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EARTHQUAKE SAFETY PRIORITIZATION OF SCHOOL BUILDINGS USING PERFORMANCE-BASED RISK ASSESSMENT IN KYRGYZ REPUBLIC

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Abstract

In 2019, the Applied Technology Council completed the ATC-142 project, conducted for the World Bank Global Program for Safer Schools (GPSS). The objective of the project was to provide technical support to Component 2 of World Bank financed Enhancing Resilience in Kyrgyzstan (ERIK) project, “Improving the safety of school infrastructure (US$ 12-13M),” aimed at safety and functionality of schools in areas of highest seismic hazard in Kyrgyz Republic. ATC and GPSS jointly created a risk-based framework to prioritize schools that had been shortlisted for remediation under criteria established by the Ministry of Emergency Situations, Ministry of Education and State Agency for Architecture, Construction and Communal Services of the Kyrgyz Republic. This paper describes the development of the framework and its results based on available information. The framework acknowledges that there are various approaches to select schools to improve given limited funds: a few schools can be made very safe, more schools can be made safe, or many schools can have their safety improved, even if not to meet modern minima. The framework addresses the complex problem of how to efficiently invest in seismic safety, based largely on the utilitarian criterion of maximizing the number of statistical lives saved per dollar spent, or equivalently minimizing the cost per life saved.

The prioritization criteria rely on determining school seismic retrofit strategies that are most beneficial in terms of lives saved per unit of funds, under the presumption that funds are limited. The results are expressed in terms of benefit-cost ratio (BCR), which is a measure of efficiency. The benefits are the statistical lives saved for a given retrofit. Use of performance-based seismic design allows design of various levels of retrofit for the prevalent typologies in the Kyrgyz Republic. Up to four retrofits with increasing base-shear capacity were developed for each of several representative index buildings. Each retrofit levels is analyzed to determine a quantifiable benefit of seismic risk reduction, and the cost of each retrofit is determined. The utility of the BCR relies on the relative accuracy of the results.

The risk-based framework was applied to all eligible schools for which necessary information was available. The framework allows the list of schools to be prioritized with the application of several policy options. The framework can also constrain choices for additional policy options. For example, one can remove retrofit options that have higher BCR if one objects to improving a building without bringing it to current safety requirements. Or one can choose retrofits with lower BCR to improve ethnic, economic, or geographic balance to the retrofit investment portfolio.

Keywords: schools; seismic retrofit; benefit cost ratio; prioritization; performance-based assessment

1. Background

This paper summarizes work conducted to provide technical support to Component 2 of World Bank financed Enhancing Resilience in Kyrgyzstan (ERIK) project, "Improving the Safety of School Infrastructure (US$ 12-13M)," a lending operation to support the Government of the Kyrgyz Republic.. The design of the program aims to facilitate scaling up efforts by creation of a risk-based framework, that allows authorities to craft a transparent and efficient seismic retrofit and renovation program that maximizes benefit (lives saved) in an environment of limited funds. As part of ERIK project, the World Bank Global Program for Safer Schools (GPSS) aims to boost and facilitate large-scale investments for the safety and resilience of new and existing school infrastructure at risk from earthquakes and contribute to quality learning environments.

The most comprehensive dataset of the 3,028 Kyrgyz public schools was compiled by United Nations Children's Fund (UNICEF) in 2013. For Component 2 of the ERIK project, the Ministry of Emergency Situations, Ministry of Education and State Agency for Architecture, Construction and Communal Services of the Kyrgyz Republic applied the following selection criteria to shortlist the national school portfolio ("candidate schools") to pool of 300 "eligible schools" for the pilot program (Figure 1):

- **State schools.** Only state schools were considered eligible for ERIK funding.
- **Year of construction.** In an effort to select schools that are not yet nearing the end of their useful life, schools built before 1970 were not included in the list of eligible schools.
- **Number of students.** To maximize the safety benefits, schools with a large number of students were selected for the list of eligible schools. The cutoff was defined as greater than 500 students for school buildings in large cities (specifically, Bishkek and Osh) and greater than 100 students for school buildings in rural areas.
- **Percent occupied.** To maximize the safety benefits, schools that are fully occupied or near fully occupied were selected for the list of eligible schools. The cutoff was defined as occupancy of 70% or more of the school capacity.
- **Areas of high seismic risk.** Schools in oblasts (administrative regions of the Kyrgyz Republic) and cities with high seismic risk were selected for the list of eligible schools.
- **Engineered school buildings.** In selecting eligible schools, it was assumed that non-engineered buildings would likely not be cost-effective to retrofit and thus it was decided that at least 70% of school buildings in the eligible schools list should be of engineered construction.
- **Eligible for funding.** Bishkek schools that were already approved for other school retrofit funding were excluded from the list of schools eligible for ERIK funding.

