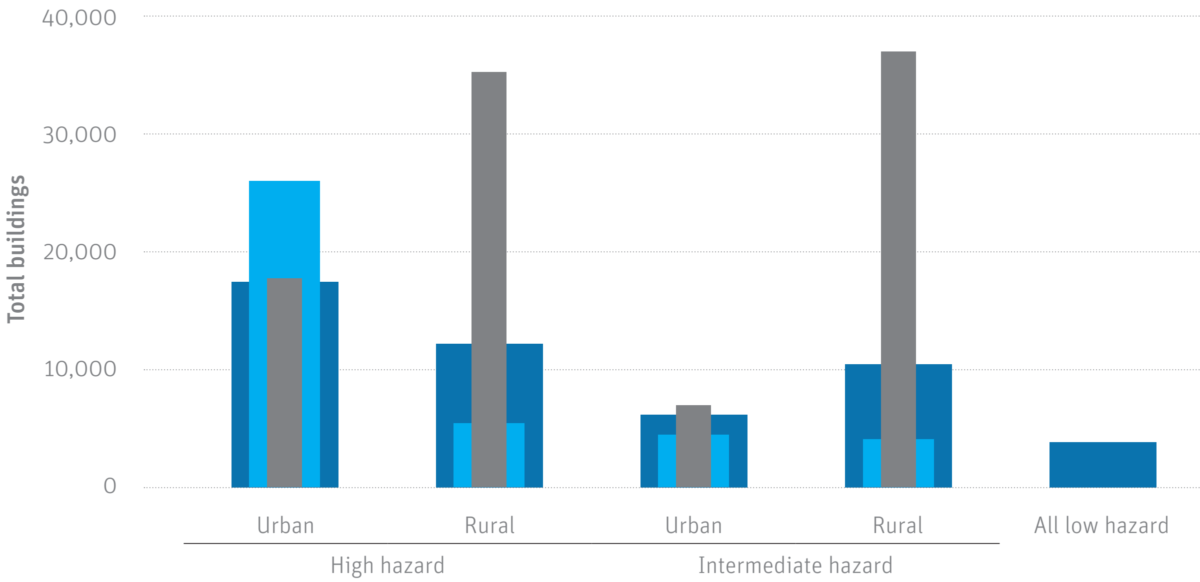
Table 6-4 outlines the interventions recommended for each type of building based on the previous considerations. This table also shows the value or cost that has to be taken into account in each of the interventions.

Table 6-4 Summary of interventions recommended for each type of building

<table>
<tr><th>Type of hazard (according to the 2016 RNE)</th><th>Environment</th><th>Group to be intervened</th><th>Intervention</th><th>Cost per square meter (USD/m²) or value associated with replacement cost (%)</th></tr>
<tr><td rowspan="5">High (zones 3 and 4)</td><td rowspan="2">Urban</td><td>High risk of collapse (HRC)</td><td>Substitution</td><td>[300,450] USD/m² + 25% (provisional classrooms) + 10% (demolition)</td></tr>
<tr><td>High damage potential (HDP)</td><td>Incremental reinforcement</td><td>30% of replacement cost</td></tr>
<tr><td rowspan="3">Rural</td><td rowspan="2">High risk of collapse (HRC)</td><td>Substitution</td><td>30% of replacement cost + 10% (demolition)</td></tr>
<tr><td>Contingent temporary intervention</td><td>30% of replacement cost</td></tr>
<tr><td>High damage potential (HDP)</td><td>Incremental reinforcement</td><td>30% of replacement cost</td></tr>
<tr><td rowspan="5">Intermediate (zone 2)</td><td rowspan="2">Urban</td><td>High risk of collapse (HRC)</td><td>Substitution</td><td>[300,450] USD/m² + 25% (provisional classrooms) + 10% (demolition)</td></tr>
<tr><td>High damage potential (HDP)</td><td>Incremental reinforcement</td><td>30% of replacement cost</td></tr>
<tr><td rowspan="3">Rural</td><td rowspan="2">High risk of collapse (HRC)</td><td>Substitution for temporary systems</td><td>30% of replacement cost + 10% (demolition)</td></tr>
<tr><td>Contingent temporary intervention</td><td>30% of replacement cost</td></tr>
<tr><td>High damage potential (HDP)</td><td>Incremental reinforcement</td><td>30% of replacement cost</td></tr>
<tr><td>Low (zone 1)</td><td>Urban and rural</td><td>All</td><td>Not included in this intervention plan</td><td>Not applicable</td></tr>
</table>

Figure 6-2 shows the distribution of school buildings according to the intervention subprogram, the seismic hazard zone and the school setting. Figure 6-3, in turn, shows the information related to the 10-year program.

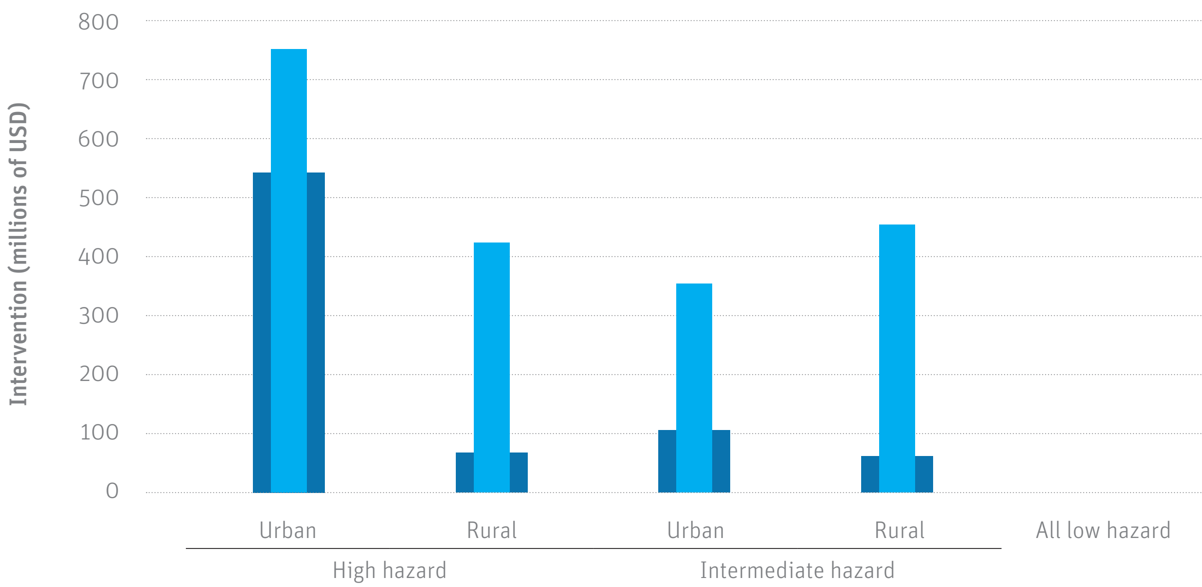
Figure 6-2 **Building intervention plan according to intervention subprogram, seismic hazard zone and school setting**



	High hazard – Urban	High hazard – Rural	Intermediate hazard – Urban	Intermediate hazard – Rural	All low hazard
Subprogram No.1	17,756	35,320	6,936	37,098	0
Subprogram No.2	26,049	5,424	4,421	4,039	0
No intervention	17,513	12,232	6,188	10,485	3,851

Classification according to geographical location

Figure 6-3 **Building intervention plan according to intervention subprogram, seismic hazard zone and school setting for the 10-year program**

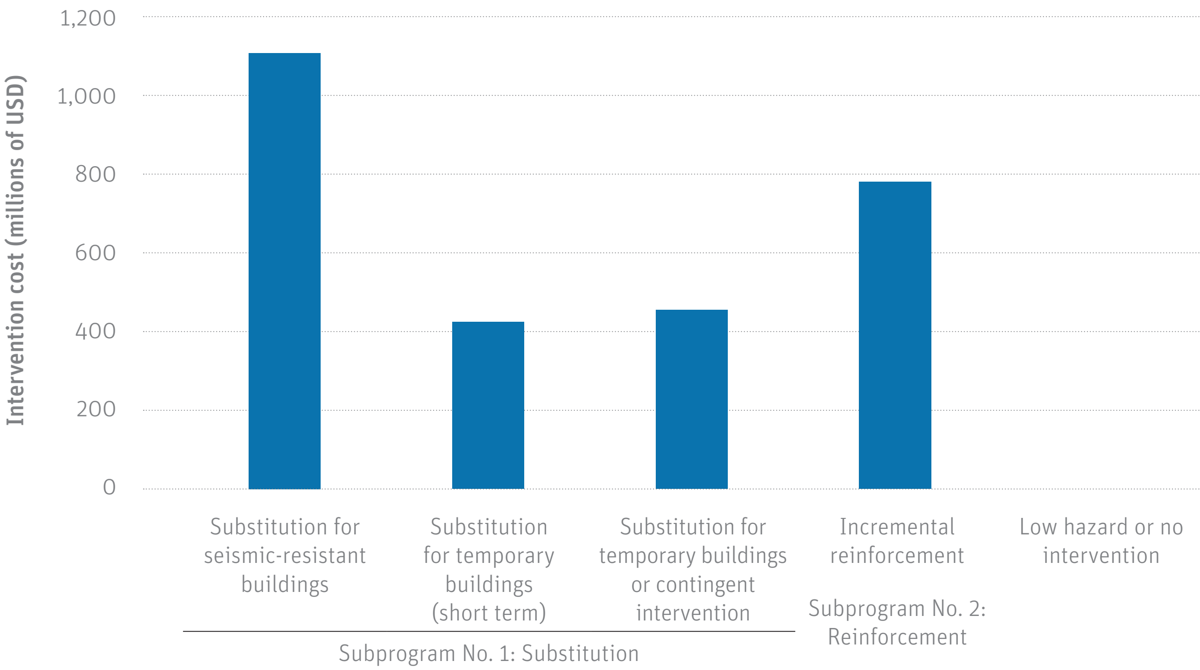


	Urban (High hazard)	Rural (High hazard)	Urban (Intermediate hazard)	Rural (Intermediate hazard)	All low hazard
Subprogram No.1	756	426	356	457	0
Subprogram No.2	546	68	106	62	0

Classification according to geographical location

Figure 6-4 shows the intervention costs according to the subprograms considered and the type of intervention in each case. This table represents the types of interventions recommended in Table 6-2, which takes into account the geographical location and level of risk.

