Technical Note

Seismic Risk Reduction Strategy for Public School Buildings in Peru

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Cover photo: “Emblematic educational institution Alfonso Ugarte, built in 1927 and structurally reinforced in 2010”
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FOREWORD

In August 2007, an earthquake with a magnitude of 7.8 (MW) 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 to support and provide technical assistance to 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.

This note presents a summary of the seismic risk assessment of the school infrastructure countrywide and a strategy for reducing its vulnerability. This study 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 given the need to make interventions in tens of thousands of school buildings, either for seismic retrofitting or replacement, this study provides an example on the approach, methodology and design of a seismic risk reduction strategy which may be useful for other countries with similar conditions.

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1. INTRODUCTION

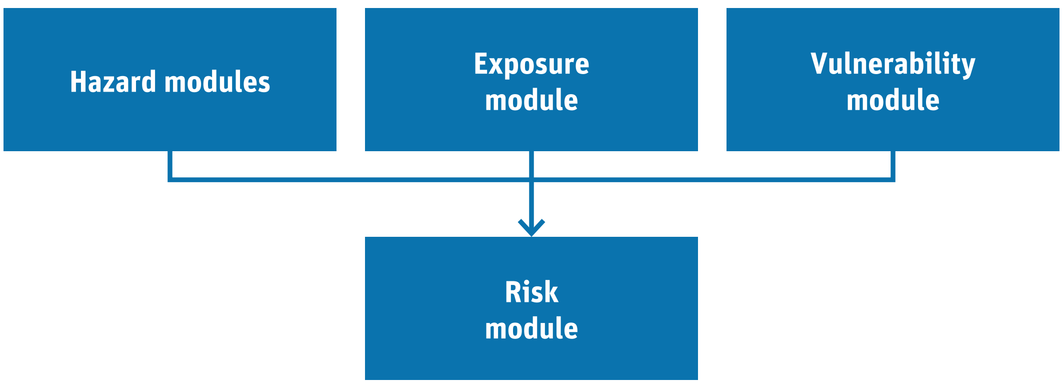
The Ministry of Education of Peru (MINEDU), through the General Directorate for School Infrastructure (DIGEIE), prepared the National School Infrastructure Plan to 2025 (PNIE). Within this framework, the MINEDU commissioned the National Institute of Statistics and Information (INEI) with carrying out the School Infrastructure Census (CIE) [1] which started on September 2013 and was completed in 2014. 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 to reduce seismic vulnerability and for the formulation of the PNIE. Under this program, a nationwide probabilistic seismic risk assessment of school infrastructure was carried out, which constitutes the basis for defining the seismic risk reduction strategies and for setting intervention priorities to optimize the required investments. In turn, the risk reduction strategy aims mainly to reduce the risk of death or injuries in the educational community to reduce damages to the property and infrastructure, and to minimize disruption of the educational services in the event of an earthquake.

2. SUMMARY OF THE METHODOLOGY

The probabilistic seismic risk assessment of the Peruvian public school infrastructure requires quantifying the seismic hazard in the area under analysis, having a thorough knowledge of the exposed components and their replacement cost, and having detailed information on the seismic vulnerability of the main structural typologies.

The probabilistic risk assessment considers the whole range of potential events that may occur in the future. In the risk assessment process, the probabilistic models take into account uncertainties which are inherent to the analytical models, and to the severity and frequency of occurrence of events. The risk model is the result of the integration of various modules associated to hazard, exposure and vulnerability, as illustrated in Figure 2-1. Reference 2 presents the detailed methodology for the analysis of risk derived from seismic events.

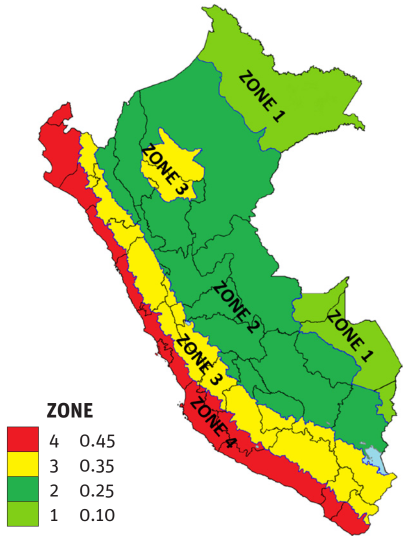
Figure 2-1 **General outline of the probabilistic risk analysis**



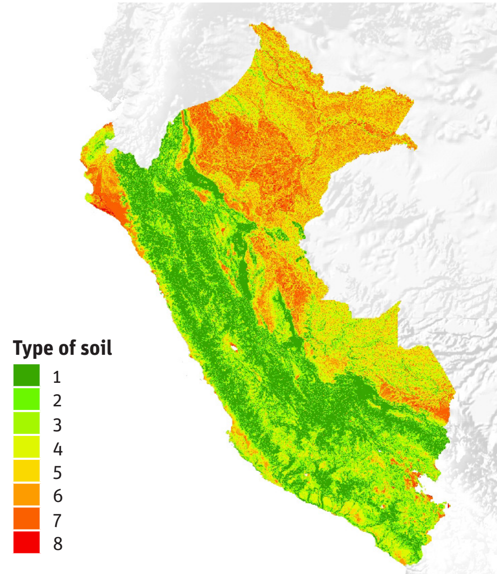
2.1 SEISMIC HAZARD

Seismic hazard is depicted using maps of distribution of the seismic intensity parameters, such as peak ground acceleration or peak acceleration of school buildings. Due to its influence, seismic hazard should include the effects of soil deposits in each particular location. Intensity maps are assessed for a sufficiently wide set of possible events that might occur, taking into account the possible magnitude ranges in the different seismic sources and the relative distances between these and the buildings under analysis. As regards this case, the seismic intensity considered for the analysis is the peak acceleration response of each structural typology. Moreover, every event is characterized by the annual average frequency of occurrence, which is obtained from the analysis of the historical frequency of events. Figure 2-2 shows the seismic hazard zones defined by the National Building Code (RNE) [3] updated in the year 2016, and the zoning proposed at country level in order to consider the soil dynamic amplification effects according to the different soil types (from 1 to 8 in accordance with Reference 4), where type 1 soil is the hardest, and type 8 soil is the softest.

