Methodology for Developing Efficient Investment Strategies for Safer and Resilient Schools

Applied Technology Council

WORLD BANK GROUP
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Global Facility for Disaster Reduction and Recovery

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Preface

The objective of this project, entitled "Building Technical Capacity in Central Asia to Design Risk-Informed Public Infrastructure Investments at Scale" (also named the ATC-148 project), is to provide technical support in the development of risk information and design of risk-reduction strategies for public facilities in Central Asia. This report summarizes the component of the work that focused on school buildings in Kyrgyz Republic, including development of a school infrastructure baseline, conduct of performance-based seismic assessments, calculation of safety benefits, and prioritization of school facilities in terms of a safety benefit-cost ratio. In addition, workshop-style presentations to strengthen technical capacity of local stakeholders on seismic risk analysis and design of risk reduction strategies were performed during the conduct of this project.

This project was implemented by the World Bank Global Program for Safer Schools (GPSS). The GPSS aims to boost and facilitate large-scale investments for the safety and resilience of new and existing school infrastructure at risk from natural hazards and contribute to quality learning environments. For the conduct of this project and development of this report, the Program partnered with the Applied Technology Council (ATC). Since 1973, ATC has been at the forefront of developing and promoting user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment. Over its history of operation, ATC has developed more than 150 major reports and engineering guidelines that have served to define seismic engineering design practice in the United States, including seismic design of new buildings, seismic evaluation and retrofit of existing buildings, and evaluation and repair of earthquake-damaged buildings; many have become de facto international standards.

Acknowledgements

This report is the result of World Bank work started in 2019 in contract with the Applied Technology Council (ATC). Numerous professionals participated in the development of this report.

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This project was developed under the leadership of Fernando Ramirez Cortes (Task Team Leader). The World Bank team included: Carina Fonseca Ferreira, Angie Paola Garcia Arevalo, and Jingzhe Wu.

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The World Bank gratefully acknowledges the ATC-148 Project Team as the leading author of this report. The Project Technical Committee, consisting David Mar (Chair), Stephanie King, and Ilya Shleykov, researched and assembled the information contained herein. Luis Alfredo Ceferino Rojas led the risk development work. Engineering design and cost estimation services were supported by Sandesh Aher, Afshar Jalalian, Alexi Kouromenos, Omer Ulker, and Sergei Utischev, and infrastructure baseline database development services were supported by Mary Criss Suárez Antúnez, André Alberto Muñoz Flores, and Jorge Manuel Morales Tovar. ATC staff, consisting of Ayse Hortacsu (Project Manager), and Carrie J. Perna, provided project management and report production services.

Reviewers

The Project Advisory Panel, consisting of Bill Holmes, Charlie Kircher, and Jose Restrepo, provided technical review, advice, and consultation at key developmental stages of the work.

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Chapter 1
Introduction

1.1 Objective

This report summarizes the development of a risk-based framework that implements prioritization criteria based on safety benefits and cost efficiency. The prioritization criteria, provided in Appendix A (in Russian), were approved by Kyrgyz Government decree in March 2018 and is implemented here on the entire school infrastructure of the country. The framework is developed to be flexible, adaptable, and transparent so that it can be used to inform efficient policies to secure seismic safety of schools in Kyrgyz Republic.

The framework is based on the methodology introduced in the ATC-142 project report, *Safety Prioritization of School Buildings for Seismic Retrofit using Performance-Based Risk Assessment in the Kyrgyz Republic*, (World Bank, 2019a), and expands the available data and information for conducting the prioritization.

1.2 Approach

Similar to the ATC-142 project, "Do the Most Good for the Most Kids" is the motto for the project. It captures the guiding objective to maximize benefit in terms of reducing seismic risk for students, predicated on the condition of limited funds. There are various approaches to select schools to improve given limited funds—a few schools can be made very safe, more schools could be made safe, or a lot of schools could be made much better than they are now. The risk-based framework developed in this project addresses the complex problem of how to most efficiently invest in seismic safety.

Determining the efficiency of a retrofit for a building at a particular site is complex. The efficiency is influenced by several factors: the specific vulnerabilities and capacity of the building, the costs of construction, and the seismic hazard. In the Kyrgyz Republic, as with many seismically active areas, smaller earthquakes are expected to occur at a much greater frequency than larger earthquakes. This characteristic of the hazard in a risk-based context suggests that retrofitting more buildings to resist smaller earthquakes may save more lives than retrofitting fewer buildings to resist larger earthquakes. Moreover, many institutions, governing bodies, and practicing engineers in the United States have frequently found that the levels of safety and damage resistance expected for new construction are very expensive to achieve in retrofits. These two trends suggest the safety vs. cost curve shown in Figure 1-1. This curve demonstrates that designing to very high levels of safety may be cost inefficient. Within the limits of the study, the framework presented in this report validates this assumption, and offers the means to efficiently improve safety for the candidate schools.

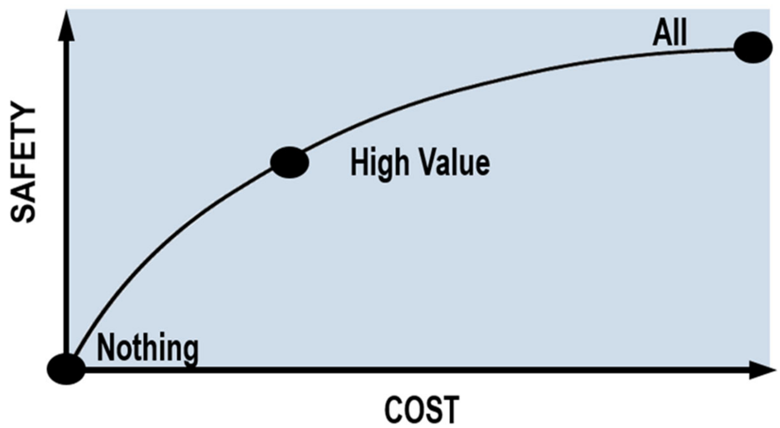

Figure 1-1 Illustration depicting concept of identifying high value risk reduction strategies to maximize benefit efficiently.