Figure 6-4 Intervention costs according to subprogram and type of intervention



Intervention cost (millions of USD)	1,112	426	457	783	0

Type of intervention

Finally, Table 6-5 shows the financial gap for the 10-year seismic risk reduction program.

Table 6-5 Financial gap summary for the 10-year seismic risk reduction program

Program	No. of buildings	Intervention value (in millions of USD)
Cost of the 10-year program		
Seismic risk reduction program	108,629	2,778
10-year program gap, differentiated by subprogram		
Subprogram No. 1: Substitution	73,645	1,995
Subprogram No. 2: Incremental reinforcement	34,984	783

6.5 SCHOOL FACILITY PRIORITIZATION BY INTERVENTION SUBPROGRAMS

Given the number of school buildings needing intervention within a 10-year period, prioritization criteria concerning school facilities must be defined. The aim is to maximize the cost-effectiveness of the interventions performed as regards the objectives set, particularly the objective of increasing the number of students benefited by the risk reduction measures. To this end, the process below is followed:

a) The cost of the interventions required in each of the school buildings is aggregated at school facility level.

b) The students using the buildings of a given school facility are quantified (CIE).

c) The probabilistic seismic risk analysis is performed, which allows the valuation of the economic loss expectancy by building and by school facility.

d) The seismic risk is reassessed considering the prioritized intervention proposed for each building typology.

e) The cost-effectiveness of interventions is assessed:

$$\frac{S}{C} = \frac{Students_{potential\ in\ the\ facility} * (AAL\%_{before\ intervention} - AAL\%_{post\text{-}intervention})}{Cost\ of\ intervention}$$

On this basis, the order of intervention priority is determined by school facility so as to maximize the benefits of the risk reduction measures according to the number of students. It is necessary to quantify the S/C ratio for each school facility and not for individual buildings, as the intervention unit for the purpose of this study is the school facility.

Priority criteria are consistently applied to each of the intervention programs proposed.

Figures 6-5, 6-6, and 6-7 show the impact of the buildings intervened in Subprogram No. 1 (substitutions) and Subprogram No. 2 (incremental reinforcement) in terms of intervention cost, number of students benefited and AAL percentage reduction at national level. This impact is measured by defining the number of school facilities to be intervened according to the amount of money available to be used in the intervention of school infrastructure.

Figure 6-5 Number of school facilities intervened by investment amount

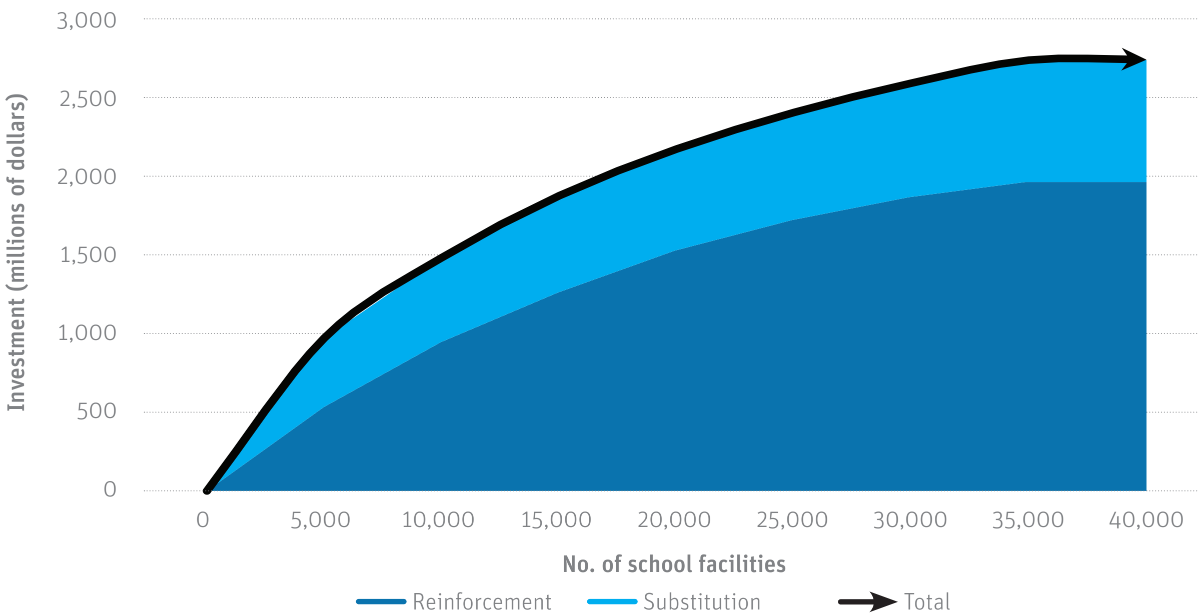


Figure 6-6 Number of students benefited by number of school facilities intervened

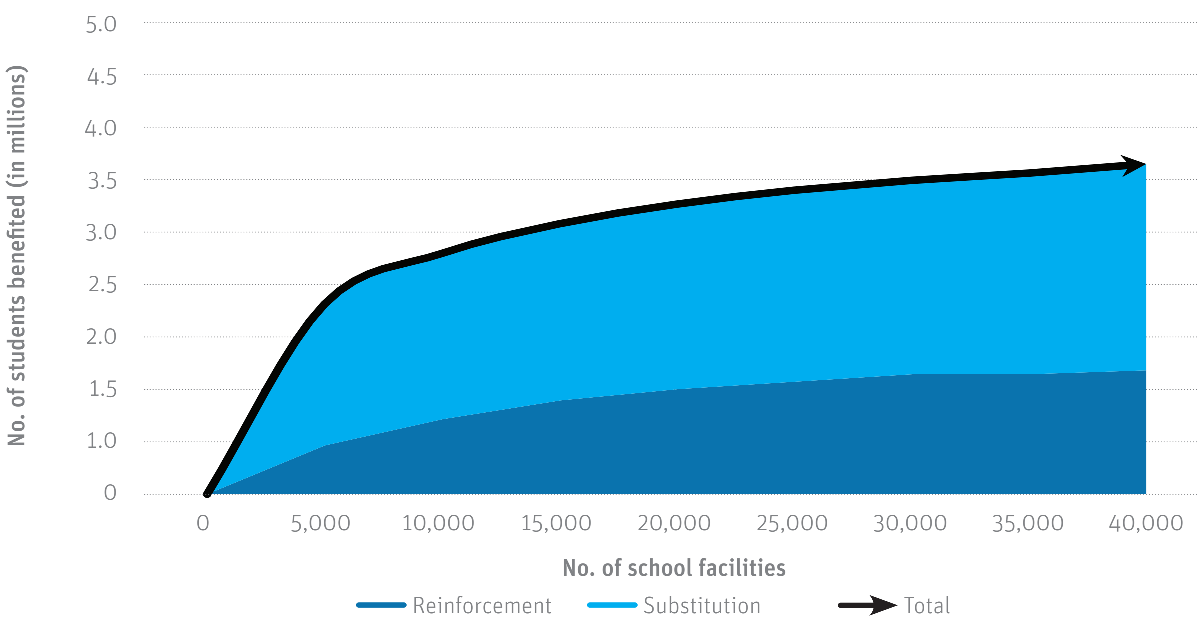
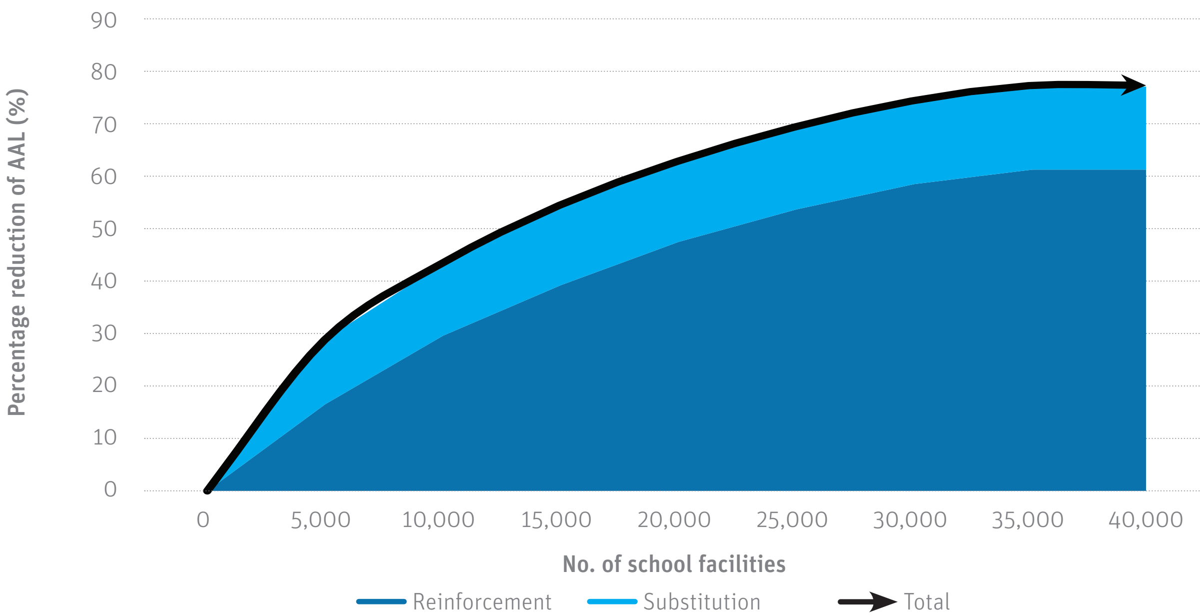