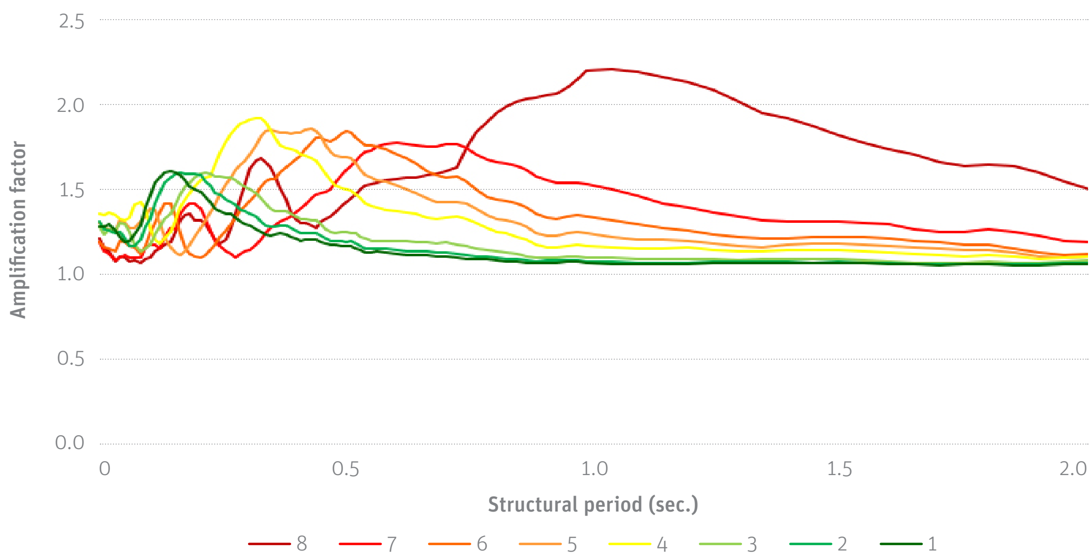
Figure 2-2 Seismic hazard zoning and soil dynamic amplification effects



a) Map of seismic hazard in RNE (2016): Peak ground accelerations without amplification



b) Classification of Peruvian soils according to methodology Vs30 [4]



c) Final amplification spectra for the eight types of soil defined

2.2 EXPOSURE

Exposure is calculated based on a georeferenced database of the exposed school buildings which may sustain damages due to the occurrence of seismic events. The information gathered includes: ID, geographical location, replacement cost and associated seismic vulnerability function. Additionally, for the purpose of evaluating vulnerability, information regarding the structural system, height, level of seismic-resistant design (seismic code level), quality of the design and construction is included, as well as supplementary information of each school building. Replacement costs are defined according to the geographical location and the school setting[1] of each school facility, and are based on the statistical analysis of the information available regarding direct construction costs (see Reference 5).

Table 2-1 provides a quantitative and economic description of the exposure of public school infrastructure to earthquakes in Peru.

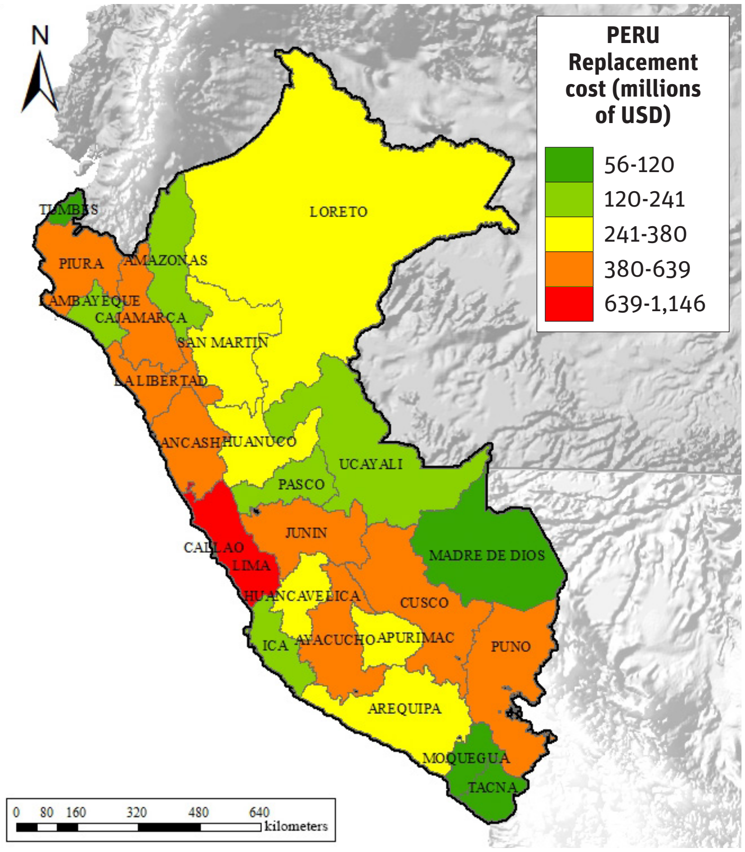
Table 2-1 Exposure of school infrastructure to earthquakes

Characteristics	Value
Number of public school facilities	40,475
Total number of buildings	187,312
Number of buildings for educational use[2]	152,660
Economic valuation of buildings for educational use	USD 8.4 billion