1.3 Intended Audience

The intended audience for this report includes:

- Decision makers who seek information regarding the priority order of schools that were considered in the project
- Program managers who seek to implement the methodology described at scale in Kyrgyz Republic or adapt it to other countries with similar circumstances
- Engineers who seek information regarding intervention options and underlying performance objectives for building types prevalent among schools in Kyrgyz Republic

1.4 Methodology Overview

The framework presented in ATC-142 project report was adapted for use in this project. Whereas the ATC-142 project scope was focused on safety prioritization of a list of "eligible" schools (300 facilities) with limited information, this work applies the safety-benefit calculation approach of the ATC-142 project to the entire school inventory in the country with more refined survey information.

This study also benefited from a similar project undertaken in the Republic of Uzbekistan conducted by the World Bank with support from the Global Facility for Disaster Reduction and Recovery (GFDRR) and the Government of Japan, which provided grant support through the Japan-World Bank Program for Mainstreaming Disaster Risk Management in Developing Countries. The Applied Technology Council served as a consultant for this work and conducted performance-based seismic assessment and developed risk reduction strategies for representative education and healthcare building types in Uzbekistan. Because of similarities in construction types and materials in Uzbekistan and Kyrgyz Republic, information developed based on school facilities in Uzbekistan are utilized in this project.

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. For the prioritization framework, all seismic retrofits targeted code-level performance for new buildings. Retrofit designs are analyzed to determine a quantifiable benefit of seismic risk reduction, and the cost of each retrofit is determined. In addition, required energy efficiency (EE) and water, sanitation, and hygiene (WASH) costs were estimated for each school.

The utility of the BCR relies on the *relative* accuracy of the results. This is much more important than the precision of any given analysis or cost estimate. Consequently, it is important to be consistent with all the assumptions for all the retrofit increments and building types. This applies both for the analyses and the cost estimates.

It is noted that whereas the performance-based assessment calculations and the risk-based prioritization were applied at the "block level," the resulting priority list is indicated at the "school level." In this report, "block" refers to a rectangular whole building or rectangular portion of building with two or more seismically separated rectangular elements. The term "school" refers to a group of buildings at a common address.

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 options. The first is using only seismic safety efficiency, i.e., prioritizing schools by benefit-cost ratio. In this case, the schools listed highest are schools where the most lives would be saved per dollar invested. The framework can also be constrained for additional policy options. For example, during the mobilization of a seismic retrofit, it may be relatively efficient to invest in improvements to energy efficiency and water, sanitation, and hygiene. These benefits (EE and WASH) cannot be directly compared to the safety benefit. However, because they draw from the same pool of funds, the policy decisions for EE and WASH investments impact safety. This report does not comment on policy options. Rather, the impacts of various policy options as they alter the framework results are presented in a transparent way to inform decision making.

The information developed in this report can be used as a starting point to develop a risk-based framework to prioritize interventions by comparing the relative accuracy of benefit-cost ratios. In this case, it is important to be consistent with all the assumptions for analyses and cost estimates for all the retrofit increments and building types. The framework can be adapted to incorporate policy options, e.g., using only seismic safety efficiency that would prioritize facilities by benefit-cost ratio, or including improvements to EE and WASH in addition to seismic safety efficiency. The various policy options would alter the framework results and inform decision making.

1.5 Report Organization

This report is organized as follows:

- Chapter 2 presents an overview of the development of school infrastructure baseline.

- Chapter 3 describes the typical characteristics and vulnerabilities for the structural typologies identified in Chapter 2.
- Chapter 4 describes typical structural analysis strategies, seismic retrofit concepts developed using performance-based assessments, and baseline assumptions for retrofit cost estimates.
- Chapter 5 describes the development of fragility and vulnerability functions.
- Chapter 6 describes development and implementation of the risk-based seismic prioritization framework.
- Chapter 7 presents findings and conclusions from the study, as well as recommended next steps and study limitations.

Lists of references and project participants are provided at the end of this report. Volume 2, *Supporting Electronic Documentation*, provides materials supporting the work documented in this report.

Chapter 2

Development of School Infrastructure Database

This chapter provides a summary of work conducted to develop a database of school infrastructure in Kyrgyz Republic.

Datasets provided by the Ministry of Education and Ministry of Preschool Education show that there are 2,262 school sites and 1,580 preschool sites in Kyrgyz Republic. However, these data did not include geographical information or information necessary to characterize and analyze the school portfolio with respect to developing preliminary intervention options for risk reduction at scale. Accordingly, it was necessary to develop a school infrastructure database in a manner that categorizes school buildings, as it is not feasible to study the seismic vulnerability of each individual school building in the country. To do this, information collected during limited field surveys was combined with previously collected information.

2.1 Field Surveys

In order to gather data on parameters that pertain to a building's seismic response, occupancy, and water and sanitation needs field surveys were conducted under World Bank financed Enhancing Resilience in Kyrgyzstan (ERIK) project. The data were collected using Global Library of School Infrastructure (Glosi) data collection tools in order to be consistent with global school taxonomy efforts by the World Bank's Global Program for Safer Schools (GPSS). Appendix B presents an update to the Glosi *Taxonomy Guide* that was published in October 2019. The primary purpose of the update was to incorporate additional options under Parameter 1 (P1), Main Structural System, to describe the following construction types prevalent in Kyrgyz Republic:

- complex masonry (CX)
- complex masonry walls and concrete frames (CXCF)
- reinforced masonry with clay/concrete bricks or blocks and horizontal RC bands (RM2)
- prefabricated large panel reinforced concrete wall system (PC1)
- prefabricated reinforced concrete frames with exterior prefabricated reinforced concrete wall panels (PC2)
- timber frames (TF)
- timber walls (plank or log buildings) (TW)

Descriptions for each main structural system are presented in Appendix B.