Figure 6-7 AAL percentage reduction by number of school facilities intervened



6.6 DISAGGREGATION OF INTERVENTIONS BY REGION

Following the same procedure of intervention prioritization for each region, the results shown in Table 6-6 were obtained.

Table 6-6 Cost of interventions by department

Department	Total No. of school facilities	Total No. of buildings	No. of HRC buildings	No. of HDP buildings	Total cost (in millions of USD)			
					Inventory	Subprogram 1	Subprogram 2	10-year plan
AMAZONAS	1,648	6,474	3,261	594	241	63	12	75
ANCASH	2,444	12,368	5,331	1,500	559	136	32	168
APURIMAC	1,622	6,879	3,911	526	339	114	13	128
AREQUIPA	1,153	6,902	1,298	2,403	362	32	56	88
AYACUCHO	2,218	9,757	5,154	906	477	142	20	162
CAJAMARCA	3,381	12,710	6,976	1,207	639	188	25	213
CALLAO	236	1,996	205	880	120	7	24	31
CUSCO	2,378	12,159	6,026	1,137	634	176	28	204
HUANCAVELICA	2,068	8,424	3,672	539	379	80	12	92
HUANUCO	2,042	8,572	4,161	799	380	92	17	109
ICA	718	4,147	862	1,283	190	28	24	52
JUNIN	2,577	10,840	4,716	2,075	629	176	62	237
LA LIBERTAD	1,995	9,403	3,798	1,985	484	118	42	160
LAMBAYEQUE	980	4,775	1,504	1,440	214	38	28	66
LIMA	2,910	20,445	4,195	9,139	1,147	174	214	388
LORETO	2,375	5,750	1,507	648	290	22	15	36
MADRE DE DIOS	266	1,303	168	49	59	5	1	6
MOQUEGUA	288	1,930	365	436	83	8	10	17
PASCO	997	3,083	839	651	198	19	19	38
PIURA	2,602	11,494	4,010	3,013	470	105	52	157
PUNO	2,201	12,365	6,273	1,063	567	164	25	190
SAN MARTIN	1,672	7,534	3,041	1,304	312	62	31	93
TACNA	327	2,313	318	311	92	7	6	13
TUMBES	299	1,644	379	582	56	10	7	17
UCAYALI	1,078	4,045	1,675	514	164	30	9	38

For each region, the following specifics were defined:

a) Preliminary[2] prioritized intervention list by school facility

b) Intervention proposals for each building and their estimated cost

c) Aggregate cost of each of the subprograms proposed

2. Final prioritization will be defined when incorporating other non-engineering criteria defined by the MINEDU.

For illustrative purposes, Table 6-7 shows part of the list of school facilities prioritized following the previous criteria for the department of Amazonas. In addition, Table 6-8 shows the detailed list of buildings located in critical facilities.

Table 6-7 Prioritization of school facilities in Amazonas

School facility ID	No. of students	Replacement cost	School facility AAL (without intervention)	School facility AAL (with intervention)	No. of buildings	Total intervention cost (USD)	S/C ratio
6083	180	477,548	16,232	34	5	64,800	3,373
10725	149	387,900	3,145	8	6	10,800	3,357
4442	35	697,789	6,246	9	8	23,200	3,348
6969	438	524,958	9,717	19	11	45,000	3,031
11386	50	1,055,519	15,630	15	5	244,900	2,919
9798	169	677,532	10,094	15	4	62,400	2,890
14281	319	1,524,016	20,659	14	11	236,800	2,792
12630	55	1,344,720	29,460	22	4	300,000	2,789
3225	154	644,345	6,928	11	9	109,500	2,437
8708	236	502,977	4,562	9	8	48,100	2,250

Table 6-8 Disaggregation of prioritized school facility buildings in Amazonas

School facility ID	Province	Area (builtm²)	Structure typology	Exposed value	Type of intervention	Cost of intervention	Students by building
6083	CONDORCANQUI	240	780-POST	103,440	None	–	39
6083	CONDORCANQUI	400	P	172,400	Substitution with other systems	40,000	65
6083	CONDORCANQUI	200	P	86,200	Substitution with other systems	20,000	32
6083	CONDORCANQUI	48	P	20,688	Substitution with other systems	4,800	8
6083	CONDORCANQUI	220	780-POST	94,820	None	–	36
10725	RODRIGUEZ DE MENDOZA	80	780-POST	34,480	None	–	13
10725	RODRIGUEZ DE MENDOZA	480	780-POST	206,880	None	–	79
10725	RODRIGUEZ DE MENDOZA	40	780-POST	17,240	None	–	7
10725	RODRIGUEZ DE MENDOZA	64	780-POST	27,584	None	–	11
10725	RODRIGUEZ DE MENDOZA	128	780-POST	55,168	None	–	21
10725	RODRIGUEZ DE MENDOZA	108	A	46,548	Substitution with other systems	10,800	18
4442	CONDORCANQUI	50	P	21,550	Substitution with other systems	5,000	9
4442	CONDORCANQUI	10	W	4,310	Substitution with other systems	1,000	2
4442	CONDORCANQUI	15	P	6,465	Substitution with other systems	1,500	3
4442	CONDORCANQUI	126	780-POST	54,306	None	–	22

The following figures, which are part of the implementation plan for each of the regions, were created with the information above. For illustrative purposes, comparative charts between two regions, Lima and Amazonas, are shown, which make evident the regional differences that may appear in the implementation of the plan.

