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PRIORITIZATION METHODOLOGY FOR SEISMIC RISK REDUCTION IN PUBLIC SCHOOLS. STUDY CASE: LIMA, PERU

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Abstract

School buildings in highly seismic areas are under permanent hazard. This situation is extremely critical for student population who attend public schools with high vulnerability factors such as insecure infrastructure, poor community preparedness and deficient conditions due to social exclusion. Risk reduction becomes a challenge to the government because of the great amount of population at risk and the lack of capacity of the authorities to attend them all simultaneously. Academia and international agencies have been working to develop risk reduction strategies for schools, e.g. retrofitting infrastructure, preparedness and planning. Although it involves different areas of knowledge, few opportunities have been created for interdisciplinary and participatory work in order to create a comprehensive and holistic vision of the problem.

In this paper, a prioritization methodology based on indicators or rankings is presented. The methodology takes into account factors related to weaknesses or capabilities in all stages of risk occurrence: classroom, school, environment, and city. Physical factors are expressed by means of two indicators: structural performance level and average annual loss. Social factors are taken into account from experts opinions, and are combined by Multi-criteria Decision Analysis (MCDA) method. Thus, schools are classified into different levels of priority according to their physical and social capabilities.

The proposed methodology is applied to the case of public schools in Lima, Peru. The consequences of applying three risk prioritization methodologies: (1) economic loss-based approach (2) structural performance-based approach and (3) methodology proposed in this paper are compared. The comparison is done in different areas: economic losses due to structural damage, operation of schools, accessibility, suitable areas for emergency care, etc. The comparison of this approach and economical losses- based approach shows that the last one would exclude small schools with high potential of injury. Approaches based only on structural performance don't appreciate organization and preparedness and this could be a disincentive for community participation

Keywords: mitigation, public infrastructure, decision making, holistic approach, risk evaluation

1. Introduction

Student populations who attend public schools in highly seismic areas are in an extreme risky situation. In past events injuries and deaths of students were caused by fallen heavy objects, partial collapses of buildings, falls, crashes and overcrowding during seismic events (Rangiehri & Ishiwatari, 2014). Deficiency and delays in humanitarian response due to social segregation, little compactness of the urban area, poor communication skills of authorities and practitioners, inaccessibility and poor community organization during the emergency response and rehabilitation stages can produce health problems and increase psychological damage in student population (Feo, et al., 2014; Rivera, 2010; Rivera, et al., 2014; Velázquez, et al., 2016; Kar & Kumar Bastia, 2006). Disruption of classes and population displacements during the reconstruction phase can generate school drop out with negative and permanent economic and social impacts for students, their families, and their communities (IFC, 2010; Masten & Osofsky, 2010).

Seismic risk reduction of student populations in highly seismic areas is crucial. Previous efforts to reduce seismic risk have ranged from corrective measures to reduce structural vulnerability to proactive initiatives focused on improving earthquake preparedness and contingency planning that increase capacities and resilience of the students, teachers, administrators and decision makers. A massive and comprehensive intervention in the system of public schools is a challenge to governments because of the great amount of population at risk and the lack of capacity of the authorities to attend them all simultaneously (Freeman, et al., 2003; Cardona, 2010). A strategy to prioritization of interventions is needed.

Some studies have proposed prioritization schemes ranking the schools by its physical vulnerability or its seismic performance of structural and non-structural elements (Grant, et al., 2007; Crowley, et al., 2008; Pina, et al., 2010; Grimaz, et al., 2011; Tesfamariam & Wang, 2012; Monfort, et al., 2012; López, et al., 2007; Mora, et al., 2015; Acharya, et al., 2012). Social factors including security and wellbeing of the student population, accessibility, incomes, presence of basic services and community organization are taken into account by various authors (IASC, 2007; Rivera, et al., 2016; Izadkhah & Hosseini, 2005) as an opportunity to increase resilience and reduce the seismic risk (Aldrich, 2012). However, social elements have been rarely used for prioritization purposes (DRELM, 2014).