A one-day training for field survey teams was held in Bishkek, Kyrgyzstan, including review of visual characteristics of each structural system, as well as best practices for collecting measurement information on field visits. Four institutions participated in the field surveys:

- Osh Technological University (OshTU)
- Kyrgyz State University Of Construction, Transport and Architecture (KSUCTA)
- International University of Innovation Technologies (IntUIT)
- GISSIP

Field surveys were conducted by local inspection teams through February 2020. Data collected were transmitted via a GIS-enabled Survey123 interface that allowed repository of data as well as photos from field surveys. A quality control process was implemented to review survey information and to ensure consistency.

Figure 2-1 shows a map of 2,010 school sites (653 preschools and 1,357 schools) visited during field surveys. Appendix C presents a summary of data collected during field surveys prepared by GPSS team.

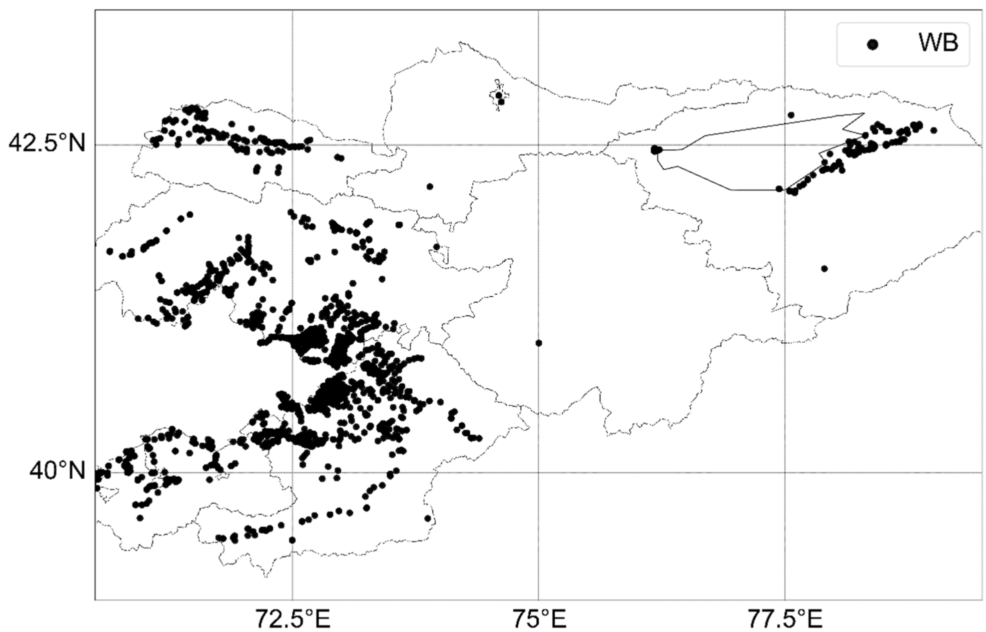

Figure 2-1 Map of Kyrgyz Republic showing location of school sites visited during field surveys.

2.2 UNICEF Database

The United Nations Children's Fund (UNICEF) and the International Strategy for Disaster Reduction (UNISDR) developed a qualitative methodology to assess school safety (United Nations Children's Fund, 2013). Figure 2-2 shows a map of the 3,014 school sites (794 preschools and 2,220 schools) with information on the UNICEF database. These data are more limited than the school portfolio reported by the Ministry of Education and Ministry of Preschool Education, likely because the UNICEF data collection efforts concluded nearly a decade ago.

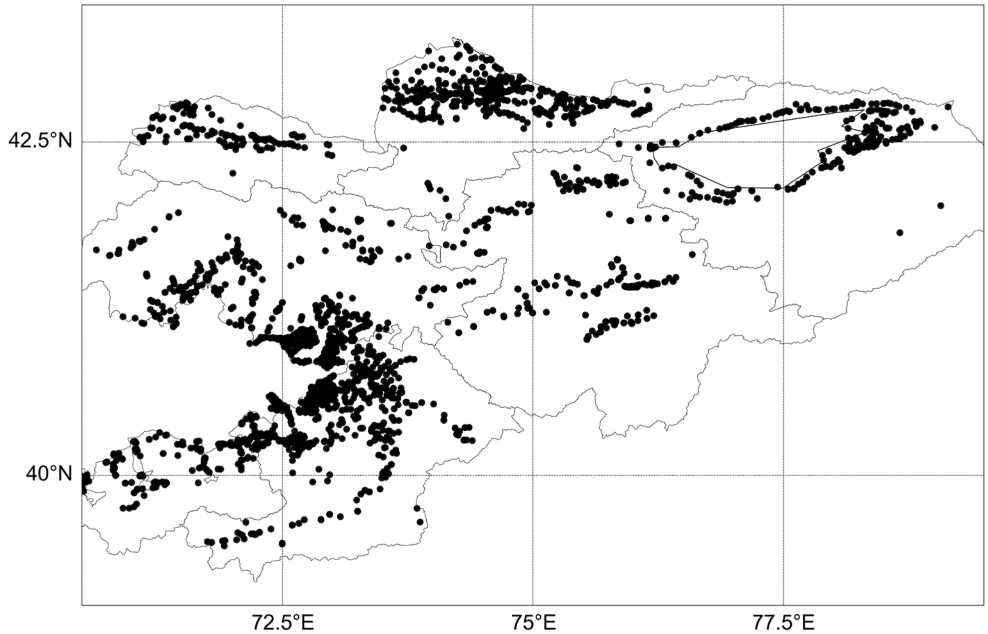

Figure 2-2 Map of Kyrgyz Republic showing location of school sites with information on the UNICEF database.