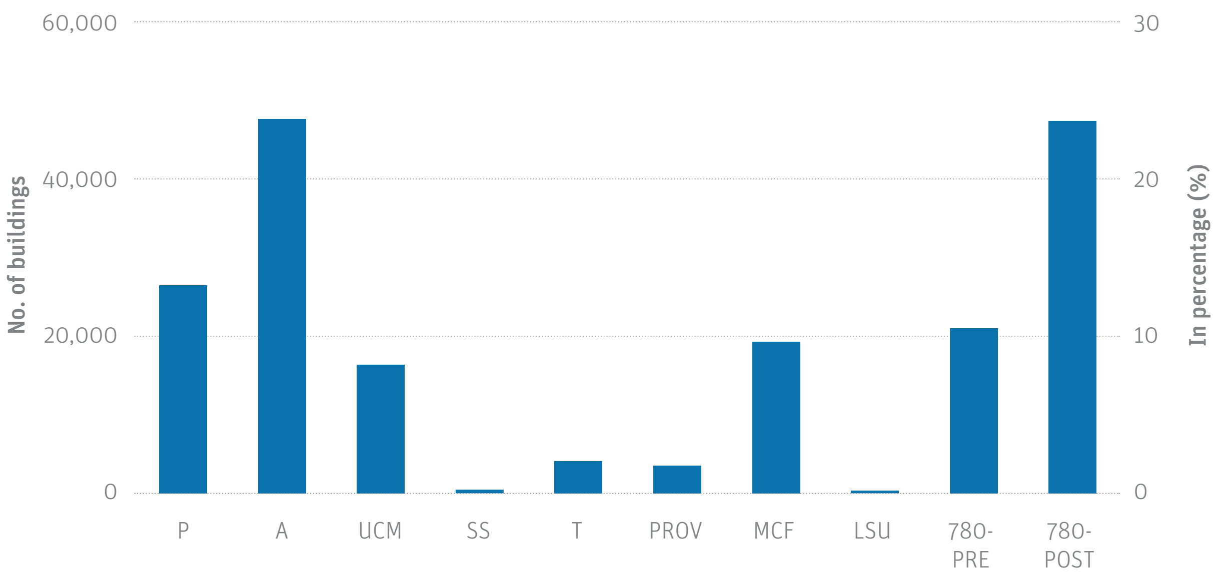
Figure 2-3 shows the distribution of the replacement costs by country regions and by structural typology for the complete inventory of buildings. The predominant structural typologies are the following: P = Precarious; A = Adobe; UCM = Unconfined masonry; SS = Steel structure; T = Timber; PROV =Provisional; MCF = Concrete frames with masonry walls built by Parents' Associations (APAFAs); LSU = Large school units; 780-PRE = 780 modular system built before the 1998 seismic standard; and 780-POST = 780 modular system built after the 1998 seismic standard. Modular 780-PRE buildings are especially relevant, as they include all the buildings with moment resisting reinforced concrete frames built between 1978 and 1997 by the national or regional governments according to the CIE. As regards their seismic response, they are characterized by a great flexibility and problems with their short columns, which lead to an anticipated structural failure in case of seismic events.

1. The methodology applied to cost estimation took into account an adjustment in the urban-rural distribution considering five school settings: big cities, mid-size cities, urban centers, connected villages, and scattered communities.
2. Buildings with lower occupancy (such as warehouses, storage rooms, restaurants, security booths, staircases, among others) are excluded from the group of "buildings for educational use".

Figure 2-3 Replacement cost by region and structural typology



a) Distribution of replacement cost by department



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%

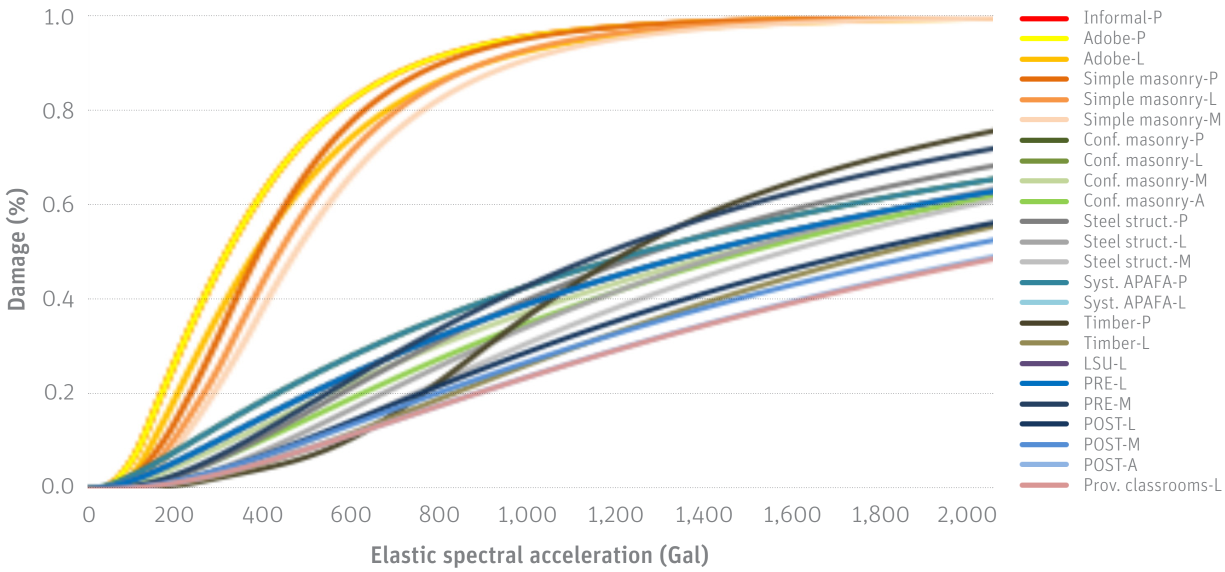
b) Distribution of exposure value at national level according to structural typology