In this paper, a prioritization methodology for school risk reduction is presented. The methodology is based on a participatory and interdisciplinary approach that combines local knowledge and technical know-how. The methodology takes into account, social and physical factors related to weaknesses that would increase the impacts on students, and capabilities that could decrease the adverse effects of a seismic event. Public schools in Lima, Peru are prioritized with the proposed methodology. Results are compared with existing schemas. Our hypothesis is that the use of physical and social factors in the elaboration of prioritization schemas could reduce damage in student population during emergency attention and post disaster rehabilitation stages.

2. Proposed prioritization objectives

Santa-Cruz et al (2016) used a community-based and multidisciplinary tool known as community-diagnosis method (Matsuda & Okada, 2006) to determine prioritization objectives for seismic risk reduction of public schools in Peru. Community diagnosis consists of two phases: a diagnostic survey and a prescriptive meeting, the latter providing space for face-to-face interaction to share survey results of previous disciplinary studies and to combine the local knowledge of various participants. The prescriptive meeting also plays the role of providing the community a solution for risk reduction.

Community-diagnosis concluded that two sets of schools must be prioritized: (1) those that could be more useful during emergency-relief work and recovery (2) those where students faced the greatest potential of injury to students. The schools of the first group contribute to school population's resilience. The second group of schools doesn't guarantee the safety of student population in futures earthquakes. Fig. 1 shows the prioritization targets. The horizontal axis represents the level of capacity and contribution to students' resilience. The vertical axis represents damage potential of injury to student population. Schools located in the upper right zone of the chart are of high priority. Low priority schools are located in left bottom zone.

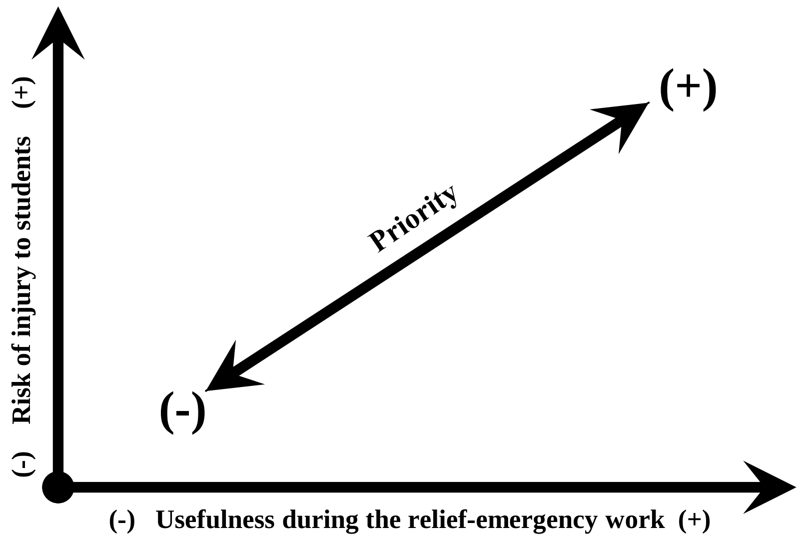


Fig. 1 – Prioritization targets

3. Prioritization Methodology

The methodology consists in four steps:

1) Data gathering. Risk information about structural fragility of school buildings, hazard and site effects, community preparedness and exposure in GIS format.
2) Evaluation of Capacity and Injury potential indicators. A list of injury potential and capacities factors and indicators are proposed. It should be validated using a community-diagnosis method. It is recommended to involve local authorities, international organizations, academics, practitioners and users.
3) Measure and evaluation of capacity levels and potential injury indexes: Injury index and capacity index are obtained by an Analytical Hierarchy Process, AHP using Potential injury and Capacity and resilience normalized indicators. Each indicator is normalized by means of a transform functions that convert indicators in a nondimensional quantities in the range of (0,100%)
4) Clasification. Five prioritization levels are defined according to potential injury and capacity and resilience indexes. A suitable intervention is proposed for each level.

4. Indicators of the Potential of injury to the students

Schools with structural weakness, low bearing capacity of foundation soils and absence of emergency exits and safety areas are more likely to produce damage to student population due to falling objects, partial collapses and overcrowding. Expected Annual Loss (EAL) and expected seismic performance level of the structure after given earthquakes are good indicators of the potential of injure to the student population.