2.3 Development of Hybrid Database

The two datasets introduced in the previous sections are not comprehensive: some schools were surveyed either by ERIK or UNICEF, and some schools were surveyed by neither effort. A hybrid dataset was developed to leverage both sources of information and set up according to the school type and the level of coverage by ERIK surveys. For each school type, that is, preschools or schools, three scenarios were evaluated:

- In rayons where there were no ERIK surveys, use UNICEF data (in yellow in Figure 2-3)
- In rayons where ERIK surveys covered at least 90% of the UNICEF data, use ERIK data (in green in Figure 2-3)
- In the remaining rayons where ERIK surveys did not cover enough schools (in purple Figure 2-3):
  - Identify schools that were surveyed by ERIK surveys and use ERIK data
  - Identify schools that were only surveyed by UNICEF and use UNICEF data

In the last scenario, it is important that there are no duplicate schools in the rayon. To ensure this, the databases were checked for duplicates using geographical locations, school names, types, addresses, director names, school sizes, and where necessary, field inspection pictures.

Figure 2-3 presents the resulting hybrid dataset that was developed for this study. Green dots indicate data from ERIK surveys, yellow dots indicate data from UNICEF surveys, and purple dots indicate data from the hybrid approach. It is noted that the total number of schools with information closely matches the total inventory by the Ministry of Education (2,256 vs. 2,262); however, there is a lack of preschool information that prevents a substantial number to be included in the study (1,021 vs. 1,580).

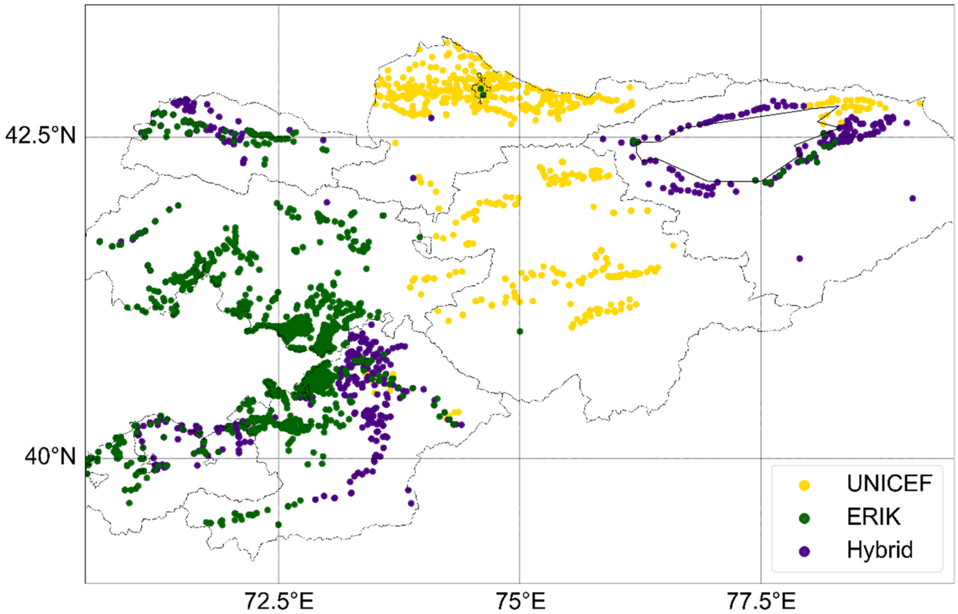

Figure 2-3 Map of Kyrgyz Republic showing distribution of schools to be included in the study.

Development of the hybrid dataset was a critical step in implementation of the risk-based prioritization framework. Although the information in the dataset may not have the highest level of certainty, the risk-based prioritization approach only requires a preliminary understanding of the whole picture. The full implementation steps involve detailed surveys of high priority schools and update of the school infrastructure database, as described in Chapter 7.

For implementation of the risk-based prioritization framework, each block at a school site should be categorized with a consistent structural typology. UNICEF utilizes a list of 13 structural typology parameters that are not consistent with Glosi. The project team reviewed the descriptions, relevant photographs, and distribution of UNICEF typologies and mapped them to Glosi typologies with known information, as summarized in Table 2-1. The mapping assignments benefited from expert judgement on expected behavior of the structures. For example, UNICEF Type 6 describes a building with wood frame, but in Kyrgyz Republic, the performance of a typical wood-frame school building with filling of soil materials is expected to behave similar to a building of adobe:

In both the ERIK and UNICEF survey results, a significant number of buildings were assigned Unknown or Mixed typologies. Because the risk framework requires distinct categorization of each block, expert judgment informed by prevalence, year of construction, and size of school were used to develop the following mapping assumptions to Glosi typologies:

- If the school was constructed before 1970, map to Adobe
- If the school was constructed between 1970 and 1986, with less than 500 students, map to CX
- If the school was constructed between 1970 and 1986, with more than 500, map to PC2
- If the school was constructed after 1987, with less than 500 students, map to CX
- If the school was constructed after 1987, with more than 500 students, map to PC2