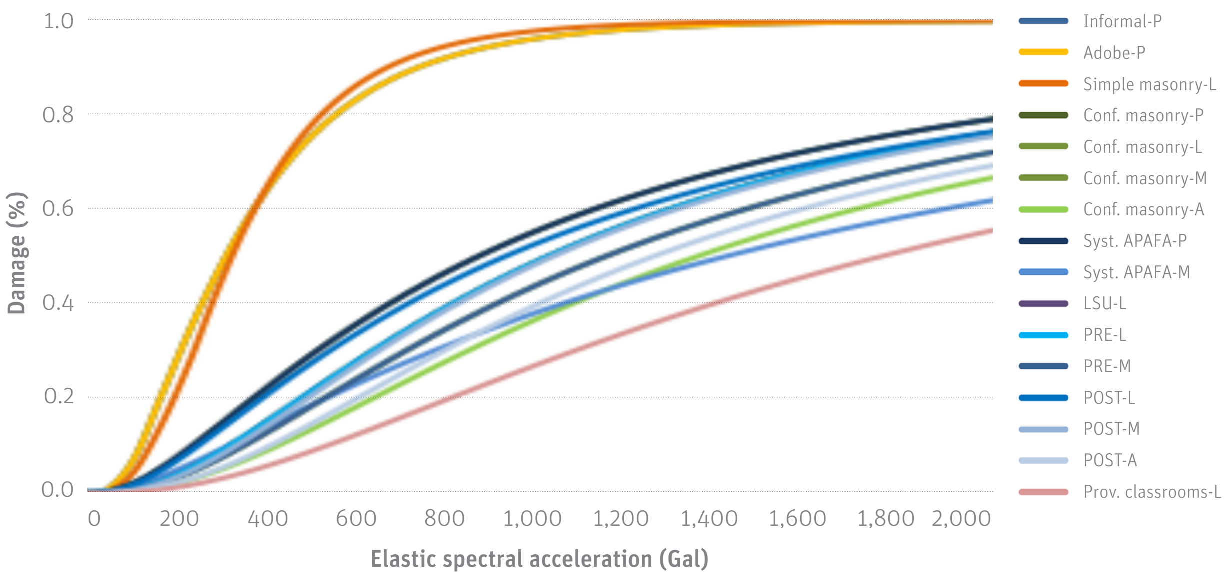
2.3 SEISMIC VULNERABILITY

Seismic vulnerability is illustrated by means of functions that relate the damage or expected losses expressed as a percentage with the seismic intensity selected. These functions represent the expected seismic behavior of the buildings from each particular typology, so their use is statistically representative when there is a wide inventory of exposed assets. Each vulnerability function is defined by a mean damage level and its variance, which makes it possible to estimate the probability function of the respective losses for different seismic intensities. This study makes use of the vulnerability functions proposed in references 6, 7, and 13. Figure 2-4 a) shows a table of the structural typologies defined for the determination of their seismic vulnerability, while Figure 2-4 b) and c) show the representative vulnerability functions used for the risk analysis.

Figure 2-4 Description of vulnerability functions used for the analysis

			Typical height		Seismic code level			
No.	Structural typology	Description	Range	No. of stories	P	L	M	H
1	Adobe (A)	Adobe	Low	1+	X	X	–	–
2	Unconfined masonry (UCM)	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	Timber structures (TS)	Timber constructions	Low	1+	X	X	–	–
6	Reinforced concrete frames (RCF)	Concrete structures with concrete frames; highly uncertain seismic response	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: The “Seismic Code Level” as used in the text is defined as follows: P = pre-code; L = low code; M = medium code; and H = high code.

2.4 RISK ASSESSMENT

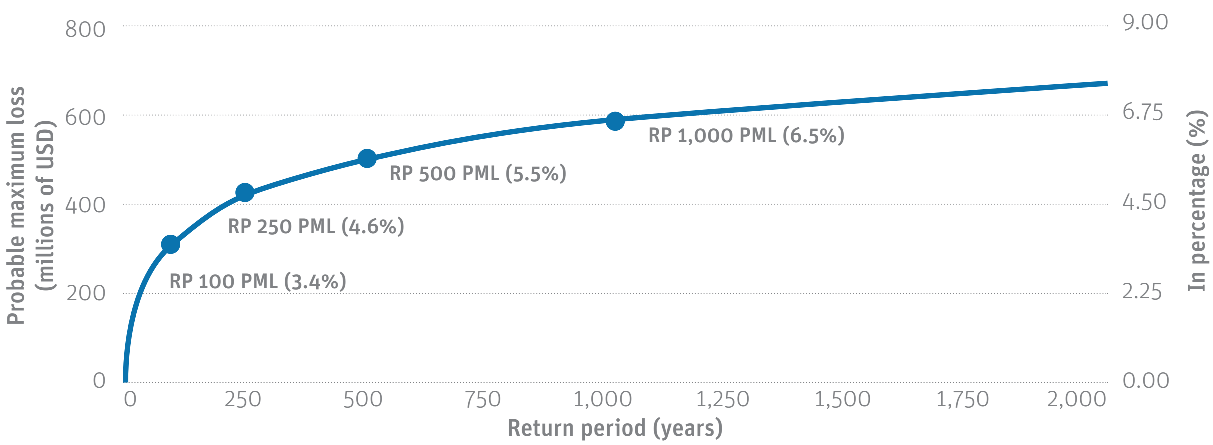
The risk assessment using probabilistic techniques with a CAPRA-type approach is widely documented. References 8, 9, 10 and 11 present in detail the methodological bases of the procedures used in this study. For the risk assessment, the hazard and vulnerability of the exposed elements are included in order to obtain parameters that indicate level of damage, physical impacts, and overall impact on the infrastructure or its occupants. Once the expected physical damage (potential average value 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 metrics, such as average annual loss (AAL) or probable maximum loss (PML) in absolute (USD) or relative (%) terms as regards the exposed value[3].

Figure 2-5 shows the basic results of the seismic risk assessment for the building inventory in the education sector in Peru.

Figure 2-6 shows the geographical distribution of average annual loss by department in absolute and relative terms as regards the respective replacement costs. In turn, Figure 2-7 shows the distribution of average annual loss by structural typology and school setting.

Figure 2-5 Results of the seismic risk assessment. Average annual loss and probable maximum loss (PML) curve

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



3. In a simple insurance scheme, the AAL represents the annual premium of insurance considering all possible earthquakes (rare and highly frequent). The PML is the loss that may occur as a result of rare earthquakes (or earthquakes with a high return period [RT], for example, 100 years, 250 years, etc.).