Application of these selection criteria to the UNICEF dataset, coupled with the data fields that are required for risk-based prioritization, such as need for confirmed location (latitude/longitude), occupancy size, and structure type designation, resulted in an eligible school database with approximately 300 schools.

Fig. 1.

2. Project Objective

This project developed a risk-based framework to assist in establishing a prioritized list ("selected schools" in Fig. 1) among eligible schools. The framework can be applied in other countries with necessary adaptations. The guiding objective of the framework is to maximize benefit in terms of reducing seismic risk for students, predicated on the condition of limited funds.

3. Methodology Overview

We developed a methodology to prioritize the seismic retrofit of existing school buildings in Kyrgyz Republic to maximize the safety benefits, cost-efficiency, and benefit-cost ratio of available funds. The method uses performance-based earthquake engineering techniques combined with available data supplemented by field investigations to estimate the vulnerability of Kyrgyz schools. It proposes various levels of retrofit that could improve the earthquake life-safety and collapse resistance for common Kyrgyz school building types. It characterizes the probabilistic seismic hazard at each school building, and combines all these data to estimate the particular retrofit costs and life-safety benefits of each of several retrofit levels. The costs and benefits are calculated to demonstrate allocation of available retrofit funds to do the most good for the most school children.

We measured benefits in terms of the long-term expected value of statistical lives saved for a given retrofit of a given building (as opposed to measuring fatalities avoided in a scenario earthquake, or considering nonfatal injuries, repair costs, the value or duration of lost use, historic or cultural value, or other loss measures). Use of performance-based seismic design allows design of various levels of retrofit for the prevalent typologies in the Kyrgyz Republic. Up to four retrofits with increasing seismic capacity were developed for each selected representative index building. Each of these levels of retrofit were analyzed to determine a quantifiable benefit of seismic risk reduction, and the cost of each retrofit is determined. In addition to the retrofit costs, expenditures to modernize energy efficiency (EE) and water, sanitation, and hygiene (WASH) for each school were evaluated. In such an approach, the absolute seismic performance is less important to the choice of which schools to retrofit. Instead, the method prioritizes practical retrofit options based on the relative safety improvement associated with each level of retrofit. Trade-offs between acceptable levels of performance and practical (i.e., cost-effective) retrofit solutions is a strategy that is regularly used in the United States and internationally. Consequently, it is important to be consistent with all the assumptions for all the levels of retrofit and building types. This applies both for the analyses and the cost estimates.

The following steps comprise the framework discussed in this paper and documented in detail in the ATC-142 report [1]:

- Identify available data from the UNICEF database of school buildings
- Develop an inspection plan to collect information relevant to the framework
- Inspect 70 the eligible schools and compile data
- Based on information from the eligible schools database and field inspections, identify characteristics of the three most common structural typologies for blocks
- Determine vulnerabilities of index buildings selected to represent structural configurations, characteristics, and attributes
- Design interventions in terms of levels of retrofit (retrofit increments)
- Estimate costs for each of the retrofit increments
- Develop vulnerability function for each index building at each retrofit increment, as well as the unretrofitted condition, informed by available information in the literature

- Calculate safety and cost efficiency index values for each increment; check code-conformance of each retrofit increment
- Develop prioritized list of schools utilizing combination of different policy options

4. Characteristic Structural Typologies for Kyrgyz School Buildings

To develop intervention options for risk reduction at scale, it is necessary to characterize and analyze the school portfolio in a manner that generalizes and categorizes school buildings, as it is not feasible to study the seismic vulnerability of each individual school building in the country. Among the eligible schools, three typologies, Complex Masonry (CX), Complex Masonry Concrete Frame (CXCF), and Precast Concrete Frame (PC) made up over 80% of the buildings. Representative index buildings were defined for each of these three typologies based on typical characteristics identified from field inspections and a review of available structural drawings.

