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 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.

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 related 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 substitution, this study is an example of 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

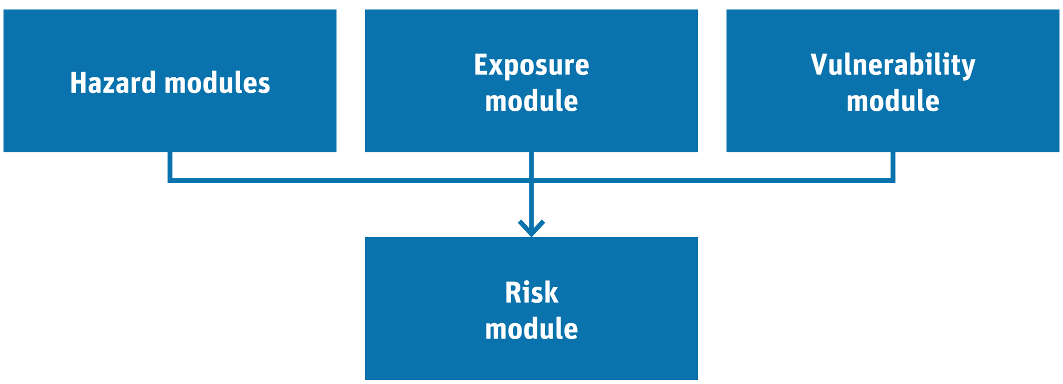
The Ministry of Education of Peru (MINEDU), through the General Directorate for School Infrastructure (DIGEIE), has been working on the drawing up of the National School Infrastructure Plan until 2025 (PNIE). Within the framework of said effort, it has commissioned the National Institute of Statistics and Information (INEI) with carrying out the School Infrastructure Census (CIE) [1] which started on September 2013 and was delivered in 2014. Besides, 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 drawing up 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 with a view to optimize the required investments. In turn, the risk reduction strategy aims mainly at reducing the risk of death or injuries in the educational community derived from seismic events, reducing damages to the property and infrastructure, and minimizing educational service disruption 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 building typologies.

The probabilistic risk estimation 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 analysis models, and to the severity and frequency of occurrence of events. The model is built on a sequence of components, as illustrated in Figure 2-1. Reference 2 presents the detailed methodology for the analysis of risk derived from seismic events.

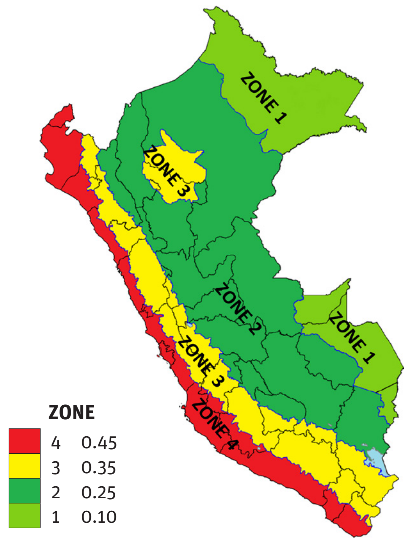
Figure 2-1 **General outline of the probabilistic risk analysis**



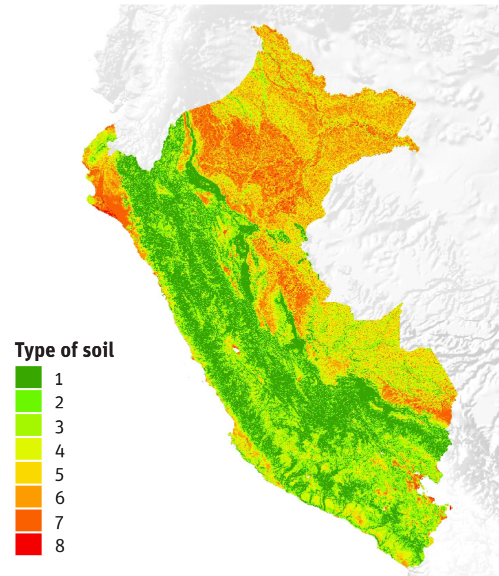
2.1 SEISMIC HAZARD

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 building typology. Moreover, every event is characterized by the annual mean 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 grading vulnerability, information regarding the structural system, height, level of seismic-resistant design, 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 construction direct costs (see Reference 5).