Figure 2-6 Geographical distribution of average annual loss by department

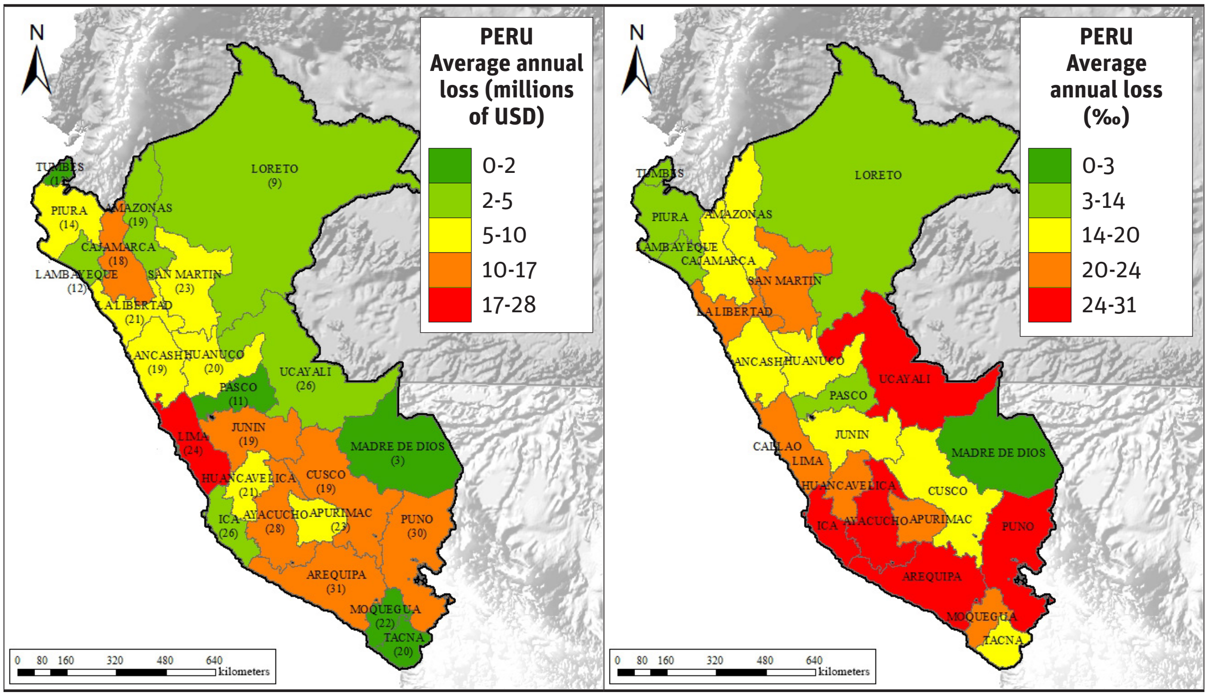
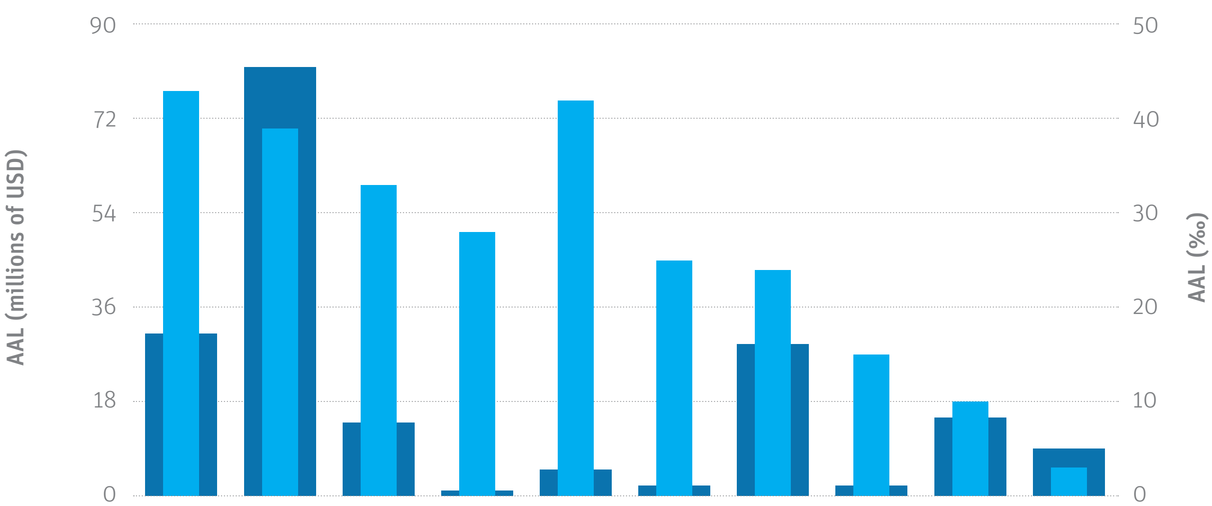
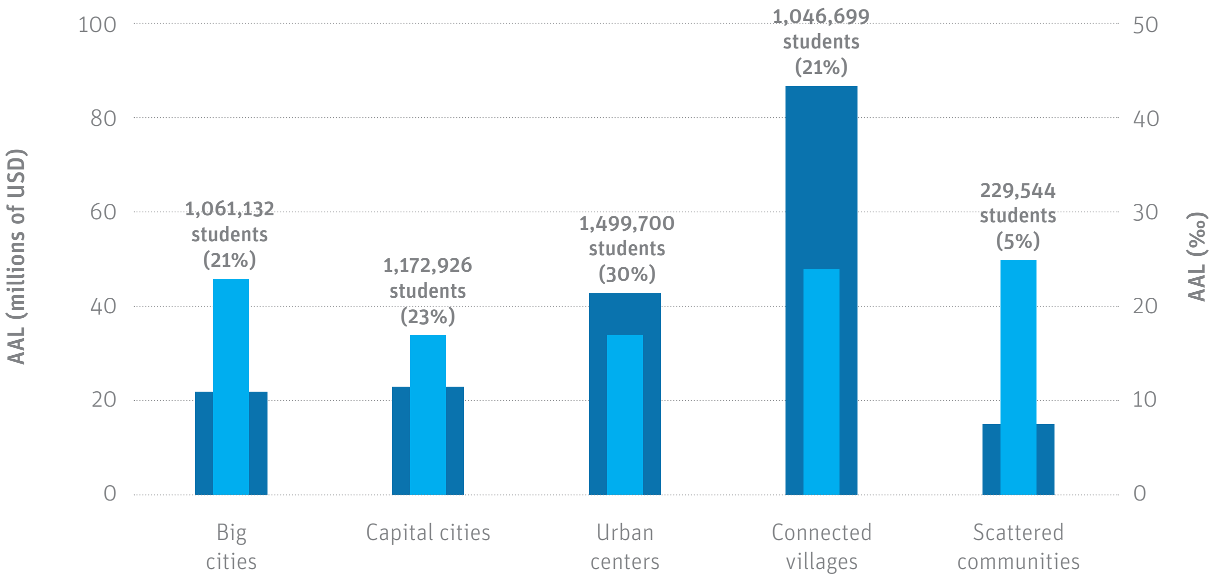


Figure 2-7 Total and relative average annual loss by (a) structural typology, and (b) school setting for the national portfolio of exposure



	P	A	UCM	SS	T	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

(a) Structural typology



	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

(b) School setting

Note: See description of structural typologies in 2.2.