Table 2-1 UNICEF Taxonomy Definitions and Mapping to Glosi Taxonomy Parameter P1

UNICEF No.	*UNICEF Description*	*Glosi P1*
1	Large-panel, flat-wall buildings from cast reinforced concrete.	PC2
2	Frame-panel building with hinged plates; frame building with brick infill; metal frames.	PC2
3	Structural system with incomplete frame where outer walls are brick and inner structures are frame.	CXCF
4	Brick building of composite structures (also called "in composite structures").	CX
5	Brick (stone) building of up to 5 floors.	URM4 for older CX for newer
6	Building of traditional construction with wooden double frame for 9-point earthquake intensity and single frame for 7-8-point seismicity with the filling of soil materials and light-weight roofing. Their seismic resistance can be considered as existing under the following conditions: The foundation and the basement are made of solid waterproof materials (concrete, brick, stone, etc.); the distance between walls (in the clear) does not exceed 5 m; wooden parts are not rotten in the lower and upper parts of the support and stands of the frame; there are metal clamps and patch plates in the intersection nodes of vertical and horizontal elements of the frame assembled with a coak or jointing.	Adobe
7	Same buildings with wooden frame which fail to meet requirements of item 6.	Adobe
8	Buildings from puddle clay (pasha) and raw brick, adobe (saman) blocks in the areas with 7-8 earthquake intensity can be considered seismically secure if the aggregate cross section of the party walls of structures in each direction (longitudinal, transverse) at the mid-level of a story makes at least 4% of the building area calculated on the basis of outer faces of walls. The following elements should be in place as well: foundation and the basement made of solid waterproof materials (concrete, brick, stone and etc.); framing of outer walls; diagonal flooring from boards on the beams; and attic roof with asbestos cement or metal roofing on wooden beams.	Adobe
9	Same buildings from puddle clay and raw brick failing to comply with the requirements of item 8.	Adobe
10	Same buildings as per item 8 in the regions with seismic resistance of 9+ without reinforcement of walls may be used for various purposes except for permanent staying of people.	Adobe
11	Frameless buildings with walls of dried clay (gualyak) are seismically non-resistant for all seismic regions, and it is not recommended for people to stay in them.	None
12	Buildings with walls from burnt brick built without any design and aseismic activities of 1-2 stories high having no damages above 2 level according to MSK-64 or IMS-98 [sic].	URM1
13	Wooden-board buildings in case of 7-8 seismic intensity in the area.	Adobe

The mapping assumptions assign blocks with larger occupancies to the PC2 typology, which is the most seismically vulnerable structure (see Chapter 3). This approach was selected for the development of the hybrid dataset to allow for conservatism in the results of the risk-based framework. It is critical for preliminary surveys to be conducted for the high priority schools to develop a database with higher confidence.

Table 2-2 presents the distribution of structural typologies assigned to each block in the hybrid dataset.

Table 2-2 Distribution of Glosi Typologies in School Infrastructure Database

Glosi	*Typology Description (Glosi Parameter P1)*	*Occurrence*
Adobe	Earthen bricks/blocks or compressed stabilized soil bricks/blocks in mud mortar	17%
URM1	Dry stone masonry (without mortar)	1%
URM4	Bricks/blocks in mud mortar	7%
CX	Complex Masonry: Masonry walls (burnt clay bricks or concrete block in cement mortar) with vertical RC confining elements (inclusions) located at the wall intersections	54%
CXCF	Complex masonry walls and concrete frames: Masonry walls (burnt clay bricks or concrete block in cement mortar) with interior RC columns and beams placed in irregular patters (they do not act like an RC Moment frame)	9%
RC2	Reinforced concrete moment resistant frame with infill walls as a stiffening element	2%
PC1	Precast large panel reinforced concrete wall system	1%
PC2	Precast reinforced concrete frames with exterior precast reinforced concrete wall panels	10%
SF2	Steel moment resisting frame with lightweight infill panels	~ 0%

Chapter 3

Characteristics of Structural Typologies

This chapter describes the typical characteristics and vulnerabilities for the structural typologies identified in Chapter 2.

3.1 Complex Masonry (CX)

This typology is a type of load bearing masonry construction where the walls incorporate vertical reinforced concrete inclusions. The inclusions contribute to resisting higher axial stresses in the walls as compared to unreinforced masonry. The inclusions are often not visible, but typically occur within the center of masonry piers and at corners and intersections of walls. Small inclusions frequently occur at boundaries of piers.

The CX typology is similar to the confined masonry (CM) typology described in previously published Glosi guidance (World Bank, 2019b). The most important difference is that with confined masonry, concrete inclusions are always at the boundaries of the walls and piers. Also, whereas confined masonry walls can form strut and tie mechanisms with the masonry confined by the inclusions, complex masonry walls do not typically form strut and tie mechanisms, because of the irregular or central placement, of the inclusions. The wall behavior of complex masonry is closer to that of unreinforced masonry. Complex masonry is also distinct from concrete frames with masonry infill (RC2) where the masonry is not load bearing, as the frames can support all vertical loads.

This typology was previously defined in the ATC-142 project for schools but was designated as CM at the time (World Bank, 2019a).

The following are typical characteristics for representative complex masonry (CX) buildings in this study:

- Buildings are comprised of seismically separate blocks that are rectangular in plan. The blocks are expected to pound during an earthquake. Pounding is not a safety issue when the floors align.
- Representative school buildings in this study are observed to be up-to three stories tall.
- Gravity loads are carried by load bearing walls and reinforced concrete headers at openings.
- The walls usually have vertical reinforced concrete inclusions. The inclusions within walls are configured as distinct square columns. The boundary inclusions at the edges of piers are rectangular, lightly tied trim elements with two long bars.
- Floor and roof diaphragms are formed with hollow core precast concrete planks. The bearing ends of the planks are tied to perimeter belt beams integrated in the load bearing walls. The diaphragms have no concrete topping, and lateral loads are transferred through clamping action from the belt beams.

- Nonstructural partitions are present. They are made with unreinforced masonry elements and poorly connected to the structure.
- The roof shape is formed with light timber framing. The framing is supported on hollow core reinforced concrete planks.
- Light entry structures are present.
- Irregularities, large chimneys, parapets, other falling hazards, pounding, or seismic retrofit were not observed.
- No freestanding columns or long span beams were observed. This is the distinguishing feature of the complex masonry concrete frame (CXCF) typology described in Section 3.3.

Figure 3-1 Typical one-story (top) and two-story (bottom) CX school buildings.

Information is based initial cursory field observations, consultation with local experts, and drawings collected during the field inspections, where available, and on detailed information collected by local engineers. Accordingly, characteristics described are primarily qualitative. The findings are informed by drawing review and analyses based on the geometry, as well as assumed material properties and details from similar buildings.

3.2 Complex Masonry (CX) Gymnasium Buildings

The complex masonry (CX) gymnasium typology shown in Figures 3-2 through 3-4 is a single-story structure with load-bearing masonry walls with concrete inclusions. The walls are similar to the CX classroom building described in Section 3.1, but the inclusions are larger distinct square pilasters and are expressed inside the building.