The Expected Annual Loss is the sum of the multiplication of the expected losses in a specific event and the annual occurrence probability of that event, for all possible events. The EAL considers the losses of each building of the school for all the events that can occur; supposing that the process of occurrence of hazard events is stationary and that damaged structures have their resistance immediately restored after an event. The EAL can be calculated with the Eq. (1) (Ordaz, et al., 1998; Ordaz, 2000):

$$\text{EAL} = \sum_{i=1}^{\text{Events}} E(L \mid \text{Event } i) F_A(\text{Event } i) \tag{1}$$

where $E(L \mid \text{Event } i)$ is the expected loss value for the event i and $F_A(\text{Event } i)$ is the annual occurrence frequency of the event i. The annual occurrence frequency of events depends on the results of hazard assessment. The loss expected value, given the occurrence of a particular event, depends on the vulnerability of the exposed element.

Seismic performance levels are: immediate occupancy (IO), damage control (DC), life safety (LS), and collapse prevention (CP) (SEAOC, 1995). Performance-Based Earthquake Engineering, PBEE, recommends performance objectives for different intensity levels for different types of structures. For example, a house or office building should satisfy objectives shown in grey in Table 1. Essential structure such as a hospital or a school must satisfy the blue ones. Limited objectives (in orange) are unacceptable for the design of new structure but could be used for retrofitting projects (FEMA, 356).

Table 1 – Performance objectives

	Immediate occupancy, IO	Damage control, DC	Life safety, LS	Collapse prevention, CP
Frequent	Basic		Limited	Limited
Occasional	Essential	Basic	Limited	Limited
Rare		Essential	Basic	Limited
Very rare			Essential	Basic

5. Indicators of the capacity and resilience.

Santa Cruz, et al (2016) present a complete discussion about the positive and negative factors that could delay the post-disaster recovery process.Accessibility in a post-disaster scenario is considered a positive indicator. For example, the location of main avenues in lower elevation and plain areas could allow for distribution of humanitarian aid or, if necessary, evacuation of injured victims. On the contrary, areas with serious difficulties due to overcrowding slope instability, and the lack of well-maintained roads and highways could delay emergency attention.

The large number of schools in the vicinity is considered to be a positive factor because the existence of these buildings could increase the possibility that local habitants would be able to continue classes and have a focal point if some schools in the area became inoperative. Well-distributed school yards inside the school would be useful for setting up prefabricated classrooms in a post-disaster reconstruction scenario.

A low income level is considered to be a negative factor because insufficient financial resources are associated with a slow recovery process. Problems of alcoholism, violence, and crime are also identified as social gaps for community cohesion. A good relationship between the school and the community would be a significant factor in the whole reconstruction process. In this case, the school building is an important community-meeting point, especially in areas characterized by low socioeconomic status. Lack of legal clearance of school could represent a risk factor since it could delay the provision of government financial aid in post-disaster reconstruction process.

In summary, schools with better capacities for post-disaster attention and rehabilitation phases are placed in urban zones with compactness and inclusive solutions, water supply, electricity and phone communication systems. On the other hand, schools that would be more useful during recovery and emergency attention are the ones that are located in zones with high population density or near communities with disadvantageous socio-economic conditions. Table 2 shows a list of potential injury and capacity and resilience factors and indicators.

6. Potential injury and capacity and resilience indexes

Indicators are normalized with transform functions (Carreño, et al., 2007; Marulanda, et al., 2009; Carreño, et al., 2012) and combined to obtain capacity index, CI, and Potential of Injury index, PI, with the AHP technique (Saaty, 1980; 2007). Fig. 2 shows examples of transform functions for seismic performance of building and minimum distance to the closest main street.

Indicators of each school are combined in a weighted–sum to obtain a ranking. Weights are estimated by pair-wise comparisons by experts and stakeholders. Results of each estimation are validated with evaluation of the index of coherency, which is estimated by the estimation of eigenvalues.