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

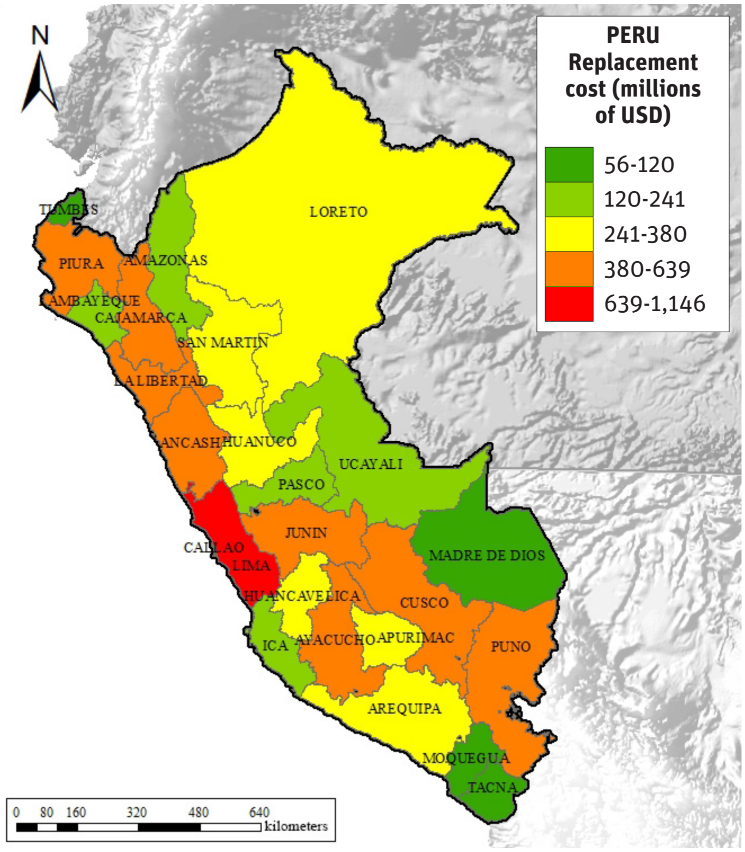
Table 2-1 Summary of portfolio of exposure of school buildings

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

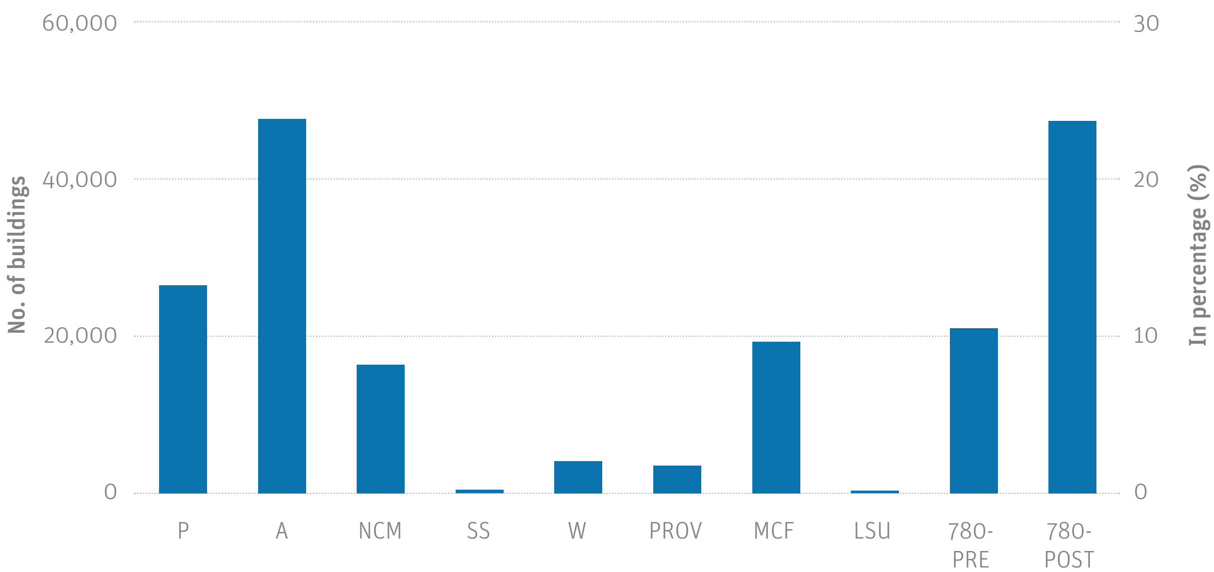
Figure 2-3 shows the distribution of the replacement costs by country regions and by building typology for the complete inventory of buildings. The predominant building typologies are the following: P = Precarious; A = Adobe; NCM = Non-confined masonry; SS = Steel structure; W = Wood; PROV =Provisional; MCF = Concrete frames with masonry walls built by Parents' Associations (PA); 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 behavior, 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 building typology**