4.1 Complex Masonry

Field inspections and review of available drawings indicate that a common typology among Kyrgyz Republic school buildings is load bearing masonry walls with horizontal seismic belts and occasionally with vertical reinforced concrete inclusions. The typology has attributes of unreinforced masonry, confined masonry, and reinforced concrete frame construction, and has been termed Complex Masonry (CX).

CX school buildings in Kyrgyz Republic are generally rectangular in plan, one to two stories tall. The buildings are often comprised of adjacent, but structurally separated blocks. While the separation will not prevent pounding during large earthquakes, the floors usually align, and this is typically not a safety issue. The diaphragms are precast hollow core concrete planks without a concrete topping slab. The planks are constrained by reinforced concrete belts (tie beams within the walls) and behave like rigid diaphragms under low demands.

Fig. 2 – Two-story CX school building in Osh.

Most buildings of this type generally do not have structural irregularities. Nor do they typically have appurtenances, such as chimneys, parapets, or other elements that can be external falling hazards. The construction materials are durable, and the buildings are generally in medium to good structural condition. An example CX building is shown in Figure 2.

4.2 Complex Masonry Concrete Frame

The CXCF typology is like the CX typology and typically one to three stories tall. It is typically composed of masonry bearing walls and concrete frames. The CXCF school buildings in the Krygyz Republic have similarities to the commonly accepted definitions for both confined masonry and reinforced concrete frames with masonry infill buildings.

The walls occur in both interior and exterior conditions, and there are occasional interior concrete framing of beams and columns. Masonry bearing walls have horizontal reinforced concrete seismic belts and occasionally with vertical reinforced concrete inclusions. The inclusions are both in the form of distinct square columns and rectangular trim elements. The CXCF typology has occasional concrete beams and columns and is defined to be larger and more complex than its CX counterpart.

Like the CX typology, the CXCF buildings have diaphragms of hollow core precast concrete floor planks connected to horizontal concrete seismic belts within the masonry walls. They are rigid under small loads. CXCF schools often have a complex configuration in plan, made up of seismically separate rectangular blocks. While the separation will not prevent pounding during large earthquakes, the floors usually align, and this is typically not a safety issue. An exception can occur where CX gyms can experience pounding from blocks with diaphragms at different heights.

Horizontal and vertical irregularities are not typical, but they do exist in some cases. The concrete columns are often shear critical. With the exception is masonry gables that sometimes occur, most buildings do not have appurtenances, such as chimneys, parapets, or other external elements that represent falling hazards. Internal falling hazards are partitions made of single wythe lightly reinforced masonry walls. The construction materials are durable, and the buildings are generally in medium to good structural condition. Example buildings are shown in Figure 3.

Fig. 3 – Typical exterior of CXCF school buildings in Kyrgyz Republic.

4.3 Precast Concrete Frame and Walls

The precast concrete frame and wall buildings (PC) are one to three stories tall and have a complete precast concrete frame system with precast wall panels. The panels were designed to not participate in the lateral resistance, as they are seismically de-coupled from the frame for low drifts. Panels span horizontally between column elements, and multiple panels are required to enclose a story level.

PC school buildings often have a complex configuration in plan, made up of seismically separate rectangular blocks. While the separation will not prevent pounding during large earthquakes, the floors usually align, and this is typically not a safety issue. An exception can occur where PC gyms can experience pounding from blocks with diaphragms at different heights.

The diaphragms are hollow core precast concrete floor planks constrained by precast reinforced concrete beams. They are rigid under small loads. The blocks generally do not include irregularities although the frames typically can form story-mechanisms at the first story. Most buildings do not have appurtenances, such as chimneys, parapets, or other external elements that represent falling hazards. The internal partitions are single wythe lightly reinforced masonry walls, that are a falling hazard. The structural materials are durable, and buildings are generally in medium to good condition. An example building is shown in Figure 4.

Fig. 4 – Typical PC classroom block in Kyrgyz Republic.

5. Seismic Evaluation, Incremental Retrofit, and Cost Estimation

Performance-based seismic assessments were conducted for a representative “index” building of each structural typology as identified in Section 4. The index buildings were evaluated in as-is and with several retrofits of varying capacities, using static nonlinear pushover analyses. The graphical display of the pushover analyses is especially useful for comparing the relative capacities of the retrofits.