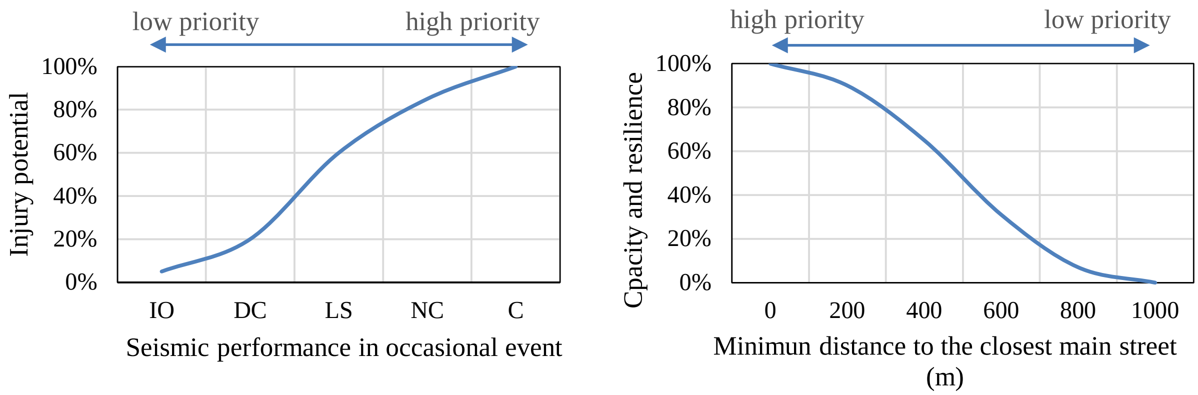


Fig. 2 – Transform function for (a) seismic performance of building and (b) Minimum distance to the closest main street

7. Classification and proposed intervention

Each school is classified according to PI and CI indexes. According to prioritization objectives high priority are given to the ones with high potential of injury and high capacity and resilience contribution. Proposed intervention must focus on reducing injuries and improving capacity and resilience levels. The intervention should include infrastructure, equipment and furniture, teaching and community training and teaching management.

In order to reduce possible injuries, structural and non-structural retrofitting are recommended. It is necessary to improve school-evacuation routes by building ramps, removing obstacles and stairs from safety areas, change furniture that do not comply with the safety recommendations, constructing additional staircases, and strengthening structure, perimeter walls, elevated water tanks, and parapets.

Capacity and resilience levels can be improved by means of preparedness, community responses, and psychological support teams. In terms of community organization, it is proposed mobilizing social and human resources to respond to potential crises through community interventions that promote solidarity among neighbours of the school and their organized participation in rehabilitation and emergency-relief processes. In addition, training potential members of the psychological support team should be able to identify negligent emergency-relief practices, such as healthcare workers prescribing unnecessary drugs or “antidepressants” to students. For the immediate school surroundings, enhancing road infrastructure is recommended. In addition, awareness-raising campaigns should continue as well as preparedness activities (like the scheduled drills), and regular emergency-management workshops for teachers and students. To address a potential post-disaster crisis, it is proposed to change to the urban model, including compactness, inclusivity and social cohesion, and improvements to the water supply, electricity and telecommunication systems.

Infrastructure of school buildings with very high potential of injury where safety of student population could no longer be guaranteed need an emergency intervention (as is the case of adobe-wall buildings and schools built according to obsolete seismic criteria (Muñoz, et al., 2004). If the school have also good capacities and resilience index, the school is classified as First priority level. Target performance objectives of building intervention must be similar to the ones for essential infrastructure.

If school has high potential of injury and doesn’t have good capacities then the school is classified as a second level of priory. The emergency intervention would have limited objectives to stabilize the structure. An option to implementing these emergency measures would be to include incremental retrofitting which entails adapting the school to regulatory requirements in partial interventions or stages (Krimgold, et al., 2002). With this, an improvement would be made in the structural performance in every stage until the performance reaches the requirements of existing construction codes.