a) Distribution of replacement cost by department



	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%

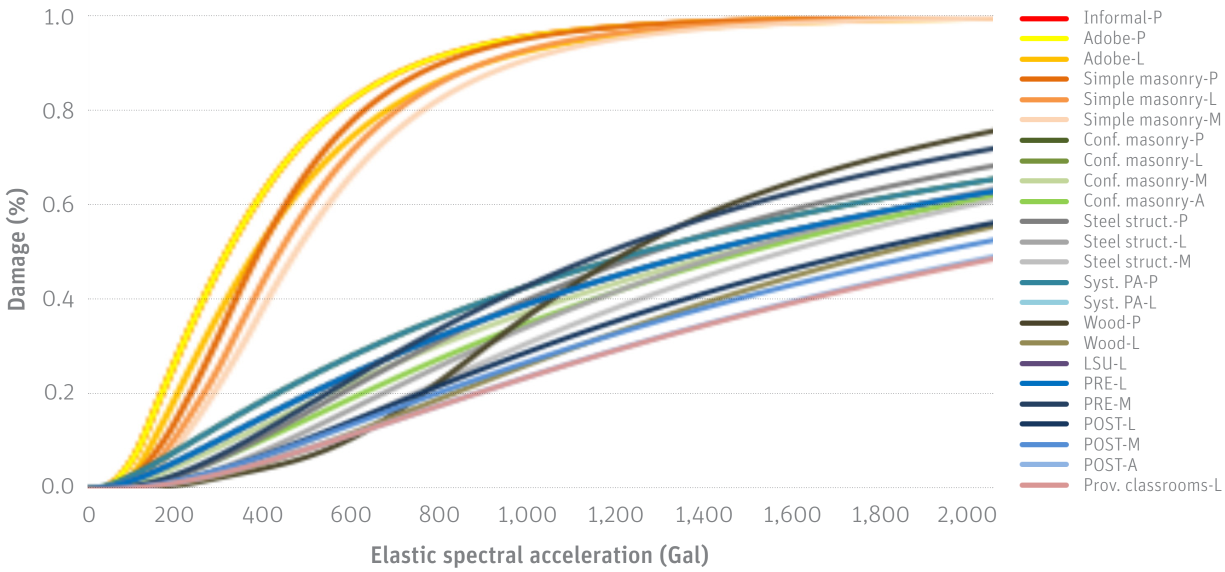
b) Distribution of exposure value at national level according to the building typology

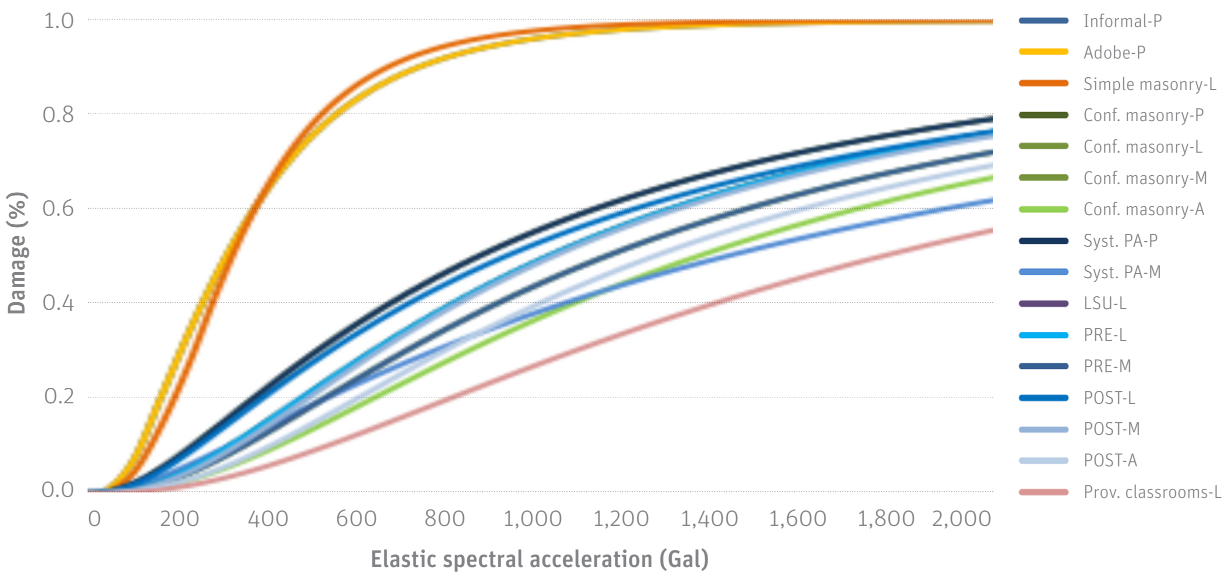
2.3 SEISMIC VULNERABILITY

Seismic vulnerability is presented by means of functions that connect the damage or loss expected expressed as a percentage with the seismic intensity selected. These functions represent the expected behavior of the buildings from each particular typology, 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 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 building 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

No.	Building typology	Description	Typical height: Range	Typical height: No. of stories	Seismic code level: 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: 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