The roof diaphragm is comprised of large precast concrete panels that span in the transverse direction from concrete pilaster to pilaster. The panels have primary ribs in the transverse direction and secondary ribs in the longitudinal direction. The diaphragms do not have a concrete topping, and lateral loads are assumed to be transferred through clamping action from the belt beams. The roof shape is formed with light timber framing.

Gymnasium buildings are often adjacent to shorter buildings and are susceptible to damage from pounding during an earthquake.

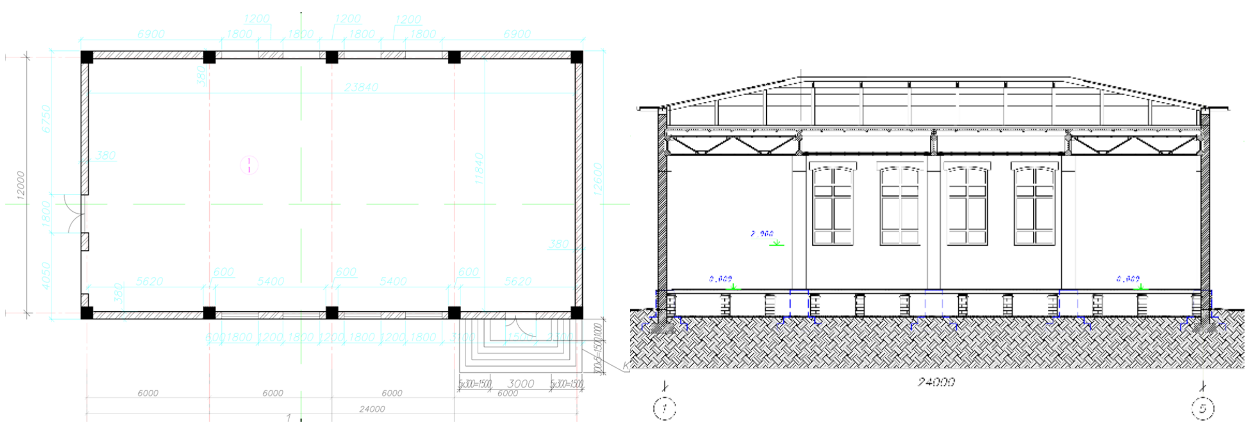

Figure 3-2 Drawings created by local engineers for CX gymnasium.

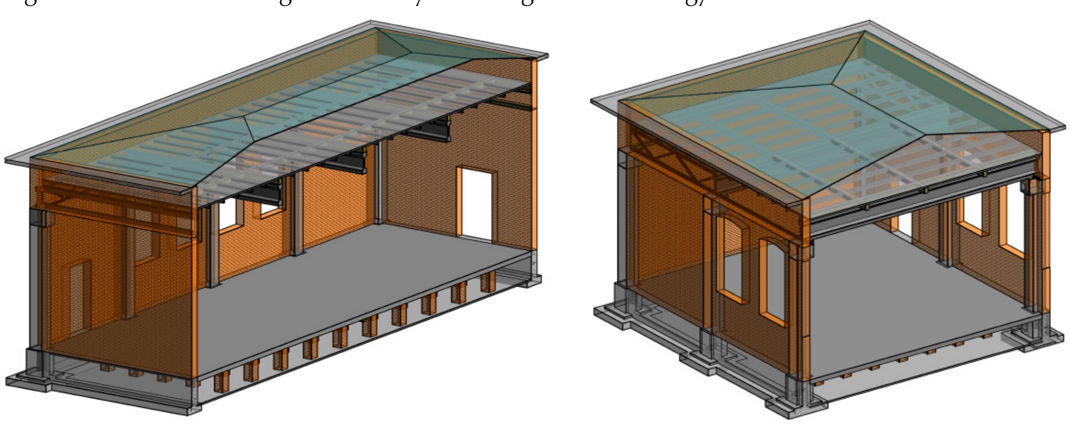

Figure 3-3 Complex masonry (CX) gymnasium building.

Figure 3-4 CX gymnasium building.

3.3 Complex Masonry with Concrete Framing (CXCF)

Data from field inspections and available drawings indicate that these type of school buildings in Krygyz Republic include some column and beam elements but lack the regular spacing of horizontal and vertical elements comprising a complete monolithic frame. This typology was previously defined in the ATC-142 project for schools but was designated as CMCF at the time (World Bank, 2019a).

This typology is typically composed of a mix of interior concrete frames and masonry bearing walls, the latter of which occur in both interior and exterior conditions, and occasional interior concrete framing of beams and columns. Masonry bearing walls have concrete inclusions, both in the form of distinct square columns and rectangular trim elements. The typology has hollow core precast concrete floor planks connected to horizontal concrete seismic belts within the masonry walls. While similar to the CX typology described above, the CXCF typology has occasional concrete beams and columns and is defined to be larger and more complex than its CX counterpart. It is observed that CXCF school buildings in Krygyz Republic have similarities to the commonly accepted definitions for both confined masonry and reinforced concrete frames with masonry infill buildings.

CXCF school buildings in Krygyz Republic are generally rectangular in plan, one to three stories tall, have rigid diaphragms, are structurally separated from adjacent blocks, and generally do not include the presence of structural irregularities or weak columns (although horizontal and vertical irregularities and weak columns do exist in some cases). Most buildings of this type do not have appurtenances such as chimneys, parapets, or other elements that represent falling hazards, and the buildings are generally in medium to good condition. Example buildings are shown in Figures 3-5 through 3-8. The following are typical characteristics for representative CXCF buildings:

- Buildings are typically three stories tall and comprise rectangular blocks. The blocks are arranged to form complex buildings. The blocks are separated by seismic joints that could pound during an earthquake.
- Buildings are larger and older than the buildings in the CX typology. The blocks and plans are also more irregular.
- Buildings may have partial basements.