Table 2 – Factors and Indicators of Potential of injury, capacity and resilience

Potential injury	Factors	Proposed Indicator	Unit	Range
Injuries causedby falling heavy objects or partial collapses. Psychological damage due to the shock.	- Seismic hazard - Soil type - Structural fragility	-EAL	$	0- Replacement cost
		-Seismic Performance of buildings	Performance level	IO, DC, LS, CP,C
	- Exposure	-Number of Student	Students	Min-Max
Potential physical damages caused by falls, crashes and overcrowding of students during the evacuation	- Implementation of emergency exits and safety areas in the school	-Certificate of civil defense technical inspection	unit	0-1
Capacity and resilience	**Factors**	**Indicator**	**Unit**	**Range**
Efficiency in humanitarian response during the emergency response and rehabilitation stages	- Accessibility and closeness to main routes	- Number of main routes in the neigbourhood	unit	0-3
		- Minimun distance to the closest main street	m	0-1000
	- Basic services and utilities	- Number of operative utilities in the school	unit	4-6
	- Socio-economic level related to social segregation and little compactness	-Income per habitant	$/inhabitant	Min-max
	-Distribution of the building and free areas inside the school	-Free Area	m²	1000 -4000
Good crisis management by local authorities and humanitarian aid	- Level of preparedness and commitment of neighboring communities	- Presence of parents organizations	unit	1=Yes/0=no
	-Presence of public areas in strategic locations	-Population density of neighboring community	Inhabitant/Km²	4000-25000
Efficiency to obtain funds for rehabilitation, reparation or reconstruction projects	- Regulation of the Ministry of Economy and Finances for Public Investment Projects -Access to Insurance and risk transfer mechanism	-Legal clearance	Unit	1=Yes/0=no

8. Study Case: Prioritization for seismic risk reduction in public schools of Lima, Peru.

8.1. Description of the problem

Lima, Peru, is located in the seismically intensive “Ring of Fire” of the Pacific Ocean and has been subjected to many earthquakes over the years (Tavera & Buforn, 1998). The city’s current residential and commercial patterns are scattered and uncoordinated, leading to socio-spatial segregation (Fernández de Córdova, 2012). Informal settlements located in the expansion areas occupy lands exposed to hazards and poor performance during seismic events. School buildings also suffer from poor construction practices arising from a lack of regulated procedures and quality supervision (Blondet, et al., 2004). With no regular budget for investment in schools, parents frequently build schools themselves after pooling their own financial resources. Most of the schools in Lima were built in a staged construction process and additional capacity has been added when there has been money from either families or the government (Santa-Cruz, et al., 2013).

In school buildings, the presence of unsupervised alcoves, dead ends, and narrow corridors are prevalent due to a lack of planning. In addition, some evacuation routes include staircases with low parapets and are likely to become overcrowded. Safety areas are located near elevated water tanks, which probably do not meet structural safety standards. The lack of technical inspections, along with insufficient training of people involved in construction and those responsible for use of the space and furniture, hinder correct definition and maintenance of safety areas and emergency exits.

Most of the schools have been built in accordance with obsolete earthquake-resistant criteria and poor quality-control processes. For typical modules built before 1997 a shear failure in columns (called a short-column failure) is likely to occur, causing the structures to collapse if the event scores higher than a VII on the Modified Mercalli Intensity (MMI) scale. More than 50% of the school buildings in Lima require total replacement to bring them into conformance with the Peruvian building code (MINEDU, 2015).

Schoolchildren in Lima have been targets of previous campaigns to raise risk awareness and build capacity for emergency preparedness. Elementary and high-school students have achieved basic level of risk awareness after community training and monitoring activities involving teachers, parents, and the students themselves (Roca, 2011). However, government entities, academic staff, teachers, and healthcare workers lack the proper training required to provide information or humanitarian aid to students affected by seismic events (Rivera, et al., 2014).

8.2. Applications of prioritization methodology

Seismic hazard was evaluated by Peruvian Institute of Geophysics (IGP) using CRISIS2007 (UNAM, 2008). School and student database were elaborated by National Institute of Statistics. (INEI, 2014) . Structural fragility information of different school types was taken from previous seismic risk analysis done by the Pontificia Universidad Catolica del Peru, PUCP. (Santa Cruz, 2013). Risk information was analyzed with CAPRA (Cardona et al 2012)Population density, main streets, socioeconomic level were elaborate by the Architecture and City Research Center at PUCP (Fernández de Córdova, 2012) and the National Institute of Statistics (INEI, 2008).