Conceptual retrofit designs were prepared for various levels of retrofits (increments 1-4) for each index building. The objective of a seismic retrofit is to increase the seismic capacity of a building, increasing the building’s ability to resist seismic demands. The general seismic retrofit approach in each increment involves providing additional strength to resist earthquake forces, additional stiffness to limit building movement (drift), or the addition of supplemental elements to allow additional displacement and maintain integrity in an earthquake. The higher increment number corresponds to greater capacity.

The index buildings in their as-is conditions were evaluated for two performance objectives, life safety (LS) and collapse prevention (CP). Life safety is a state that poses a danger of injury and/or loss of life that could occur with a partial collapse within the building resulting from accelerations experienced by components of the building or from drifts within the building. Collapse Prevention (CP) is a state that poses a danger of injury and/or loss of life that could occur with a side-sway collapse of a major portion of the building. The fatality rates due to reaching these limit states is 1.5% for LS and 30% for CP.

Each retrofit increment has different design approach to improve capacity. The lower increments primarily add displacement capacity and the higher increments add strength and displacement capacity. We selected multiple increments because we did not know at the outset which approach would prove to be the most efficient. Not all meet the CP or LS performance objectives under the hazard corresponding to the design earthquake for the Kyrgyz code. Figure 5 is a simple illustration for non-engineer stakeholders to show how each retrofit increment differs in the strategy for adding displacement capacity, strength, resistance to collapse, and resistance to falling hazards.

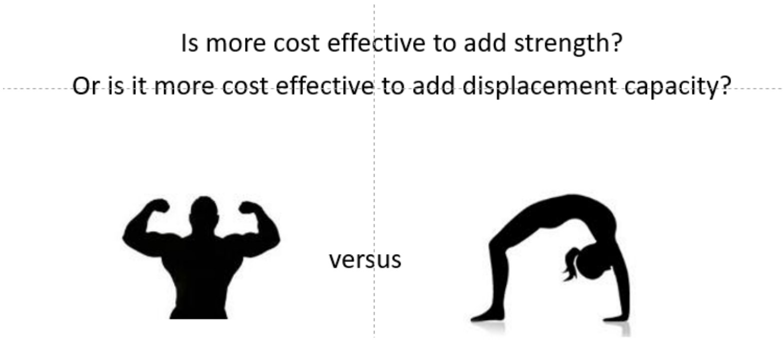

Fig. 5 – Graphic illustration depicting design for strength vs. flexibility.

Relative capacities of the increments are a progression starting from the as-is condition of the building. A series of partial collapse failures are expected in the as-is condition of each typology due to increased accelerations acting on components of the building even at relatively low levels of shaking from relatively frequent earthquakes. Examples include the out-of-plane failure of heavy nonstructural wall partitions, out-of-plane failures of non-load-bearing structural walls, and other similar events. In the retrofit approach, these initial series of failures are lumped into a single event because they occur at similar accelerations. Early failures do not occur due to drift in masonry buildings because they are stiff and relatively strong although brittle. These types of failures occur prior to a side-sway collapse of the overall building.

Increment 1 is designed to mitigate these initial failures and allows the existing building to reach its full capacity in terms of peak strength but does not improve the displacement capacity. Once the retrofit of Increment 1 is in place, the next event is the global collapse of the buildings due to a side-sway mechanism.

Increment 2 is designed to increase seismic resistance of the building, primarily by increasing the displacement capacity prior to collapse. This is accomplished by a variety of means which differs for each typology. It is intended to add benefit primarily by forestalling the CP limit state. For example, with the Precast Concrete Frame (PC) buildings, Increment 2 added reinforce concrete jackets around the shear critical columns.

Increment 3 is designed to further increase seismic resistance of the building by adding significant strength in addition to displacement capacity.

Increment 4 is designed to further increase seismic resistance of the building. It is aligned to satisfy the strength requirements expected in the upcoming Krygyz Republic code [2] for retrofits. Increment 4 is the only retrofit with significant foundation strengthening. It is intended to improve both the LS and CP limit states.

Index buildings were analyzed using pushover analysis techniques based on nonlinear static analysis procedures in ASCE/SEI 41-17 [3]. Two different analysis techniques were used to create the pushover curves for the index buildings and their retrofits:

- The CX and CXCF index buildings are dominated by the response of the brick masonry wall elements. Both buildings are relatively stiff, and the behavior is more influenced by the strength and the nonlinear response of the elements, as compared to the elastic stiffness. The piers and walls vary greatly throughout the structure due to variation in size, the presence of inclusions, and variation of axial loads. The responses tend to be controlled by brittle behavior. For these reasons, the overall capacities were determined by summing the backbone curves of the individual elements. The curves are per ASCE/SEI 41-17.