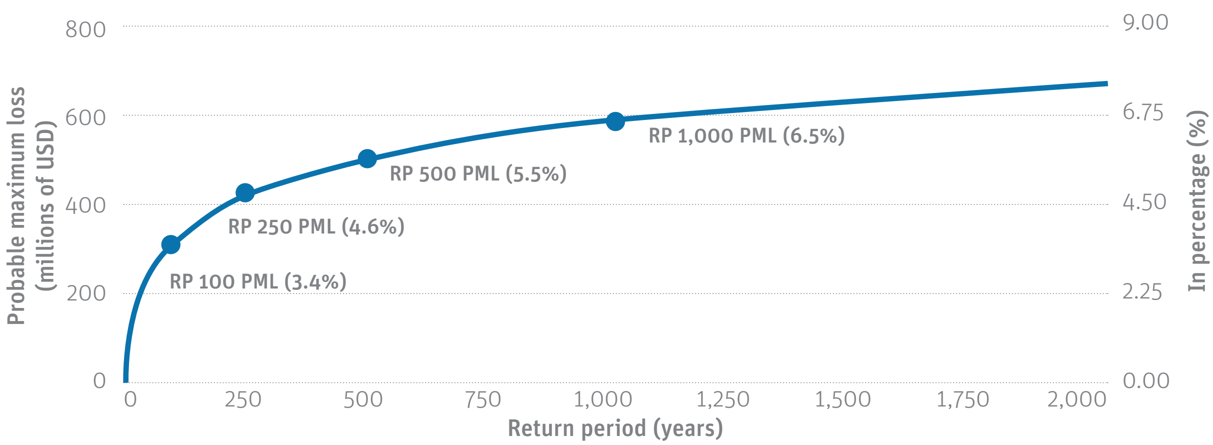
The risk assessment using probabilistic techniques with a CAPRA-type approach is widely documented. References 8, 9, 10 and 11 present in detail the methodological bases of the procedures used in this study. For the purpose of risk assessment, the hazard and vulnerability of the exposed elements are 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 building 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 x106**	**%**
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