Table 3 shows the indicators and their weights used for the estimation of potential of injury and capacity and resilience indexes. They were estimated using an AHP technique based on the expert opinion of 11 stakeholders from governments, academics and professionals in Peru. Capacity and resilience indicators with more weight are the ones related to community and parents organizations (Number of buildings built by parent’s organizations, 22%) and student density (16%). The indicators with less importance were those related to accessibility (main routes in the neighborhood, 7%) and socio-economic level (income per capita, 8%).

Classification criteria are presented in Table 4. High potential of injury is associated to a limited performance objective defined as Life Safety LS Building Performance Level for occasional earthquake demand. From Fig 2 PI related to LS is 60%. A Ci greater that 0.5 represents that the school has satisfactory conditions for post-disaster recovery.

Table 3 – Indicators of Potential of injury, capacity and resilience

Index	**Indicator**	**Weight**
Potential of injury, PI	Seismic Performance of buildings in occasional event	100%
	Total	**100%**
Capacity and resilience, CI	Free Area	15%
	Number of operative utilities in the school	13%
	Number of main routes in the neighborhood	7%
	Minimum distance to the closest main street	11%
	Student density	16%
	Population density of neighboring community	10%
	Income per capita	8%
	Number of buildings built by parents organizations	22%
	Total	**100%**

Table 4 –Classification criteria

Priority	**Potential of injury**		**Capacity and resilience**	
1	Performance in occasional event= Life safety	PI>0.60	In average, conditions for recovery are satisfactory	CI<0.50
2	Performance in occasional event= Life safety	PI>0.60	In average, conditions for recovery are unfavorable	CI>0.50

8.3. Results

Fig. 3 shows the cumulative frequency curves of PI and CI. Approximately 1000 buildings have PI greater than 0.6. There are 500 schools that have good capacities. Fig. 4 shows the classification of schools according the proposed methodology.

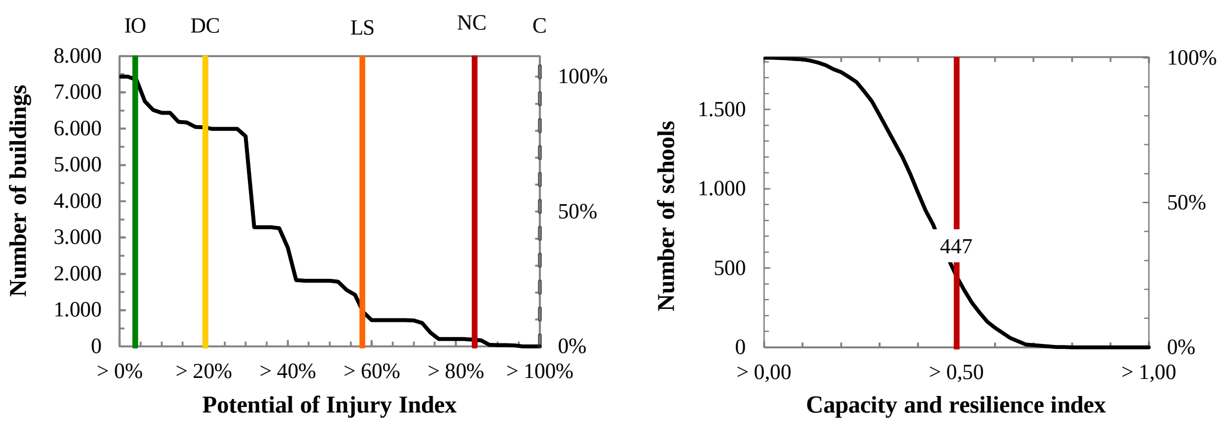
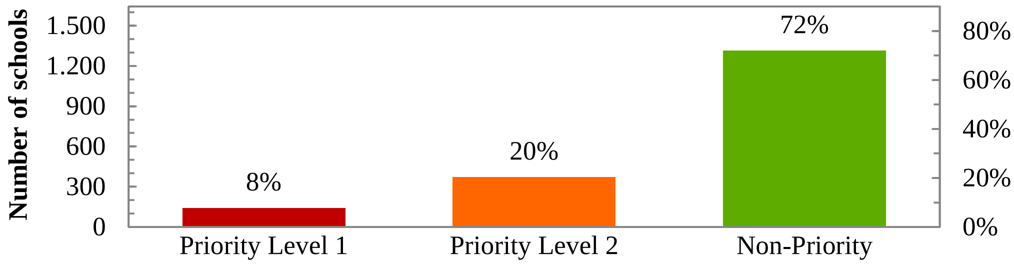


Fig. 3 –Potential of injury and capacity indexes of public schools in Lima.