- The precast index building (PC) has a flexible frame and a relatively regular configuration. The response is dominated by the stiffness of the frame. An inelastic model was created using fiber elements to capture the flexibility and the nonlinear response.

Capacities were determined using nominal strengths per the drawings and modified for expected strength properties and material strength equations of ASCE/SEI 41-17. The masonry strengths and the expected strength were selected per the Krygyz Republic code. Material strength information was assumed when specific information was not available.

Cost estimates were developed for each of the conceptual retrofit increments based on 2018 Kyrgyz Republic rates and construction norms.

The retrofit levels compare as follows:

- The ratio of structural costs for Increment 1 as compared to Increment 4 ranges from 5% to 24%.
- The ratio of structural costs for Increment 2 as compared to Increment 4 is approximately 50%.
- The ratio of structural costs for Increment 3 as compared to Increment 4 is approximately 85%.

5.1 CX Building Example

The following seismic deficiencies were identified in typical complex masonry school buildings in Krygyz Republic:

- Inadequate strength and brittleness of masonry walls
- Lack of positive connection between masonry walls and floor or roof diaphragms parallel to floor and roof planks
- Inadequate lateral capacity for nonstructural masonry partitions
- Inadequate lateral anchorage for the entry structure

Increment 1 for CX eliminates the partial collapse mechanisms that would be expected prior to the building reaching a complete side-sway collapse in both directions. Increment 2 for CX builds on Increment 1 and adds displacement capacity to the controlling mechanisms by providing reinforced concrete jackets around critical masonry elements. Increment 3 is similar to Increment 2 but the jackets for the interior walls extend two levels in both transverse and longitudinal directions. The two-level jackets eliminate uncertainty in the response of the walls by eliminating unprotected bricks. This allows higher rocking displacements at the collapse limit. Increment 3.5 adds strength to Increment 3 in the controlling transverse direction in order to meet the minimum strength requirements expected for the forthcoming Kyrgyz Republic retrofit code. Increment 4 is designed eliminate all unsecured brick to achieve the LS limit state.

Fig. 6 shows simplified backbone curves for all increments. Increments 2 and 3 add displacement capacity, Increments 3.5 and 4 add strength and displacement capacity. Figure 7 shows the costs of each increment, including the added costs for improved energy efficiency EE and improved water sanitation and hygiene WASH.

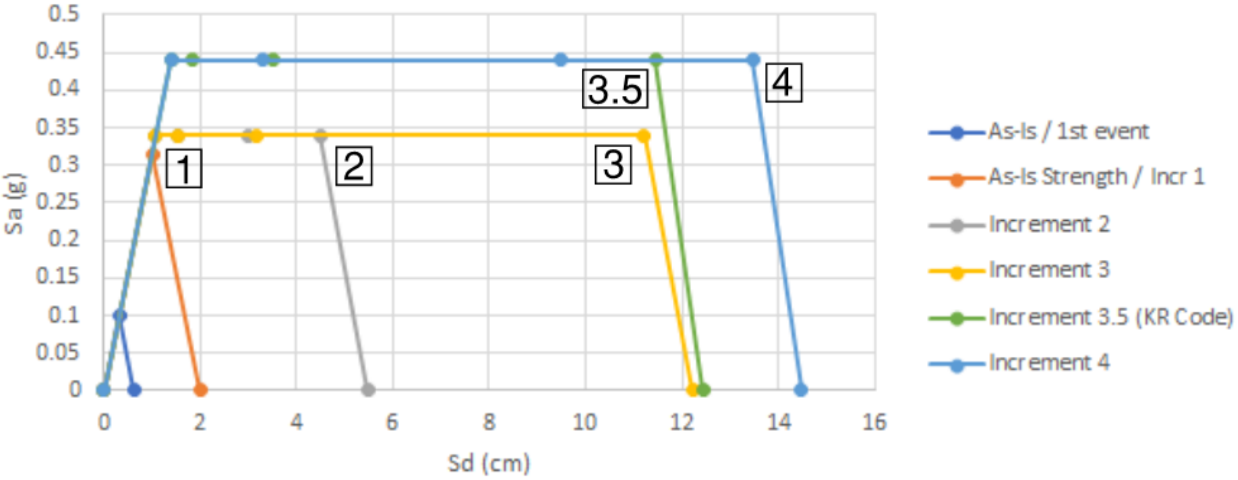

Fig. 6 – Pushover curves (spectral acceleration versus spectral displacement) for Increments 1 through 4 for CX index building, transverse direction.