As can be observed in these figures, risk tends to be geographically concentrated according to the seismic hazard level and the dominant construction characteristics in each region of the country. On the other hand, the most vulnerable structural typologies—and the more frequent ones—such as precarious, adobe, unconfined masonry, concrete frames with masonry walls, and 780-PRE systems are the ones that accumulate the greater risk. From the school settings perspective, connected villages concentrate a higher risk in terms of AAL.

3. SEISMIC RISK REDUCTION STRATEGY

In order to define an optimal seismic risk reduction strategy, it is necessary to carry out the following tasks:

1. Define the main objectives and priorities.
2. Define the intervention options by structural typology according to their level of risk.
3. Estimate the total cost of interventions.
4. Define the criteria to prioritize the interventions.
5. Carry out the optimization of the intervention strategy and the prioritization of the intervention subprograms.
6. Disaggregate the intervention plan by region for implementation.

3.1 GENERAL OBJECTIVES AND PRIORITIES OF THE PLAN

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

1. Reduce the risk of death or injuries in the community resulting from seismic events (maximizing the number of benefited students).
2. Reduce damages to the infrastructure and protect the property.
3. Minimize disruption of the educational service.

3.2 INTERVENTION OPTIONS BY STRUCTURAL TYPOLOGY

The intervention of school buildings is aimed at correcting possible structural defects and at providing the structure with an appropriate combination of stiffness, resistance and ductility which may ensure its adequate structural behavior in future seismic events under the terms established in the seismic-resistant design standard E030 of the Peruvian National Building Code [3]. Four main intervention alternatives are defined:

- **Conventional retrofitting:** The retrofitting intervention is made in a single phase and in such a way that the school building reaches the level of seismic response established by the E030 Standard [3].
  - I **Incremental retrofitting:** The structural intervention is carried out in two or more phases with a targeted performance level to be achieved in each phase.
- **Replacement** of school buildings by new seismic-resistant buildings: It is applied when there is no technical and/or financial feasibility for structural retrofitting. It involves the demolition of the existing building, the installation of temporary classrooms, and the design and construction of a new building.
- **Contingent intervention** to prevent collapse: It is a type of intervention for highly vulnerable structural typologies with the sole purpose of preventing collapse. It is a temporary intervention that would be carried out when the above alternatives are technically, financially or logistically impossible.

Table 3-1 summarizes the recommended intervention options according to the level of risk of the structural typologies.

Table 3-1 Possible types of structural intervention

Types of intervention	Buildings with high risk of collapse (HRC)	Buildings with high damage potential (HDP)	Buildings with expected adequate performance
Definition and characteristics	Poor seismic response; their intervention implies major technical difficulties, high costs, and few guarantees of functionality.	Regular seismic response under earthquakes of medium/high magnitude. Intervention is technically, functionally and economically feasible.	Seismic-resistant buildings
Structural typology	• Adobe (A) • Unconfined masonry (UCM) • Precarious (P) • Provisional (PROV)	• Large school units (LSU) • Moment resisting concrete frames (MCF) • 780-PRE modules	• 780-POST modules
Intervention options	a) Replacement by new seismic-resistant buildings. b) Replacement by temporary classrooms (in the short term) while modular alternatives are defined. c) Contingent intervention to prevent collapse.	a) Incremental retrofitting with interventions carried out in phases. Compliance with fundamental requirements established by the country regulations must be achieved in the initial phase. b) Conventional retrofitting with a single intervention phase for the building to fully comply with all requirements established in the country regulations. c) Contingent intervention in buildings located in medium and low hazard zones.	Not required

3.3 ESTIMATION OF THE TOTAL COST OF INTERVENTIONS

Based on the groups of structural typologies previously defined and the associated lines of intervention, intervention subprograms and their approximate implementation cost were defined. Table 3-2 summarizes the information for each of the subprograms.

Table 3-2 Summary of the 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: Replacement of HRC buildings	97,110	4,660
Subprogram No. 2: Conventional retrofitting	39,933	1,353
Subprogram No. 3: Buildings in low seismic hazard zones	2,689	19

3.4. 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 expected adequate seismic performance (ASP)
- Buildings located in low seismic hazard zones

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

Table 3-3 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: Replacement by new construction	73,645	1,995
Subprogram No. 2: Incremental retrofitting	34,984	783

3.5 SPECIFIC PRIORITIZATION OF INTERVENTIONS AT THE SCHOOL FACILITY LEVEL

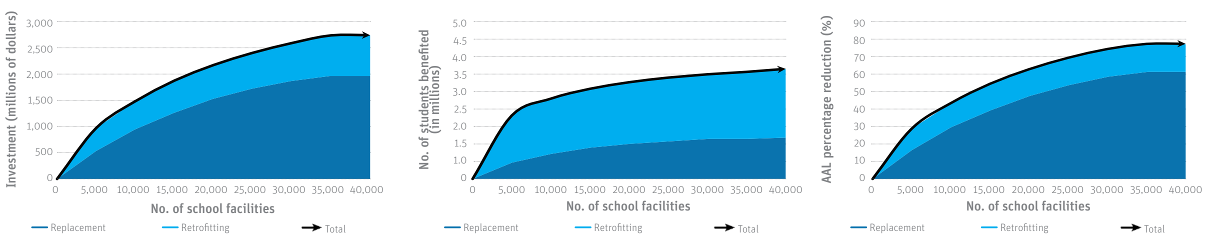
Considering the number of school buildings which require an intervention within a 10-year period and the budget limitations, it is necessary to optimize the intervention strategy and to prioritize the school facilities to be intervened in each of the subprograms. The aim is to maximize the cost-effectiveness of the interventions performed in line with the objectives set, particularly the objective of increasing the number of students benefited by the risk reduction measures. This analysis is made at the level of each school facility since, in practice, this is the level at which each intervention will take place. The prioritization is based on the cost-effectiveness analysis of the interventions, which is defined as follows:

$$CE = \frac{N_S \cdot (AAL_i - AAL_f)}{C}$$

Where CE = cost-effectiveness indicator; NS = number of potential students in each school facility; AAL_i = average annual loss at initial state (in millions); AAL_f = average annual loss at final state (once the proposed intervention has been implemented, in thousands); and C = cost of the proposed intervention.