Figure 6-8 Comparison of results for Lima and Amazonas

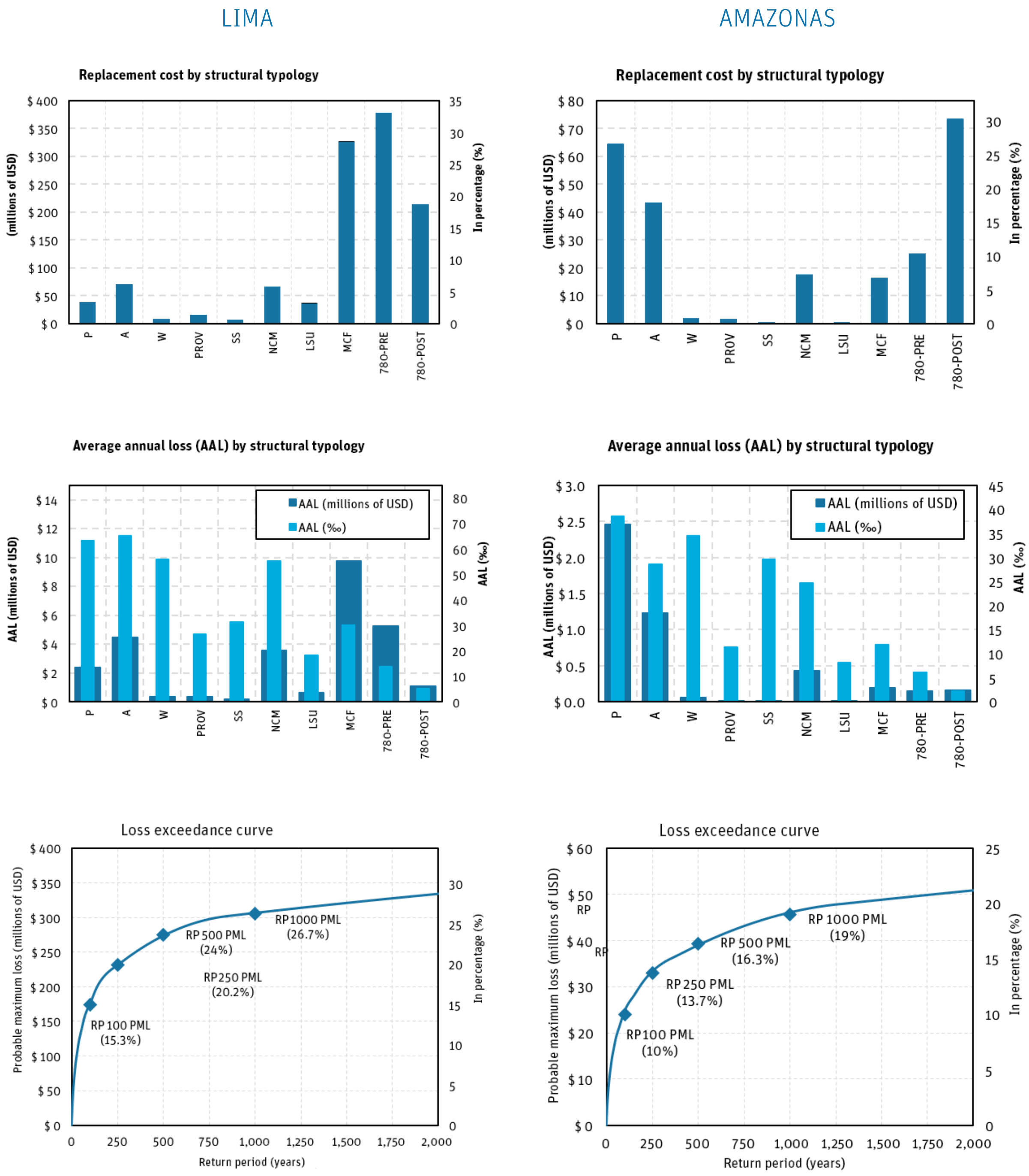


Figure 6-8 Comparison of results for Lima and Amazonas

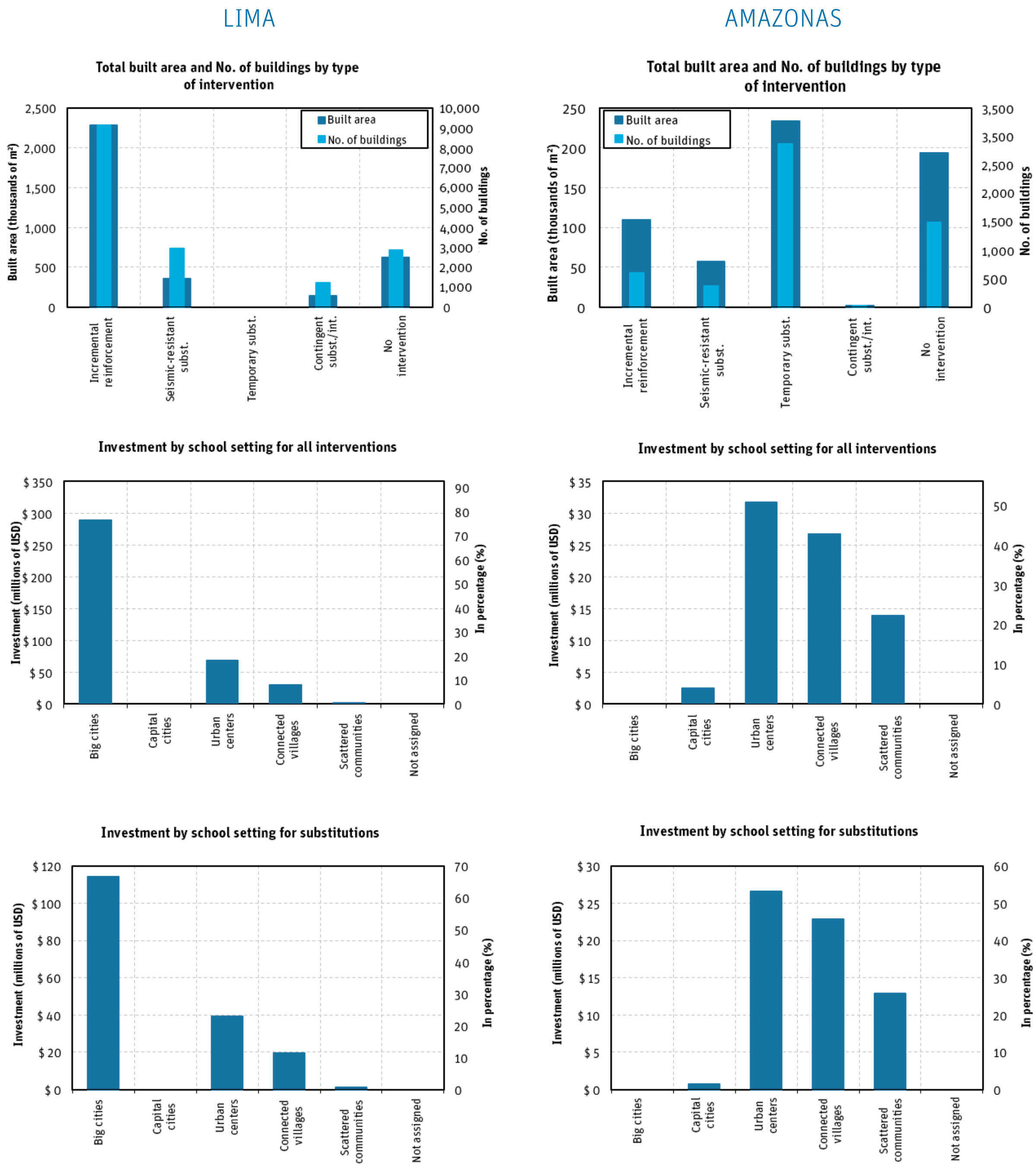


Figure 6-8 Comparison of results for Lima and Amazonas

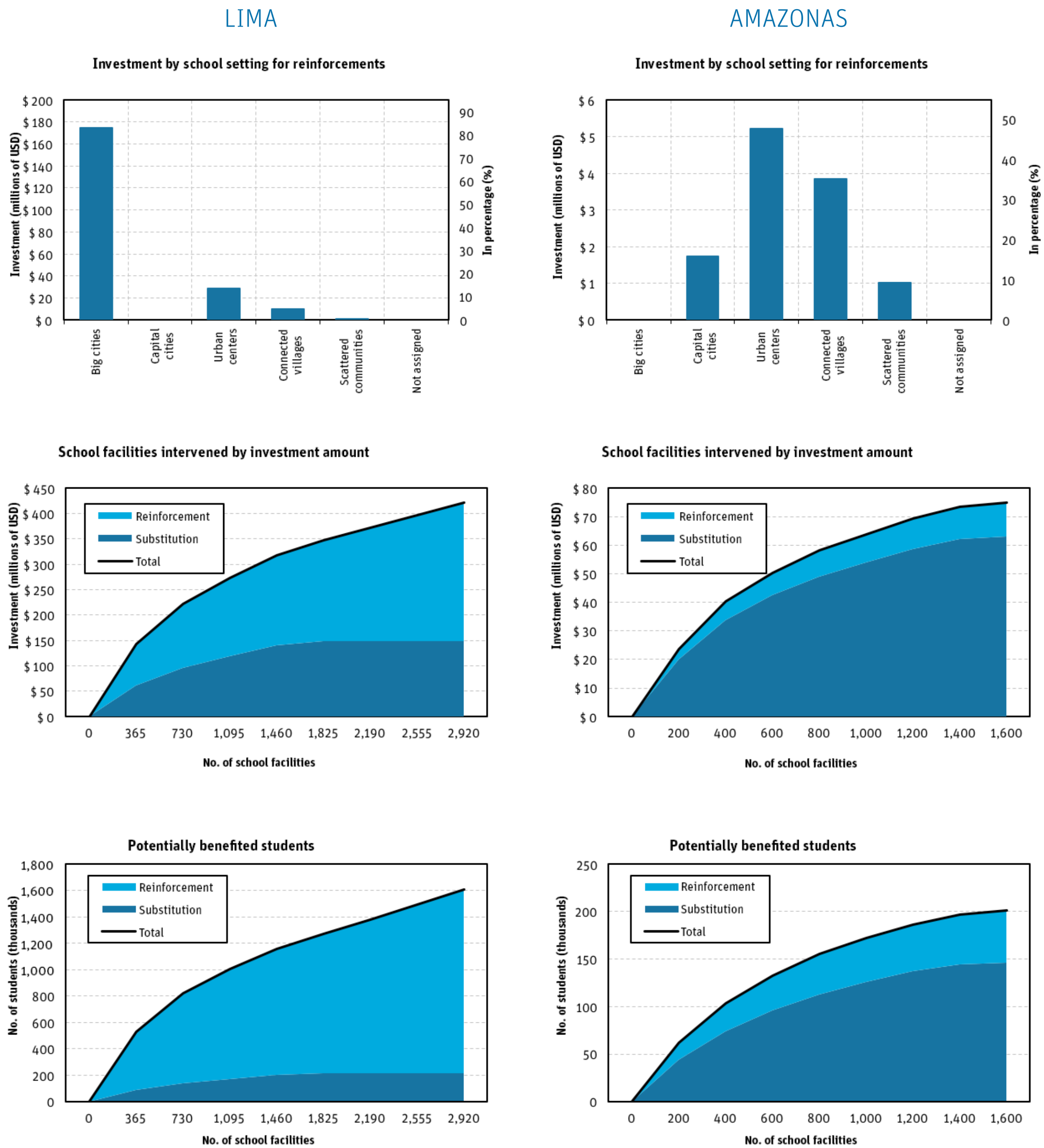
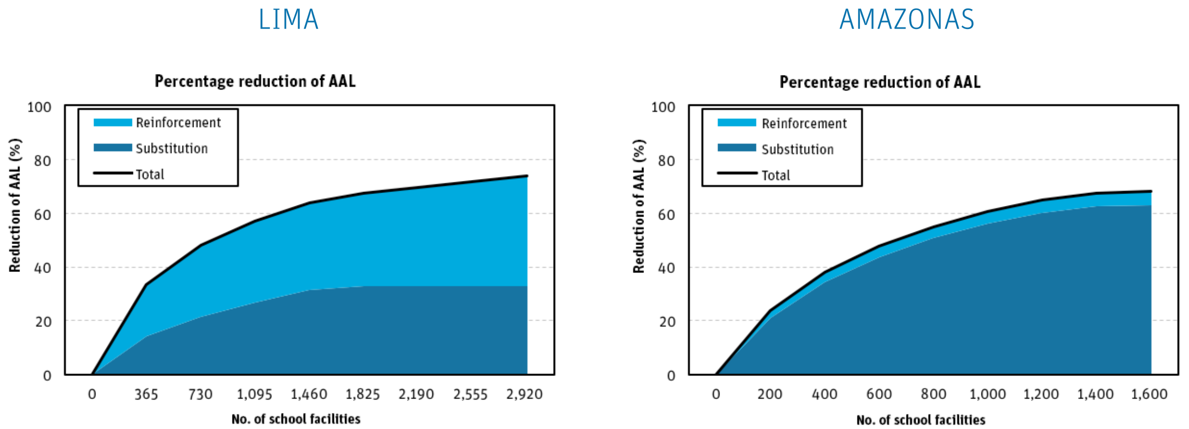