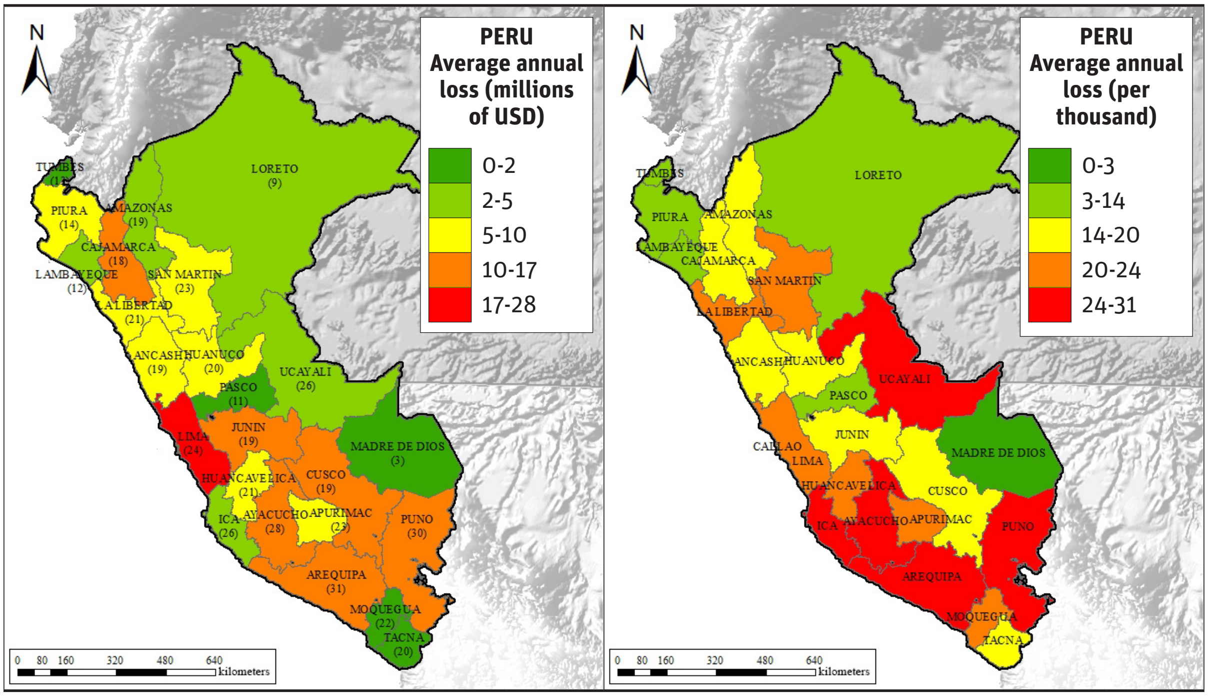
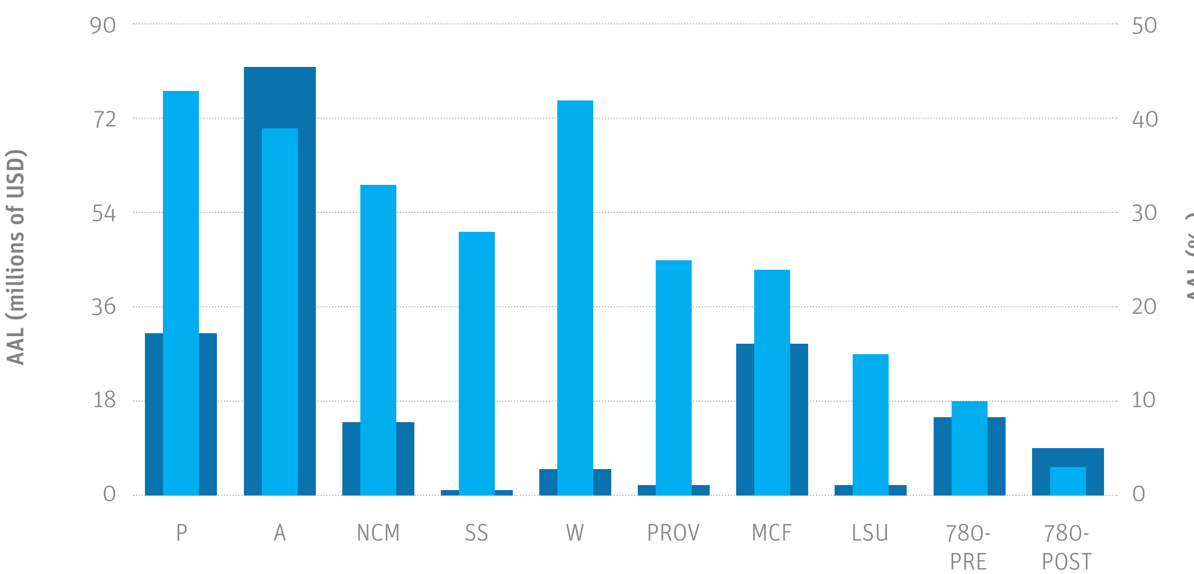
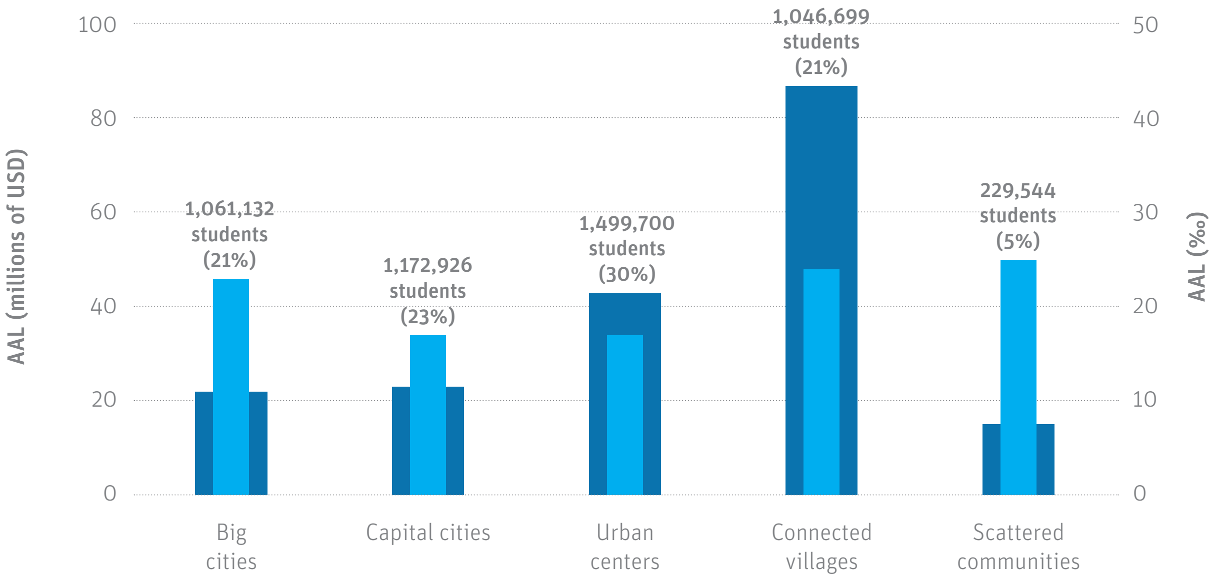


Figure 2-7 Total and relative average annual loss by (a) building typology, and (b) school setting for the national portfolio of exposure



	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

(a) Structure 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 building typologies in 2.2.

As it 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 building typologies—and the more frequent ones—such as precarious, adobe, non-confined 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. Setting the main objectives and priorities.
2. Defining the intervention options by building typology according to their level of risk.
3. Estimating the total cost of interventions.
4. Defining the criteria to prioritize the interventions.
5. Carrying out the optimization of the intervention strategy and the prioritization of the intervention subprograms.
6. Disaggregating 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. 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.