Based on this, 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. Priority criteria are consistently applied to each of the intervention subprograms proposed. Figure 3-1 shows the impact of the buildings intervened in *Subprogram No. 1: Replacement of HRC buildings, and Subprogram No. 2: Incremental retrofitting of HDP buildings*, in terms of intervention cost, number of students benefited and AAL percentage reduction at national level. These figures have been evaluated using the list of facilities sorted form the most critical to the less critical one, and aggregating the listed values.

Figure 3-1 Impact of intervention measures. a) Cost of intervention; (b) Number of students benefited; and (c) Risk percentage reduction according to the number of school facilities intervened



a) b) c)

Based on a given budget availability, Figure 3-1 a) allows for the estimation of the number of facilities to be intervened. On this basis, the number of students benefited and the percentage in risk reduction of the portfolio can be also estimated using Figure 3 1 b) and c), respectively.

From these figures, it may also be concluded that Subprogram No. 2 is more efficient in terms of the number of students benefited, while Subprogram No. 1 is more efficient in terms of effective seismic risk reduction as regards the AAL. On the other hand, given a certain sum allocated for the optimization in line with the previous criteria, a greater relative investment should be made for the replacement of buildings as compared with the required amount for seismic retrofitting.

3.6 DISAGGREGATION OF INTERVENTIONS BY REGION

The intervention plan requires the implementation by region, as available resources are usually allocated and executed at the regional level. The following information is required for each region of the country:

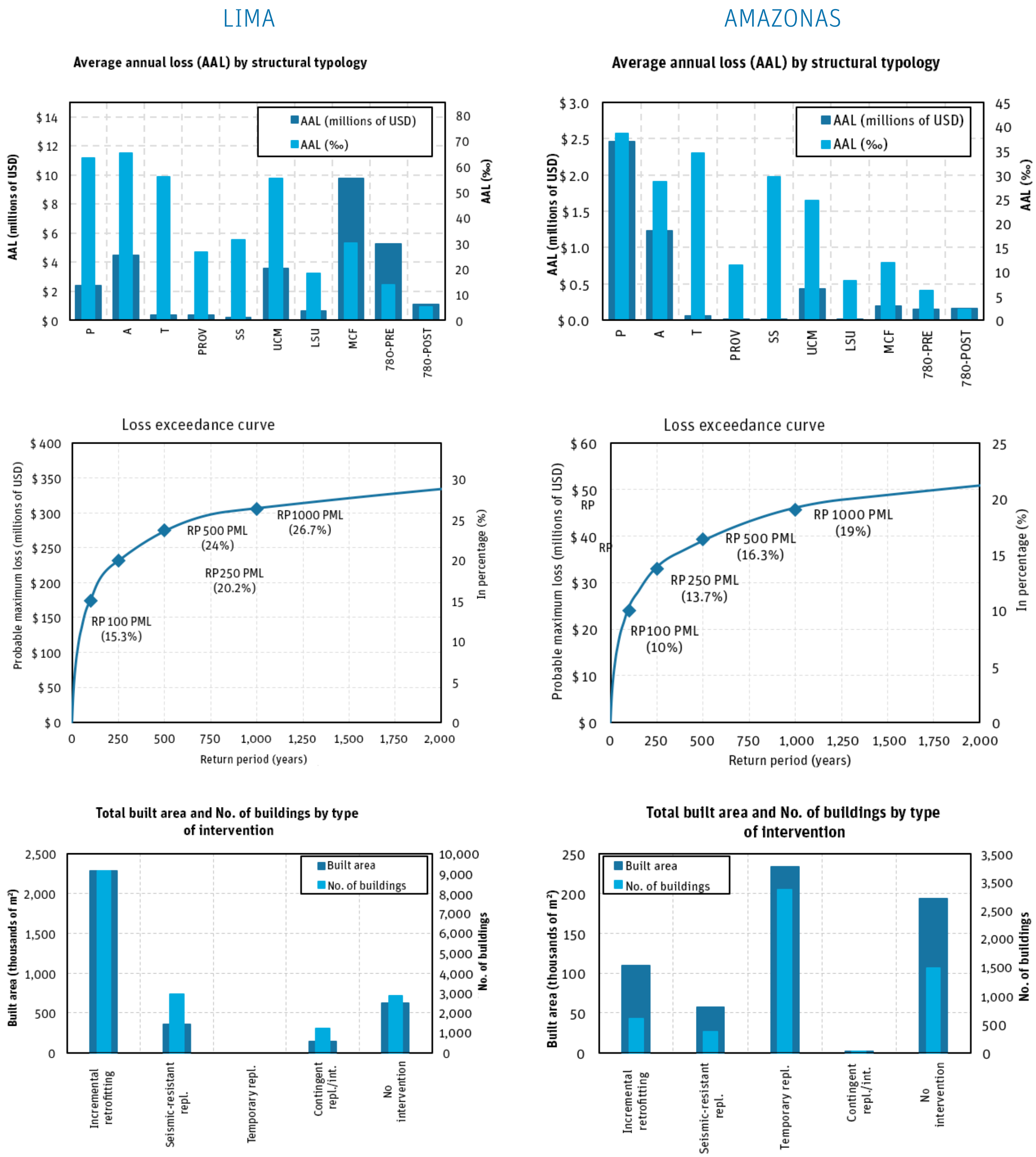
a) List of prioritized school facilities for intervention purposes

b) Intervention proposals for each building and their estimated cost

c) Aggregate cost of each of the subprograms proposed

For illustrative purposes, comparative charts between two regions, Lima and Amazonas, are shown, which make evident the regional differences that may appear during the implementation of the plan.