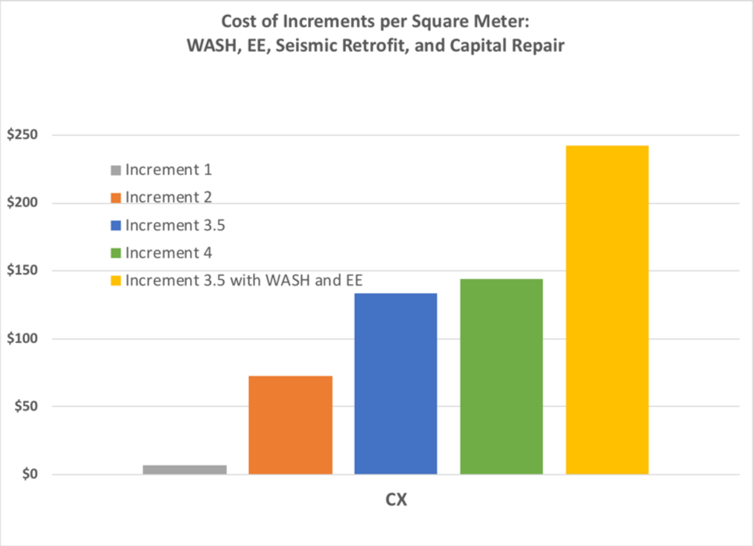

Fig. 7 – WASH, EE, seismic retrofit, and capital repair cost estimate per square meter for CX typology at different retrofit increment levels.

6. Risk-based Prioritization Framework

The prioritization framework relies on the calculation of two indices that can be combined into a benefit-cost ratio, in which benefit is measured in terms of lives saved and cost is measured in terms of retrofit cost. The framework has the following approach:

- Seismic hazard is characterized on a school-by-school basis. This captures the signification variation in the seismic demand, a key driver for the prioritization.
- Seismic vulnerability of a building, in the form of a function giving the mean fraction of building occupants killed given a ground motion level, is estimated. If a partial collapse occurs, then 0.5% of the occupants are assumed to be killed. The fatality rate is assumed to be 30% under side-sway collapse.
- Prioritization indices and benefit-cost ratio are calculated.
- Prescriptive performance levels (LS and CP) are checked for compliance.

Based on the vulnerability function developed for each building, two prioritization indices, A_1, safety/benefits index; and A_2, cost/efficiency index, are calculated for each eligible school.

6.1 Safety/Benefits Index A_1

The safety/benefits index, A_1, represents the safety benefit per student per unit cost of the retrofit. It is calculated as follows:

$$A_1 = \frac{B_r}{V} = \left(\frac{EAL}{V} - \frac{EAL_r}{V}\right) \times t \tag{1}$$

where:

B_r = benefit of retrofit r, in terms of reduced number of fatalities during the life of the building

V = estimated time-averaged population of students at the building, i.e., accounting for nighttime and weekend hours during which the building is unoccupied

$$= Occs \times h \tag{2}$$

where:

$Occs$ = actual number of occupants during school hours

h = fraction of the week during which the school is occupied

$$\frac{EAL}{V} = \int_{x=0}^{\infty} y(x) \left| \frac{dG(x)}{dx} \right| dx \tag{3}$$

$$\frac{EAL_r}{V} = \int_{x=0}^{\infty} y_r(x) \left| \frac{dG(x)}{dx} \right| dx \tag{4}$$

where:

EAL = expected annual number of fatalities under as-is conditions

EAL_r = expected annual number of fatalities under retrofit r

$G(x)$ = mean exceedance frequency of ground motion x, events per year

$y(x)$ = seismic vulnerability function for as-is condition

= $y_Q(x)$ if among the buildings examined with performance-based earthquake engineering

$y_r(x)$ = seismic vulnerability function under retrofit r

= $y_{Q,r}(x)$ if among the buildings examined with performance-based earthquake engineering

t = expected remaining useful life of the structure.