Figure 6-8 Comparison of results for Lima and Amazonas



Based on this information, the regional governments may do the following:

1. Given an amount of available resources, carry out an initial tentative distribution among the intervention subprograms proposed.
2. Quantify the following three parameters according to the desired investment in each program:
   - Impact on the number of students benefited by interventions
   - Risk percentage reduction as regards initial risk
   - Number of school facilities or buildings intervened
3. Redistribute the amounts by program until coming to a high impact solution with specific criteria for the region.
4. Check the list of school facilities prioritization in order to identify the geographical location and the characteristics of the facilities included. In particular, the list indicates the type of intervention recommended and the estimated budget for each building.
5. Set the terms for the execution of specific intervention projects and commission the final designs and intervention works.

In order to simplify and facilitate the organization of information and its dissemination, several formats were designed, including basic information for each of the regions. Annex 6.1 includes a typical format for illustrative purposes.

CONCLUSIONS

The analyses made in the present study allow for a series of conclusions to be drawn as regards the elements that have to be considered in the design and implementation of a seismic risk reduction strategy for school facilities. Those elements are listed below.

a) The main objectives of the seismic risk reduction plan for school infrastructure are the following:
   - Reducing the risk of death or injuries in the community resulting from seismic events (maximizing the number of benefited students).
   - Minimizing damages to the infrastructure and protecting the property.
   - Reducing educational services disruption.

b) The level of seismic risk identified in the study allows for the classification of the school infrastructure inventory into buildings with high risk of collapse, high damage potential, and good seismic performance.

c) The Government of Peru faces a significant challenge as 51% of the buildings belong to the building typologies with high risk of collapse and 21% of the buildings have high damage potential.

d) Based on this categorization, the study suggests the corresponding programs of substitution, reinforcement and contingent intervention as strategies to reduce seismic risk. As part of the reinforcement program, the implementation of incremental reinforcement is suggested as an innovative and economical technique promoted by the World Bank.

e) The direct costs assigned according to the program, climatic zone and school setting allow to estimate that the financial gap that the Government of Peru will have to bridge in the next 10 years amounts to USD 2,778 millions.

f) The average annual loss enables the quantification of risk at building, facility, district, provincial, and regional level. This information provides a baseline which is distributed throughout the territory, and constitutes a tool for policy decision-making at the national and subnational levels.

g) The average annual loss before and after the intervention, the number of students, and the intervention cost may be combined in a prioritization criterion that maximizes cost-effectiveness given the size of the inventory (187,312 buildings) and the country's economic limitations.

h) The average annual loss of the inventory amounts to USD 190 millions, which, in relative terms, equals 2.1% of its replacement cost. This loss does not include loss of content, nor indirect losses derived from the disruption to operations and loss of profit. In comparison to the analysis of similar inventories, this figure is relatively high, which is attributed to the high seismic hazard and the high vulnerability of most of the inventory components.

i) Risk is not uniformly distributed in the inventory. The first 15,000 school facilities (38%) concentrate more than 55% of the risk. The distribution of the average annual loss in the country shows that most southern regions, the capital city and one northern region have the highest seismic risk (which amounts to between USD 10 millions and USD 28 millions). The average annual loss is critical in adobe school buildings and in the country's rural areas classified as connected villages.

j) The probable maximum loss for events with a return period of 1,000 years is USD 739 millions, which correspond to approximately 8% of the inventory replacement cost. This figure is also high in comparison with equivalent inventories from other regions and countries.

k) The risk metrics estimated for each region are systematized in formats with graphics and maps that facilitate communication and the drafting of intervention strategies.

l) The main components of the intervention plan are as follows:

   - Criteria applied to the definition of the interventions for the different building typologies identified
   - An estimate of the economic investment for seismic risk mitigation (financial gap) and the definition of an investment plan in line with budget availability
   - The definition of the optimal intervention strategy
   - Prioritization criteria for each intervention line proposed, which may allow for the maximization of the stated objectives in relation to risk reduction
   - Organization of the technical information required to implement the action plans by region

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ANNEX 6.1

Typical Format for a Region with Information of the Seismic Risk Reduction Strategy

SEISMIC RISK REDUCTION STRATEGY FOR SCHOOL INFRASTRUCTURE IN PERU
Region: Amazonas

SUMMARY OF THE OPTIMAL INTERVENTION STRATEGY PROPOSED

General objective and scope

This document offers an overview of the bases for the design and implementation of regional programs for seismic risk reduction of the school infrastructure in Peru with the aim of achieving the following objectives and priorities:

1. Reducing the risk of death or injuries in the community resulting from seismic events.
2. Minimizing damages to the infrastructure and protecting the property.
3. Reducing educational services disruption.
4. Benefiting the largest number of students from the seismic risk reduction perspective.

As a result, the following priorities related to the direct impact on school infrastructure are defined:

- Reducing total or partial risk of collapse.
- Reducing impacts on non-structural elements.
- Reducing impacts on building's content and equipment.

The regional programs for seismic risk reduction of school infrastructure are set forth within the framework of the 2015 National School Infrastructure Plan (PNIE). The programs are based on an optimal intervention strategy for risk reduction in the main buildings located in critical school facilities. For each of the regions in the country, a prioritized order of intervention by school facility is presented in order to attain the maximum cost-effectiveness in achieving the above mentioned objectives and priorities. Based on the reference budget available, each regional government will be able to select one or more priority intervention programs and define the number of school buildings and facilities which may be intervened in each program.

The methodology applied allows to respond the following specific questions:

1. How should resources be invested sensibly and efficiently in order to maximize the achievement of seismic risk reduction objectives in the school infrastructure of each region in Peru?
2. Which school facilities and buildings should be prioritized?
3. How many resources are needed to carry out the intervention of the whole inventory?
4. How to select the intervention program, and what is its scope with the available budget?
5. Which are the terms for the prospective commissioning of the final designs and reinforcement works?

Limitations and considerations

The intervention strategy for seismic risk reduction in the Peruvian school infrastructure is based on the following limitations and considerations:

a) The information used is taken from the School Infrastructure Census (CIE, 2013).

b) For the seismic risk analysis, reference replacement costs are used, which take into account the geographical location and how easy or difficult it would be to perform a substitution in that area.

c) Economic valuations for the different possible types of interventions are used. The following reference nominal values are used:

– Substitution for seismic-resistant buildings (use of temporary classrooms)	300-450 USD/m^2 + extras
– Substitution for any kind of acceptable structural system (short term)	30% of replacement cost + extras
– Temporary acceptable substitution (short term) or contingent intervention	30% of replacement cost + extras
– Incremental reinforcement[3]	30% of replacement cost

d) Cost variations associated with particular macroeconomic conditions have not been taken into account, for example, those appearing after the occurrence of catastrophic events due to shortage of materials and skilled labor.

e) Typical intervention alternatives, according to the experience of the PRONIED, are considered. No new options of intervention have been studied, except for the incremental reinforcement proposed for the 780-PRE systems.

3. Incremental reinforcement of 780-PRE: Reinforcement of the building in order to prevent collapse and protect lives. More than one stage is required to fully comply with design regulations.

Recommended optimal intervention strategy

The recommended intervention strategy is based on the following:

a) The buildings selected are those requiring some kind of intervention and that may bring about an effective seismic risk reduction.