Figure 3-2 Comparison of results for Lima and Amazonas



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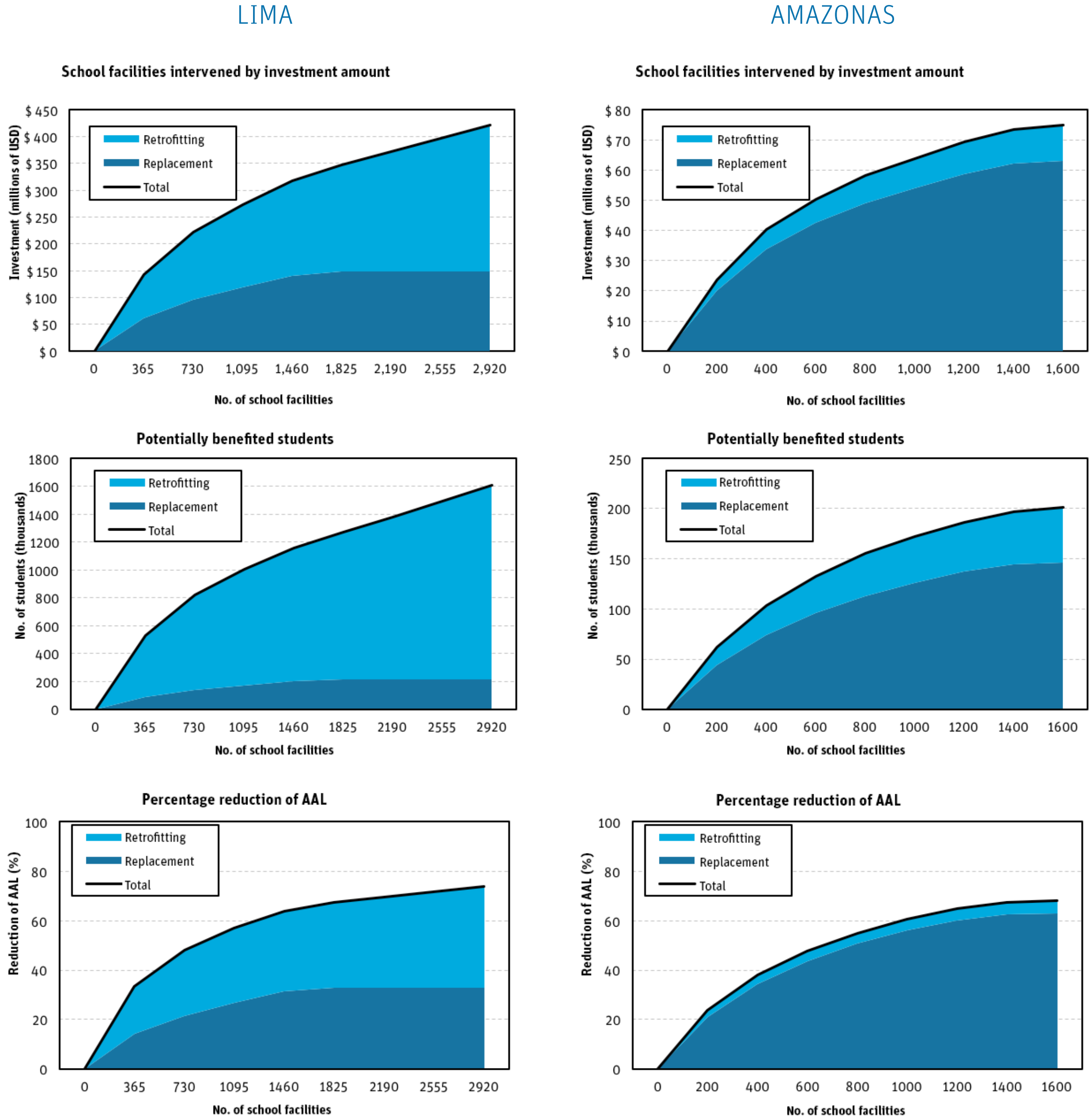

Based on this information, regional governments can carry out the implementation of the plan following the procedure below:

1. Define the amount of resources to be invested in each of the subprograms.
2. Quantify the following three parameters according to the desired investment in each subprogram:
    - Impact on the number of students benefited by interventions
    - Percentage of reduction in risk compared to initial risk
    - Number of school facilities or buildings intervened

3. Redistribute the amounts by program until reaching a high impact solution in accordance 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. Based on the above, set the terms for the execution of specific intervention projects and commission the final designs and intervention works.
6. Final phase of the plan implementation.

4. CONCLUSIONS

The analytical work in this present study allows to draw a number of conclusions regarding the elements to consider in the design and implementation of a seismic risk reduction strategy for school facilities. Those elements are listed below.

a) The average annual loss of the inventory is USD 190 million, 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 components in the inventory.

b) 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 budget limitations.

c) 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 regions in the south, the capital city and one region in the north have the highest seismic risk (between USD 10 million and USD 28 million). The average annual loss is critical in adobe school buildings and in the country's rural areas classified as connected villages.

d) The probable maximum loss, for events with a return period of 1,000 years, is USD 600 million, which correspond to approximately 6.5% of the inventory replacement cost. This figure is high in comparison with equivalent inventories from other regions and countries.

e) The risk metrics estimated for each region allows to define the intervention strategy, which includes the following components:

    - Criteria applied to the definition of the interventions for the different structural typologies identified
    - An estimate of the economic investment for seismic risk mitigation (financial gap) and the definition of an investment plan in line with the available budget
    - The definition of the optimal intervention strategy

- Prioritization criteria for each intervention line proposed, which may allow to maximize the risk reduction objectives
- Organization of the technical information required to implement the action plans by region

f) The main objectives of the seismic risk reduction plan for school infrastructure are the following:

- Reduce the risk of death or injuries in the community resulting from seismic events (maximizing the number of benefited students).
- Reduce damages to the infrastructure and protect the property.
- Minimize disruption of the educational service.

g) The direct costs assigned according to the program, climatic zone and school setting allow to estimate that the investment needs that the Government of Peru will have to cover in the next 10 years amounts to about USD 2,778 millions.

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

i) Based on this categorization, the study proposes replacement, retrofitting and contingent intervention programs as strategies to reduce seismic risk in school buildings. As part of the retrofitting program, the implementation of incremental retrofitting is suggested as an innovative and cost-effective technique.

The proposed methodology represents an important contribution to the optimization of seismic risk mitigation programs for school buildings in Peru and in other countries with similar problems.

5. REFERENCES

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