- At the perimeter along the longitudinal elevations, gravity loads are carried by load bearing walls and headers at openings. The three-story load-bearing walls for CXCF are thicker than those observed in the two-story CX typology.
- At interior lines of support, gravity loads are carried by load bearing walls, beams, and columns. Freestanding columns and long span beams occur.
- The density of walls is less than that found in the CX typology.
- The walls typically have vertical reinforced concrete inclusions at the boundaries, but this was not always observed. These boundary inclusions are lightly tied trim elements, rather than distinct columns. They are rectangular in plan, with two long bars. The walls occasionally have inclusions that are configured as distinct square columns.
- Rigid floor and roof diaphragms are formed with hollow core precast concrete planks tied to perimeter belt beams integrated in the load bearing walls. Available drawings for both the CX and CXCF buildings referred to a common Series catalogue of assembly details for this condition. The specific details are larger for the CXCF conditions. The diaphragms are untopped and work through clamping action from the belt beams.
- Nonstructural partitions are present. These are made with unreinforced masonry elements and are poorly connected to the structure.
- The roof shape is formed with light timber framing.
- Gymnasiums are present in these schools. Pounding at misaligned levels is a vulnerability.
- Other irregularities, weak columns, chimneys, parapets, other falling hazards, or seismic retrofit were not observed.

Information is based on structural drawings collected during the field inspections. The availability of drawings was limited. Accordingly, characteristics described are primarily qualitative, and the findings are informed by the drawing review.

Figure 3-5 Exterior of 3-story CXCF school building.

Figure 3-6 Interior of CXCF school building.

Figure 3-7 Typical exterior of CXCF school buildings.

Figure 3-8 Typical interior of CXCF school buildings.

3.4 Precast Reinforced Concrete Frames with Exterior Precast Reinforced Concrete Wall Panels (PC2)

The precast concrete frame (PC2) typology defined for this study is a two-way reinforced concrete frame that supports hollow core concrete floor and roof planks. The exterior walls are small panel precast wall panels that span horizontally between columns. This typology is distinct from large panel precast building (PC1) and precast gymnasium with masonry infill (PC3) structure types described in GLOSI (World Bank, 2019b). For example, in PC1 buildings, large precast panels are load bearing and extend full height between floors. In PC2 gymnasia with masonry infill, the masonry walls are the primary lateral elements. The commonly accepted definition of precast concrete buildings includes both forms.

School sites typically comprise an arrangement of seismically separate rectangular blocks. The blocks are susceptible to pounding during an earthquake. This is not a significant safety risk when the floors and roof levels align. However, this is a safety risk when the floors and or roofs do not align, such as at gymnasium buildings.

PC2 buildings shown in Figure 3-9 generally do not include the presence of structural irregularities or weak columns. Most buildings do not have appurtenances, such as chimneys, parapets, or other elements that represent falling hazards. The buildings often show signs of deferred maintenance and damage to finishes. However, in most cases, this does not affect the structural condition. The following are typical characteristics for representative PC2 buildings:

- The framing system consists of precast columns, precast beams, precast hollow core planks, and precast wall panels.
- The columns are often weak, brittle, shear critical, and poorly detailed. The frames are also susceptible to story mechanisms where the failure is concentrated in the columns at a single level.
- The wall panels are of lightweight construction and detailed to not participate in carrying vertical and lateral loads.
- Floor and roof diaphragms are formed with hollow core precast concrete planks. They are tied to perimeter precast beams. The diaphragms do not have a concrete topping and work through clamping action from the precast beams. They are deemed to be ridged for light loads.
- Nonstructural partitions are present. They are made with unreinforced masonry elements and are poorly connected to the structure.
- Gymnasium buildings are present in these schools. Pounding at misaligned levels is a vulnerability.
- Irregularities, chimneys, parapets, other falling hazards, or seismic retrofit are not present.

Information is based on limited measurements and non-destructive investigations by local engineers and consultations with local experts. Various relevant catalogues for similar precast concrete buildings (IIS-04 series) were reviewed to identify details of construction considered to be typical. However, assumptions were made due to missing critical information.

Figure 3-9 Three-story PC2 building.

3.5 Precast Reinforced Concrete Frames with Exterior Precast Reinforced Concrete Wall Panel (PC2) Gymnasium Buildings

The precast concrete frame (PC2) gymnasium typology is a single-story structure with loads supported by the beams and columns. The exterior walls are small panel precast wall panels that span horizontally between columns. The panel outline is visible in photo on the right in Figure 3-10.

The roof diaphragm is similar to that found at the CX gymnasium. Large precast concrete panels span in the transverse direction of the gym. The panels have primary ribs in the transverse direction and secondary ribs in the longitudinal direction. The diaphragms have no concrete topping, and lateral loads are assumed to be transferred through clamping action from the belt beams. The roof shape is formed with light timber framing.

Gymnasium buildings are often adjacent to shorter buildings, and susceptible to damage from pounding during an earthquake. See the connector building in the left image in Figure 3-10.

Figure 3-10 PC2 gymnasium.

3.6 Reinforced Concrete Frame with Masonry Infill (RC2)

The reinforced concrete frame with masonry infill (RC2) typology has a complete cast-in-place frame. The masonry infill between frame members is not load bearing. However, it does participate in the response by stiffening and strengthening the frame, since it appears to be constructed tight to the frame. The infill, as observed in Figure 3-11, is only one wythe thick and susceptible to out-of-plane failure. Some masonry walls do not frame between columns and beams. These are deemed to be nonstructural partitions since the masonry is incapable of forming compression struts without a frame to react against. There were no observed provisions for independent frame deflection. The typology has hollow core precast concrete floor and roof planks for the diaphragms. They are assumed to be connected to horizontal beams.

The following are typical characteristics for representative RC2 buildings:

- Buildings are typically two stories tall and comprise rectangular blocks. The blocks are separated by seismic joints that could pound during an earthquake. Since the floors and roofs align, this is not considered a safety issue.
- Rigid floor and roof diaphragms are formed with hollow core precast concrete planks. These are assumed to be tied to beams. The diaphragms are untopped and work through clamping action from the belt beams.
- Nonstructural partitions are present. These are made with unreinforced masonry elements and appear to be poorly connected to the structure.
- The roof shape is formed with light timber framing.