- Buildings located in low seismic hazard areas are not included.
- Only buildings with uses involving high-occupancy are included.

b) Each building is assigned a single level of intervention according to its **location** and its **structural typology**, which may be any of the following:

- **High risk of collapse (HRC).** Substitution is defined as the level of intervention required given a **high risk of collapse** in intermediate or high intensity seismic events. Experience shows that the prospective intervention of such buildings implies big technical difficulties, high costs and few guarantees of achieving acceptable levels of seismic resistance. Mainly buildings located in high seismic hazard areas.
- **High damage potential (HDP).** Reinforcement is defined as the level of intervention for building typologies with **high damage potential** whose structural intervention is feasible from the technical, functional and economic points of view. Within this level of intervention, the incremental reinforcement is considered a feasible solution (which would allow to reduce the probability of collapse and the loss of human lives, without necessarily fulfilling all the requirements of the current regulations).

c) **Prioritization** is based on the expected cost-effectiveness **(C/E)**, which is an indicator that allows to assess the efficiency in reducing impacts on students due to seismic risk in light of economic investments determined by school facility in the form of substitution or reinforcement works.

d) The 10-year intervention plan is set forth as follows:

- Program of seismic risk reduction/Intervention by school facility:
  - Intervention subprogram No.1: Substitution of buildings with high risk of collapse.
  - Intervention subprogram No. 2: Reinforcement of buildings with high damage potential.

e) The following **procedure for the definition of the scope of the investment program** is proposed:

1. Defining the total amount of available resources and tentatively dividing it into the intended subprograms.
2. Using the figures attached to quantify the following three parameters according to the investment aimed at in each program:
   - Risk percentage reduction as regards initial risk
   - Impact on the number of students benefited by interventions
   - Number of school facilities or buildings intervened
3. Redistributing the amounts by program until coming to a high impact solution with specific criteria for the region.

4. Checking the list of school facilities prioritization in order to identify the characteristics of the facilities included. In particular, the list indicates the type of intervention recommended and the estimated budget for each building.
5. Based on the above, setting the terms for the execution of specific intervention projects and commissioning the final designs and intervention works.

CONVENTIONS USED IN THE DOCUMENT

Naming conventions for structural systems	
Structural system name	**Structural system code**
Precarious	P
Adobe	A
Wood	W
Provisional classroom	PROV
Steel structure	SS
Non-confined masonry	NCM
Large school unit	LSU
Reinforced concrete frames with or without masonry walls	RCF
780-PRE module	780-PRE
780-POST module	780-POST

Naming conventions for provinces		
Province name	**Province code**	**No. of students**
CHACHAPOYAS	CHAC	13,033
BAGUA	BAG	24,742
UTCUBAMBA	UTC	28,802
CONDORCANQUI	COND	21,827
BONGARA	BONG	6,043
LUYA	LUYA	12,602
RODRIGUEZ DE MENDOZA	ROD	6,029

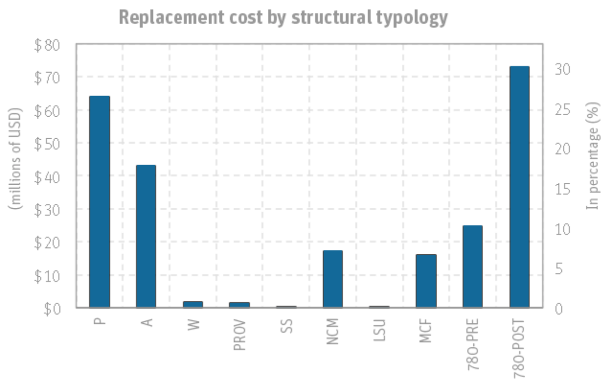
Naming conventions for works executing entities	
Executing entity name	**Executing entity code**
PA/Self-construction	PA
Private company	PC
Development partners	DP
National government/Special project	NG
Regional/Local government	RG

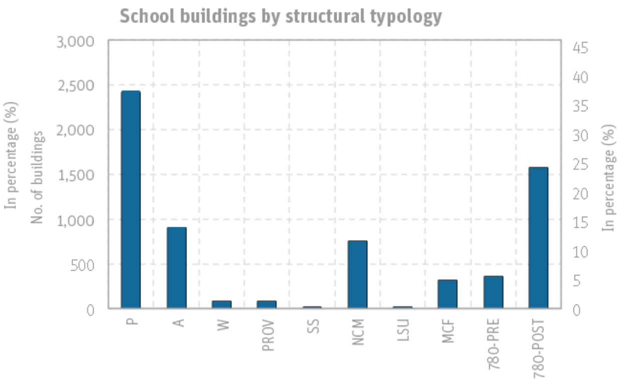
Naming conventions for school settings		
Setting	**Description**	**Zone**
1	Big cities	Urban
2	Capital cities	Urban
3	Urban centers	Urban
4	Connected villages	Rural
5	Scattered communities	Rural

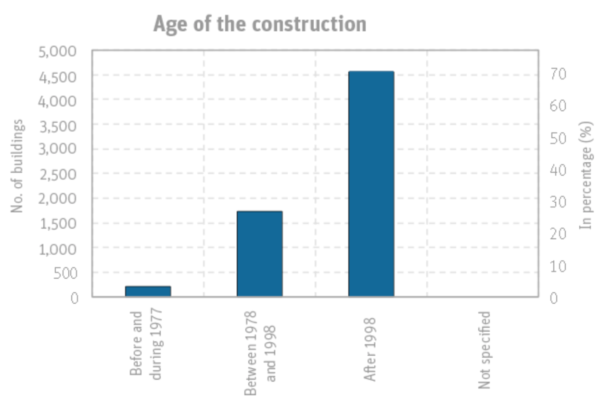
Naming conventions for types of intervention	
Type of intervention	**Intervention code**
Incremental reinforcement	Incremental reinforcement
Substitution for seismic-resistant buildings	Seismic-resistant subst.
Short-term substitution for temporary buildings	Temporary subst.
Temporary substitution or contingent intervention	Subst./ Contingent Int.
No intervention	No intervention

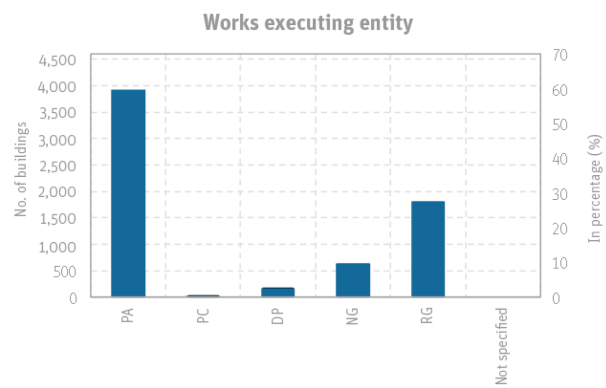
GENERAL EXPOSURE INFORMATION

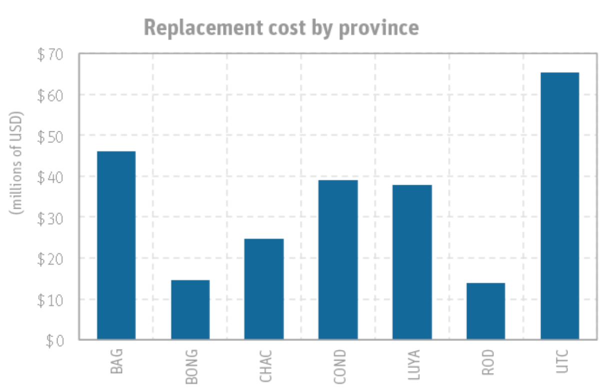
Number of Inhabitants	375,993	Total school facilities	1,648
Surface Area (km^2)	39,249	Total buildings	6,474
Built Area (m^2)	651,840	Replacement cost (millions of USD)	241.2