	Priority Level 1	Priority Level 2	Non-Priority
#	141	371	1.313
%	8%	20%	72%
m²	187.241	428.047	1.439.394
Struct. Reinf. (M S/.)	S/. 104,18	S/. 183,22	S/. 387,11
Struct. Reinf. 2nd Stage (M S/.)	-	S/. 165,48	S/. 216,76

Fig. 4. Classification of public schools according the proposed methodology

9. Comparison of proposed prioritization methodology

In this chapter, we compare the proposed methodology (M1), a structural performance-based approach (M2) and an economic losses-based approach (M3). Table 5 shows the characteristics of the schools, its indexes CI and PI and the EAL.

At first, we compare two schools 1-A and 1-B. They are small schools but have high PI. If we consider the structural point of view, 1-B is more important than 1-A. Proposed methodology considers school 1-A more important because it would be more useful during emergency attention and post disaster recovery (it is near a main street and has well-distribute areas inside the school). On the other hand, if we consider only economic losses then both schools are not considered as a priority.

Table 5. Comparison of three different approaches for prioritization

Case	PI	CI	EAL	Priority Level		
				M1	M2	M3
A	0.74	0.62	S/. 4,896	**Level 1 (48°)**	**Level 2 (157°)**	No priority 1,677°
B	0.95	0.44	S/. 18,952	**Level 2 (142°)**	**Level 1 (1°)**	No priority 1,084°
C	0.55	0.33	S/. 279,264	**Non-Priority**	766°	**Level 1 (7°)**

According to M1, school 1-B should be included in an incremental retrofitting program with limited performance objectives, to reduce the level of damage (DC) in occasional events in the first stage of intervention. In this way, we reduce the potential of injury to the students of this school but we can't guarantee immediate occupation of the school. On the other hand, school 1-A should be part of a complete retrofitting program so we can guarantee that the building is operative (IO) after an occasional event and this situation would be very advantageous due to the capacities of the school and more useful due the conditions of the affected population near the school. Since incremental retrofitting is cheaper than complete retrofitting intervention, authorities could use limited resources efficiently.

According to M3 school 1-C is of very high priority because it has a high value of EAL (it has the 7th greatest value of EAL) and it should be included in the retrofitting program. If we do so, seismic performance will be enhanced from DC-LS to IO. But this school has low capacities to post-disaster attention and the possibilities to become a community meeting point for emergency attention and recovery are low. In this case, resources are not used efficiently.

10. Conclusions

A prioritization methodology for public school risk reduction to address the situation of high risk and limited resources is presented. It is based on indicators that take into account factors related to weaknesses or capabilities at all stages of risk occurrence: classroom, school, neighborhood, and city. It analyzes physical, psychological, and social factors that may have an impact on the student population during emergency attention and post disaster rehabilitation.

The methodology is applied to the case of public schools of Lima and it is proposed two levels of priority in order to achieve the objectives of the prioritization methodology. First level of priority includes schools with high potential of injury and capacities and resilience conditions. Fir this group of schools, it is proposed a structural rehabilitation with enhanced performance objectives. Second level of priority includes schools with high potential of injury and unfavorable conditions for resilience. In this case, limited rehabilitation objectives and incremental retrofitting intervention are proposed.

The comparison of this approach and economical losses- based approach shows that the last one would exclude small schools with high potential of injury. Approaches based only on structural performance don't appreciate organization and preparedness and this could be a disincentive for community participation.

The next step is to determine a methodology to analyze the feasibility of the retrofitting measures to reduce structural fragility and interventions to increase the resilience and capacity of the education systems from a multi-criteria point of view.

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