3.2 INTERVENTION OPTIONS BY BUILDING TYPOLOGY

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 seismic-resistant design standard E030 of the Peruvian National Building Code [3]. Four main intervention alternatives 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 by the E030 Standard [3].
    - I **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.
- **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 a new building.
- **Contingent intervention** to prevent collapse: It is a type of reinforcement of highly vulnerable building 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 risk level of the building 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 good seismic performance expectancy
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
Building 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

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: Substitution of HRC buildings	97,110	4,660
Subprogram No. 2: Conventional reinforcement	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 good seismic performance expectancy (GSP)
- Buildings located in low seismic hazard zones
- Interventions by means of substituting HRC buildings
- Intervention of HDP buildings

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: Substitution	73,645	1,995
Subprogram No. 2: Incremental reinforcement	34,984	783

3.5 SPECIFIC PRIORITIZATION OF INTERVENTIONS AT SCHOOL FACILITY LEVEL

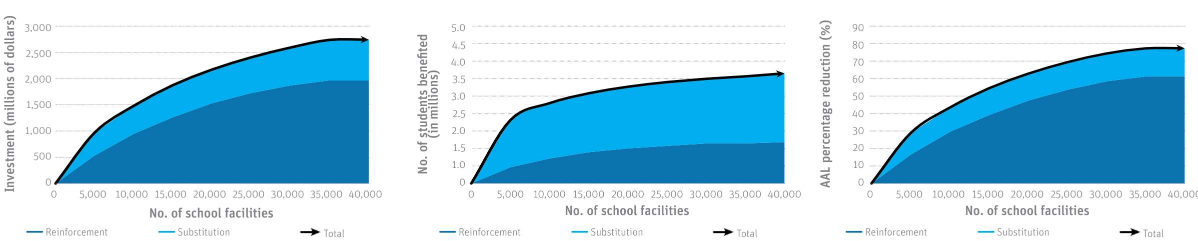
Considering the number of school buildings in need of intervention within a 10-year period and the budget limitations, it is necessary to optimize the intervention strategy and to prioritize the school facilities to be intervened in each of the subprograms. The aim is to maximize the cost-effectiveness of the interventions performed as regards the objectives set, particularly the objective of increasing the number of students benefited by the risk reduction measures. This analysis is made by school facility since, in practice, this is the minimum intervention unit. The prioritization is based on the assessment of the cost-effectiveness 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 intervention proposed has been made, in thousands); and C = cost of the intervention proposed.

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. 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: Substitution of HRC buildings, and Subprogram No. 2: Incremental reinforcement 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 risk percentage reduction of the inventory 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 substitution of buildings as compared with the required amount for building reinforcement.

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 in the implementation of the plan.