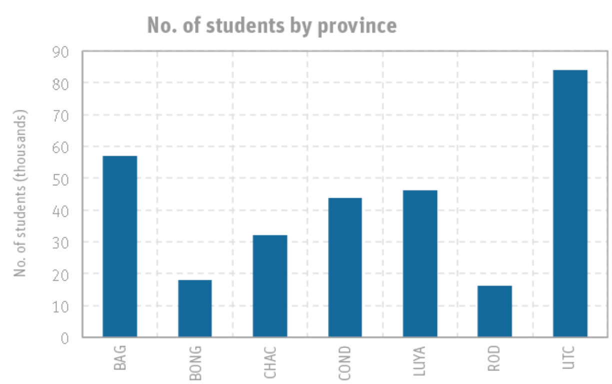






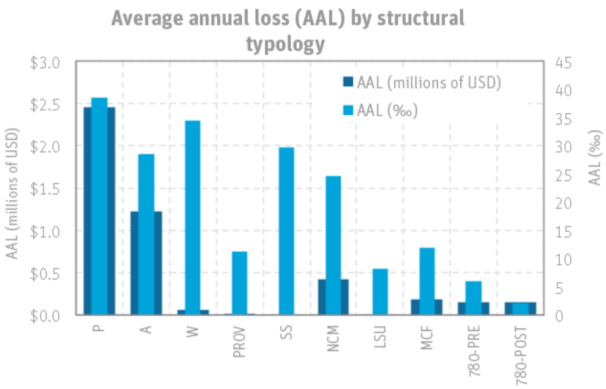


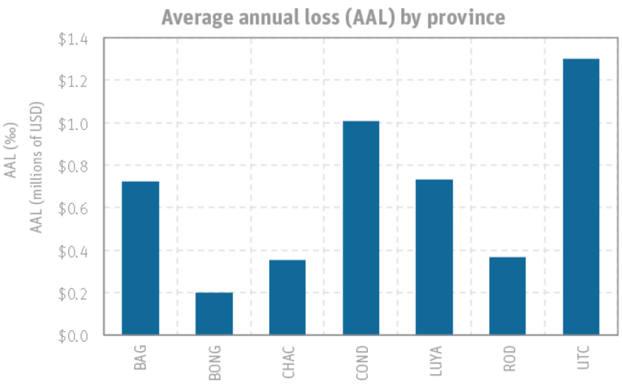


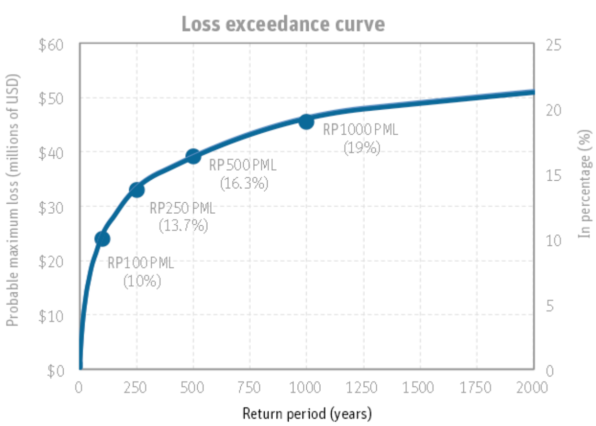


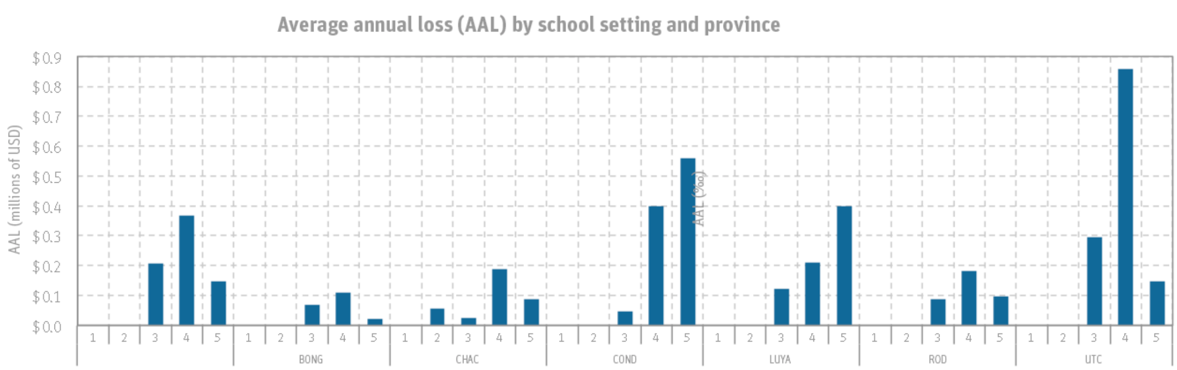
SUMMARY OF SEISMIC RISK ANALYSIS RESULTS

Number of inhabitants	375,993	Replacement cost (millions of USD)	241.2
Total school facilities	1,648	AAL (millions of USD)	4.7
Total buildings	6,474	AAL (‰)	19.5





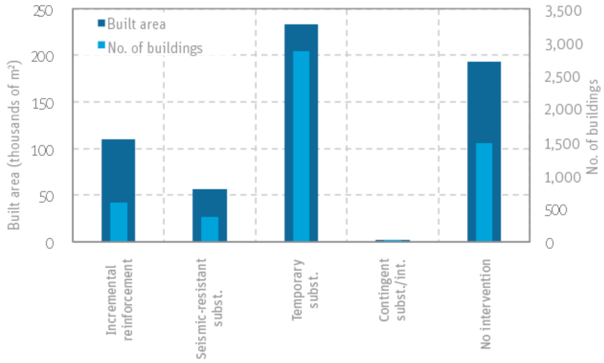




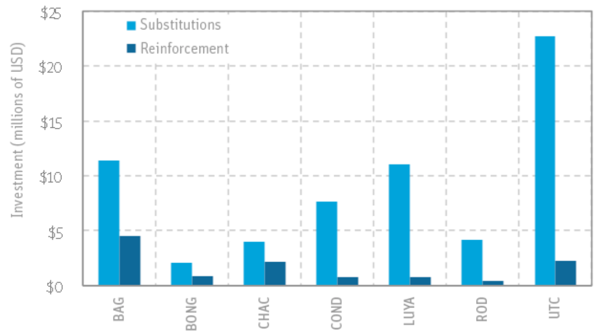
SUMMARY OF INTERVENTIONS

No. of buildings to be reinforced	594	Investment in reinforcement work (millions of USD)	11.8
No. of buildings to be substituted	3,261	Investment in substitutions (millions of USD)	63.1
Total buildings to be intervened	3,855	Total investment (millions of USD)	74.9

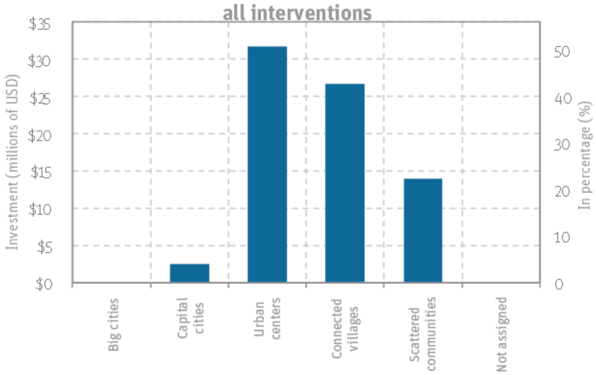
Total built area and No. of buildings by type of intervention



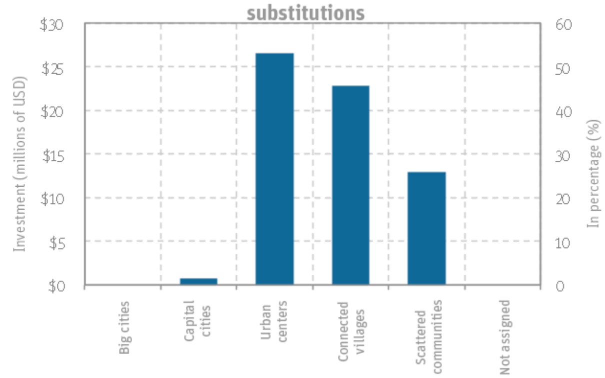
Total investment by province and type of intervention



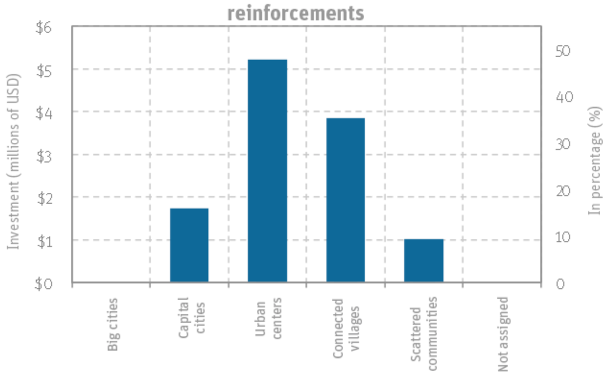
Investment by school setting for all interventions



Investment by school setting for substitutions



Investment by school setting for reinforcements



RISK MITIGATION STRATEGY

SEISMIC RISK REDUCTION PROGRAM: INTERVENTION BY SCHOOL FACILITY

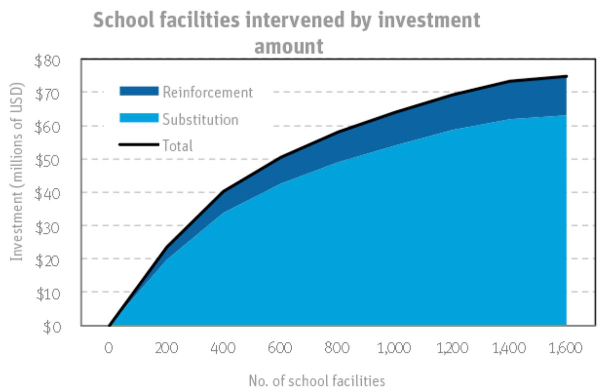
Financial gap

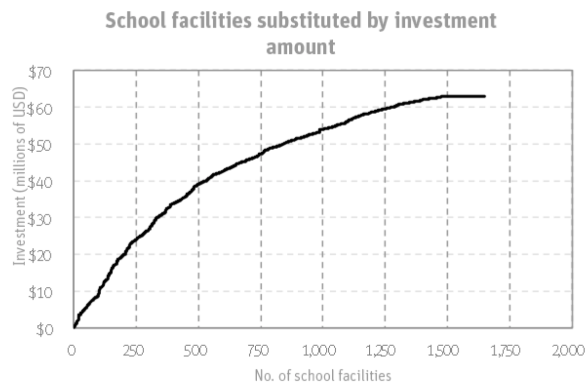
Type of intervention	No. of buildings	Investment (millions of USD)
Reinforcement	594	USD 11.8
Substitutions	3,261	USD 63.1
Total	**3,855**	**USD 74.9**

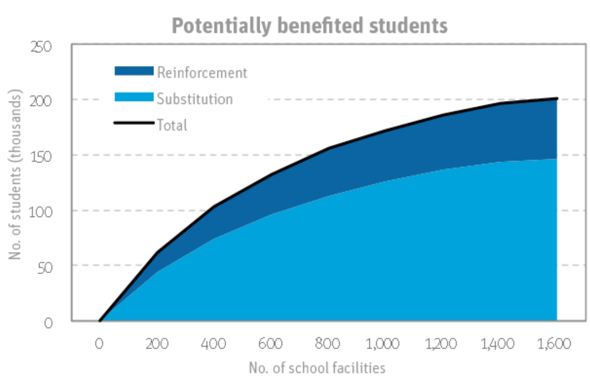
INTERVENTION SUBPROGRAM No. 1: SUBSTITUTIONS