6.2 Cost/Efficiency Index A_2

The cost/efficiency index, A_2, represents the number of students benefited by a retrofit per unit cost of the retrofit. A_2 is calculated as follows:

$$A_{2,r} = \frac{Occs}{C_r} \tag{5}$$

where:

Occs = actual number of occupants during school hours

C_r = cost of retrofit *r*. The cost might be a square-meter value multiplied by the area of the building.

6.3 Calculate Benefit-Cost Ratio

The benefit-cost ratio is calculated as a combination of the two prioritization indices, A_1 and A_2:

The benefit-cost ratio of retrofit *r* is calculated as follows:

$$BCR_r = A_{1,r} A_{2,r} h = \frac{B_r}{C_r} \tag{6}$$

where:

BCR_r = benefit-cost ratio of retrofit *r* for the particular building

$A_{1,r}$ = safety/benefits index of retrofit *r* for the particular building in question

$A_{2,r}$ = cost/efficiency index of retrofit *r* for the particular building in question

h = fraction of the week during which the school is occupied

B_r = benefit of retrofit *r*, in terms of reduced number of fatalities during the life of the building

C_r = cost of retrofit *r*. The cost might be a square-meter value multiplied by the area of the building.

7. Application of Risk Framework

The study produced several options and insights for how best to allocate the retrofit money. The output is a table that prioritizes schools to be retrofitted, based on efficiency (most lives saved per USD), depending on policy constraints selected.

One can allocate the funds based purely on efficiency: maximizing the number of lives saved for the available funds. With $12 million, using the pure-efficiency prioritization option, the Kyrgyz Republic can seismically retrofit 55 schools that together have 49,000 occupants. Considering how frequently events of various intensities occur, the pure-efficiency retrofit option would save 3,200 lives at a cost per life saved of $3,600. This condition reveals that the less expensive lower retrofit increments are significantly more efficient than the more expensive higher retrofits with more capacity. This primarily due to the shape of the hazard curve and the relatively low frequency of massive earthquakes.

Alternatively, one can constrain the retrofit so that the schools meet the performance criteria that emerging Kyrgyz Republic building codes demand for retrofit of schools. Only retrofit increments 3.5 and 4 satisfy these criteria. One can allocate some of the funds to retrofit EE and WASH at the same time as the seismic retrofit. One can also require that, where the retrofit cost exceeds 50% of the replacement cost of the existing school, one should demolish and replace the school rather than retrofitting it. Each of these policy decisions has merit. However, these constraints each add cost, and the available funds do not go as far. Under such a prioritization scheme, the Kyrgyz Republic can use the available funds to retrofit 26 schools that together have 25,000 occupants, saving an estimated 2,000 lives at a cost per life saved of $5,500.

Both prioritization schemes maximize benefit (lives saved), within the context of the particular policy. The prioritization framework allows the examination many other policy scenarios. In any scheme, the framework ensures that the schools creating the greatest benefit are retrofitted first.

Each school is unique and will differ in important ways from the sample buildings considered here. Because of these differences, the ultimate cost and benefits of the retrofit will vary from the estimates presented here. However, the prioritization scheme should help the Kyrgyz Republic be informed in creating policy. Thus, it allows to focus on the buildings that are most likely to save the most lives for the available funds.

The proposed framework and prioritization list of schools for intervention was unanimously approved and endorsed by relevant government agencies and the Parliament of the Kyrgyz Republic. With support from the Global Facility for Disaster Reduction and Recovery (GFDRR), the World Bank has initiated a second phase of the Technical Assistance to extended this analysis to the whole portfolio of school and pre-school facilities countrywide. Additionally, the government and the World Bank are discussing a potential Additional Financing for ERIK project to scale up Component 2.

8. Global Library of School Infrastructure

The characteristics identified for Kyrgyz Republic school buildings will be included in the Global Library of School Infrastructure (GLOSI) [4] recently launched by the Global Program for Safer Schools . GLOSI characterizes school buildings from around the globe utilizing 12 taxonomy parameters. This allows different project teams working in different countries to identify a comprehensive set of information about index buildings in different countries. GLOSI includes technical documents, tools (for example, applications for data collection), and a catalog of index buildings with specific information about failure modes, vulnerability functions, and documented retrofitting projects.

9. Acknowledgements

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