Figure 3-2 Results comparison for Lima and Amazonas

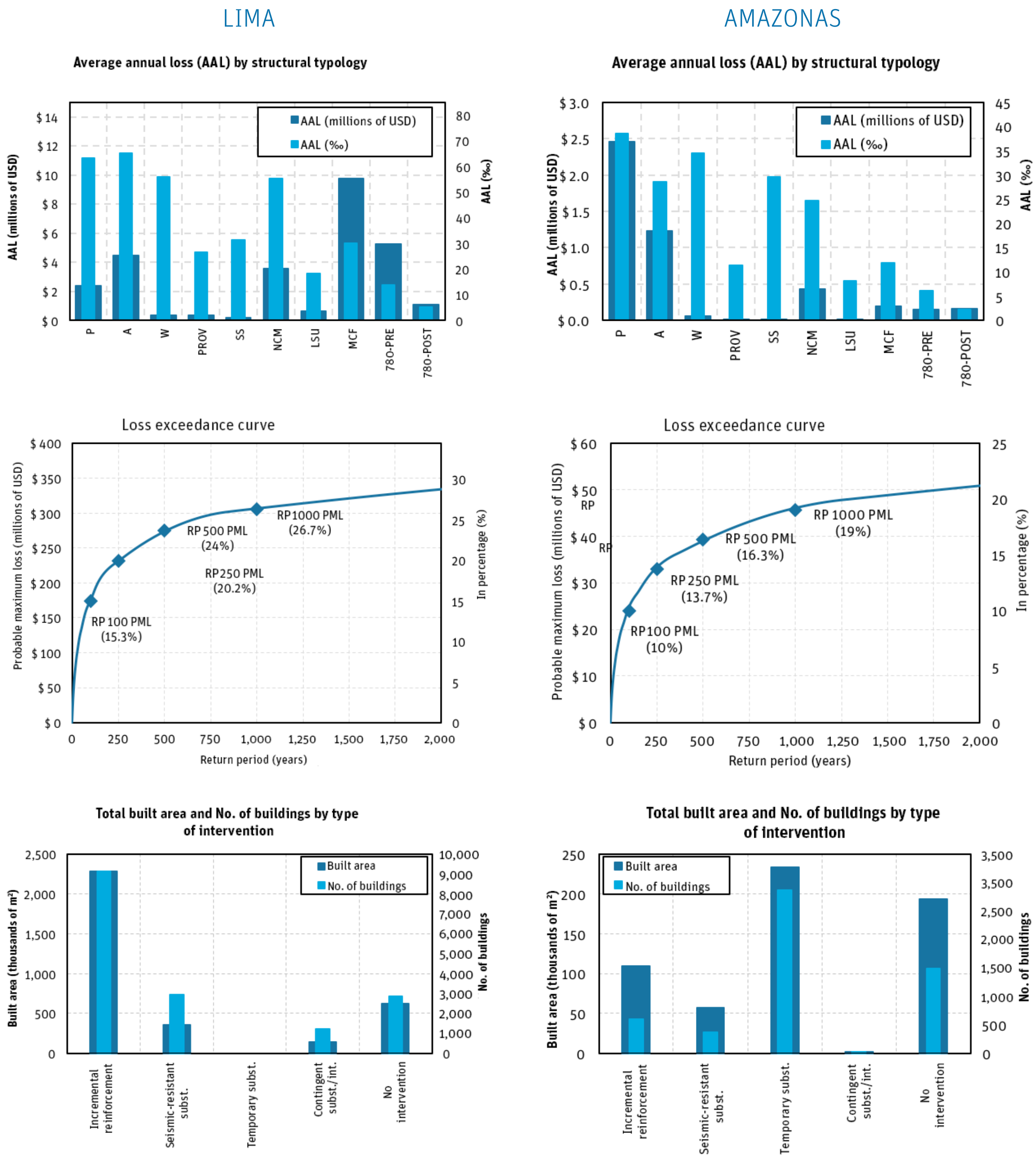
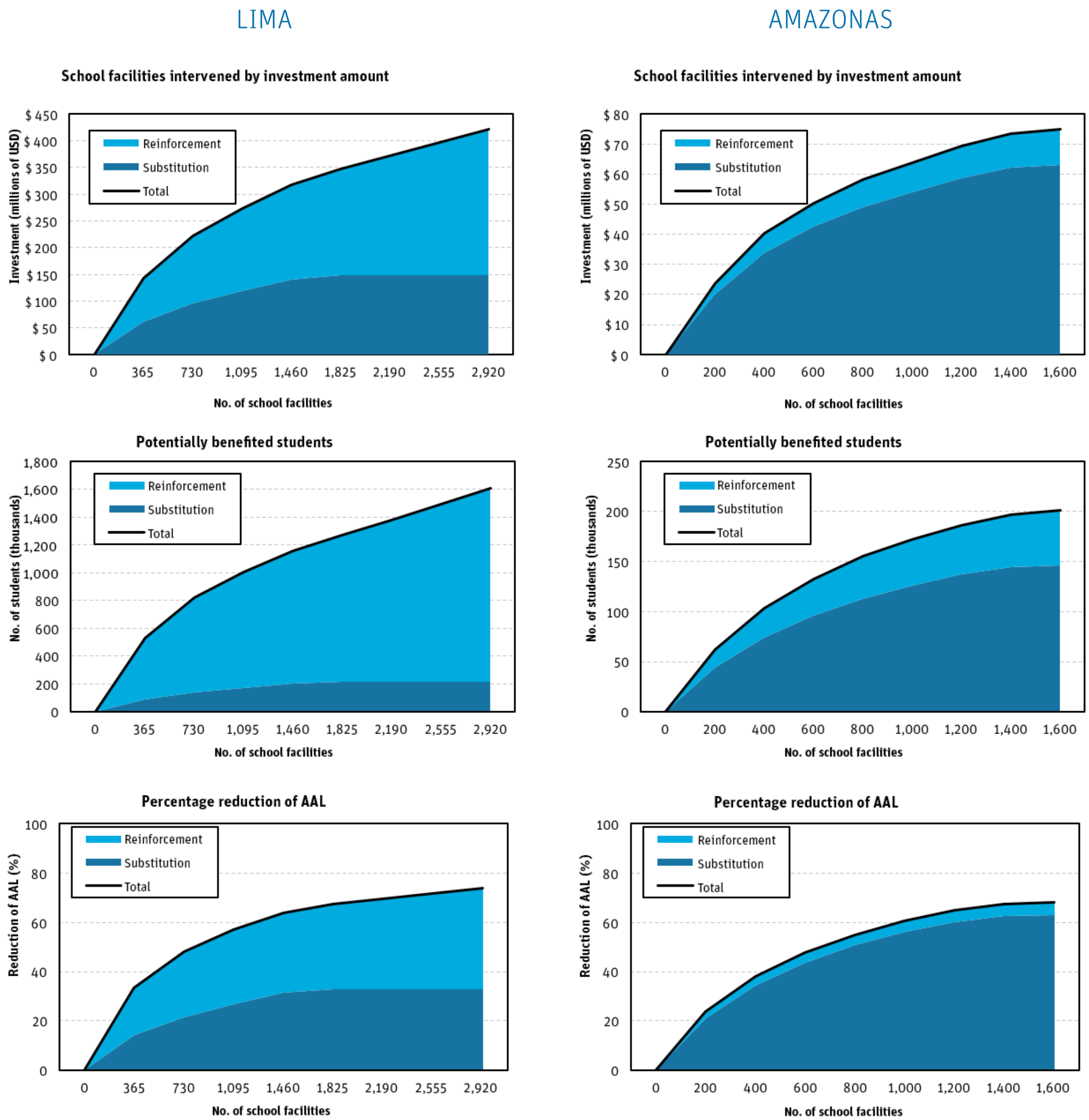


Figure 3-2 Results comparison for Lima and Amazonas



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

1. Defining the amount of resources to be invested in each of the subprograms.
2. Quantifying the following three parameters according to the desired investment in each subprogram:
    - Impact on the number of students benefited by interventions
    - Risk percentage reduction as regards initial risk
    - Number of school facilities or buildings intervened

3. Redistributing the amounts by program until coming to a high impact solution in accordance with specific criteria for the region.
4. Checking 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, setting the terms for the execution of specific intervention projects and commissioning the final designs and intervention works.
6. Final phase of the plan implementation.