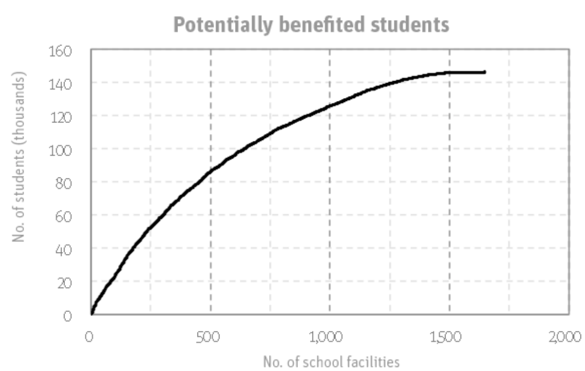
Financial gap

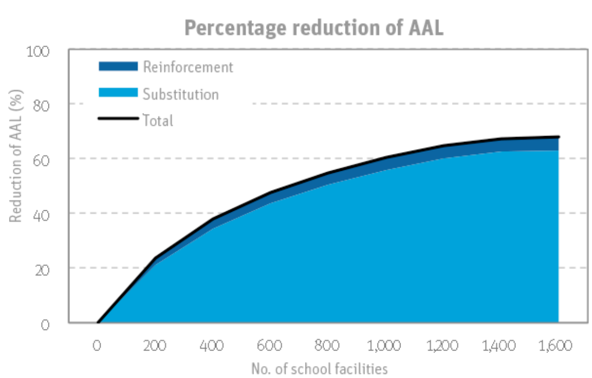
Type of intervention	No. of buildings	Investment (millions of USD)
Reinforcement	0	USD 0
Substitutions	3,261	USD 63.1
Total	**3,261**	**USD 63.1**

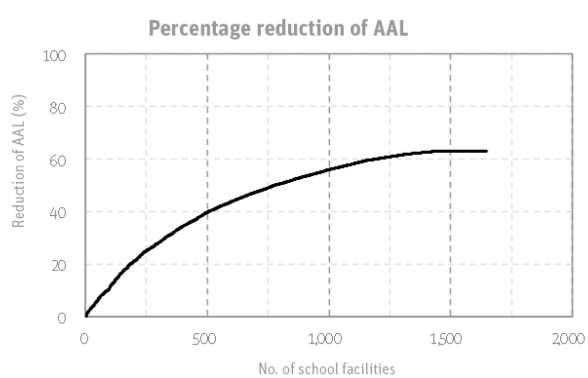










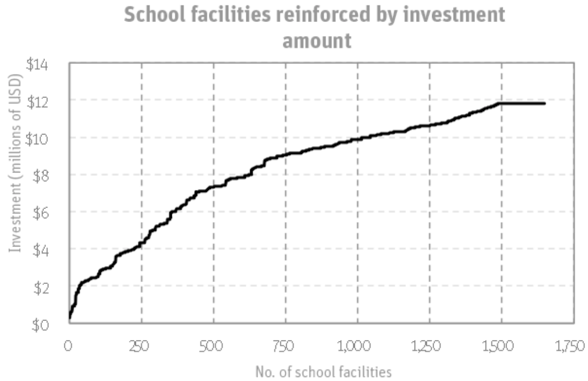


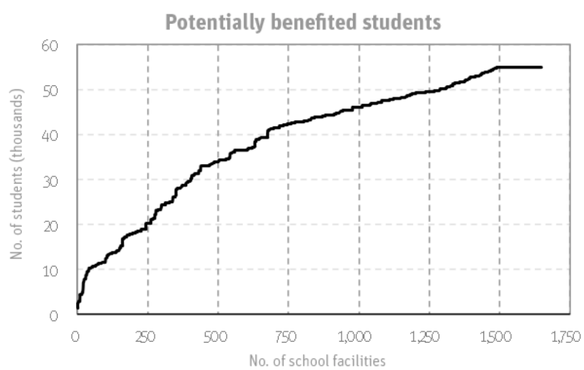
RISK MITIGATION STRATEGY

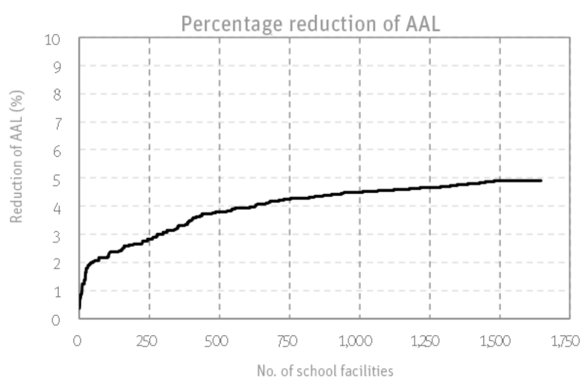
INTERVENTION SUBPROGRAM No. 2: INCREMENTAL REINFORCEMENTS

Financial gap

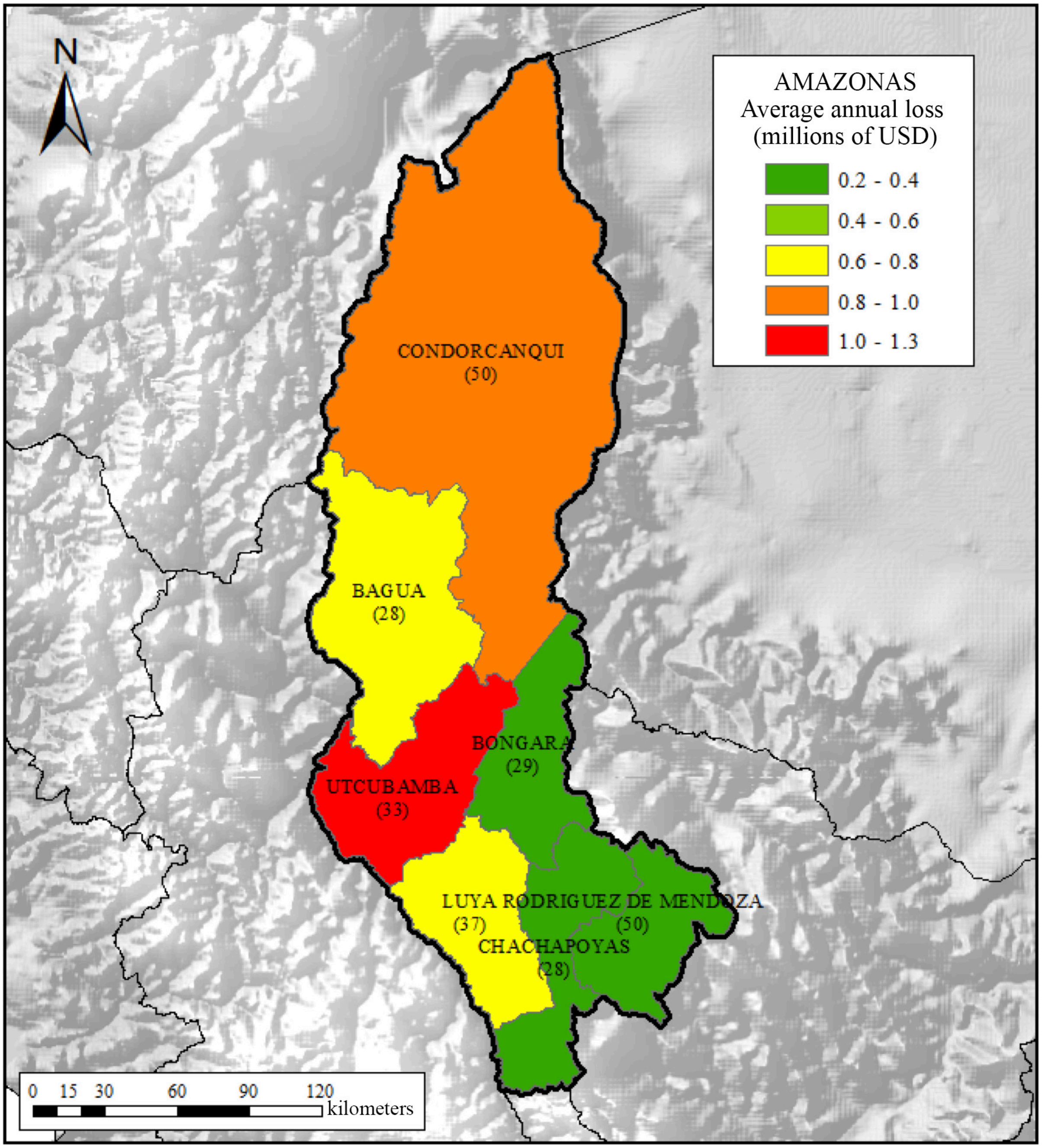
Type of intervention	No. of buildings	Investment (millions of USD)
Reinforcement	594	USD 11.8
Reconstruction	0	USD 0
Total	**594**	**USD 11.8**







ILLUSTRATIVE MAP



Note: The colors of each province correspond to the AAL in monetary value, and the value between brackets corresponds to the relative AAL per thousand. The latter is calculated as follows: AAL (‰) = AAL(USD)*1,000/exposed value (USD).

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