4. 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 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.

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 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.

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 allow for the definition of the intervention strategy, which includes the following components:

    - 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

f) 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.

g) 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 about USD 2,778 millions.

h) 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 a high damage potential. For the rest of the buildings, an acceptable behavior is expected, but their intervention in the short term is considered a priority.

i) Based on this categorization, the study suggests programs of substitution, reinforcement and contingent intervention as strategies to reduce seismic risk in school buildings. As part of the reinforcement program, the implementation of incremental reinforcement is suggested as an innovative and economical technique.

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

5. REFERENCES

1. Instituto Nacional de Estadística Informática (INEI) y Ministerio de Educación (MINEDU), *"Censo de Infraestructura Escolar (CIE)"*. 2013, Lima: Peru.
2. Universidad de los Andes, *"Evaluación del riesgo sísmico del portafolio de edificaciones en locales escolares en Lima Metropolitana y Callao a partir de los resultados del CIE"*. Report prepared for the World Bank, 2014, Bogotá D.C: Colombia.
3. Norma E-030. 2015 "Diseño Sismorresistente". Lima: Ministerio de Construcción, Vivienda y Saneamiento- SENCICO.
4. Allen T., and Wald D. (2009). Short Note. "On the Use of High-Resolution Topographic Data as a Proxy for Seismic Site Conditions", U.S. Geol. Surv. Open-File Rept. 2009
5. Universidad de los Andes. *"Asesoría técnica en la definición y establecimiento de criterios de intervención y priorización que contribuyan a un mejor planeamiento, eficiencia y sostenibilidad en materia de infraestructura educativa"*. Centro de investigaciones y obras civiles (CIMOC). Report prepared for the World Bank, 2016.

6. Yamin, L., Hurtado A., Barbat A., Bernal G., Cardona O., *Earthquake Vulnerability Assessment of Buildings for Catastrophic Risk: Analysis in Urban Areas,* in 15 World Conference on Earthquake Engineering (WCEE). 2012, Lisbon, Portugal.

7. ISDR, U.N., UNISDR. GAR13: Global Assessment Report on Disaster Risk Reduction. 2013 Geneva, Switzerland.

8. ERN-AL. Metodología de Modelación Probabilista de Riesgos Naturales. Informe Técnico ERN-CAPRA-T1-1. Consorcio Evaluación de Riesgos Naturales - América Latina; 2011.

9. Cardona, O. D., Ordaz M., Yamin L., Marulanda M., Barbat A., "Earthquake Loss Assessment for Integrated Disaster Risk Management". Journal of Earthquake Engineering, 2008. 12(sup2): p. 48–59.

10. Cardona, O.D., and Yamin L. E., *Seismic Microzonation and Estimation of Earthquake Loss Scenarios: Integrated Risk Mitigation Project of Bogota, Colombia.* Earthquake Spectra, 1997. 13(4): p. 795–814.

11. Yamin, L., Ghesquiere F., Cardona O., Ordaz M., "Modelación probabilista para la gestión del riesgo de desastre, El caso de Bogotá Colombia". 2013, Bogota, Colombia: Banco Mundial, Universidad de los Andes.

12. Pontificia Universidad Católica de Perú (PUCP), *"Evaluación probabilista del riesgo sísmico de locales escolares en la ciudad de Lima".* Report prepared for the World Bank, 2014, Lima: Peru.

13. Yamin L. E., Hurtado A., Barbat A. H., Cardona O. D. "Seismic and wind vulnerability assessment for the GAR-13 global risk assessment". International Journal of Disaster Risk Reduction. 2014;10:452–60.

14. Instituto Nacional de Estadística Informática (INEI) y Ministerio de Educación (MINEDU), *"Manual del Evaluador Técnico"* Censo de Infraestructura Escolar (CIE). 2013, Lima: Peru.

15. Building Seismic Safety Council. 2009. FEMA 420. "Engineering Guideline for Incremental Seismic Rehabilitation". Washington D.C: Federal Emergency Management Agency.

16. Pontificia Universidad Católica del Perú, Universidad Nacional de Ingeniería *"Evaluación simplificada de las tres técnicas de reforzamiento más apropiadas. Propuesta de actualización del reglamento nacional de edificaciones para incorporar el reforzamiento incremental en edificaciones escolares tipo 780 construidas antes de 1997".* Report prepared for the World Bank, 2016, Lima, Peru.

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