Information is based on structural drawings collected during the field inspections and consultation with local experts. The availability of drawings was limited. Assumptions were made regarding the material properties and details.

Figure 3-11 Reinforced concrete frame with infill (RC2).

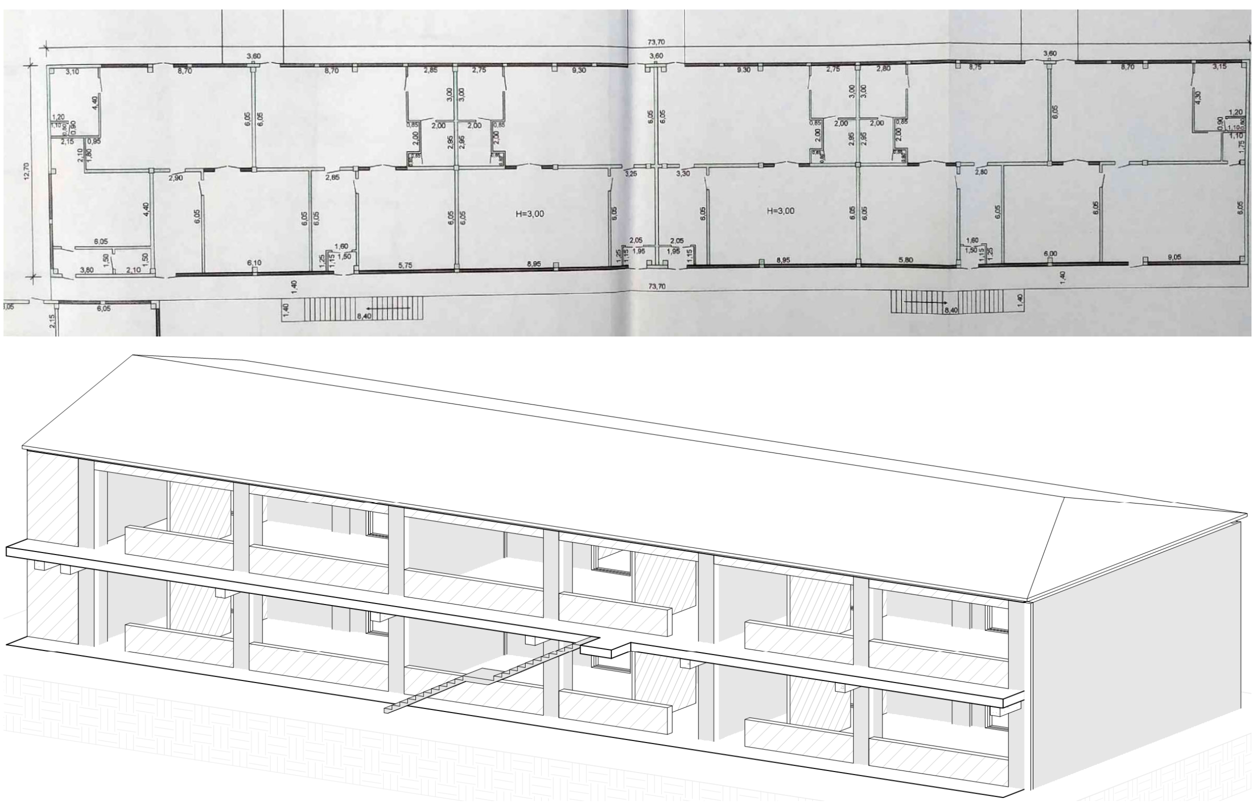

Figure 3-12 Reinforced concrete frame with infill (RC2).

Chapter 4
Seismic Retrofit Concepts and Cost Estimate Approach

This chapter describes performance-based assessments and typical seismic retrofit concepts developed for representative masonry wall and frame buildings, as well as baseline assumptions for retrofit cost estimates. The retrofits were developed in response to the existing building's behavior, as revealed by the nonlinear analyses. The structural typologies identified in Chapter 3 have different failure modes, thus different analysis strategies were employed for wall buildings (complex masonry, complex masonry concrete frame, and reinforced concrete with masonry infill) and frame (precast reinforced concrete frame) buildings.

4.1 Analysis Strategy for Wall Buildings and Frame Buildings with Masonry Infill

The strategies described below were implemented for pushover analyses of wall buildings as well as frame buildings with masonry infill, i.e., complex masonry (CX) classroom, CX gymnasium, complex masonry concrete frame (CXCF) classroom, and reinforced concrete with masonry infill (RC2) classroom. The behavior of these typologies is dominated by the masonry walls because they are much stiffer and stronger than the reinforced concrete inclusions in the case of CX and the reinforced concrete frame in RC2. Each building was analyzed using pushover analysis techniques based on nonlinear static analysis procedures in ASCE/SEI 41-17 (ASCE, 2017).

The information is limited to the geometry of the walls, floor heights, precast floor plank thicknesses and orientations. No material tests were performed, nor was there any non-destructive investigation. Material properties and the presence of reinforced concrete inclusions or belt beams are assumed, based on recommendations from the local engineers, experts, previous studies and drawing reviews of similar CX buildings in the region. Foundation design values are based on the deadload pressures obtained by modeling the geometry, with the ultimate soil pressure assumed to be three times the deadload pressure. Overall, the geometric information, plus key assumptions based on similar typologies can yield reasonable analytical results. This is because the overall building response is dominated by the masonry wall geometry, the distribution of building weight, as determined by the walls and floor loading patterns from the hollow core plank orientations.

Masonry elements are subject to four modes of failure when loaded in the plane of the wall. These are bed joint shear, diagonal shear, flexure with toe crushing, and flexure with rocking, as shown in Figure 4-1. Wall or pier geometry, along with the axial load, determine which of the modes will occur.

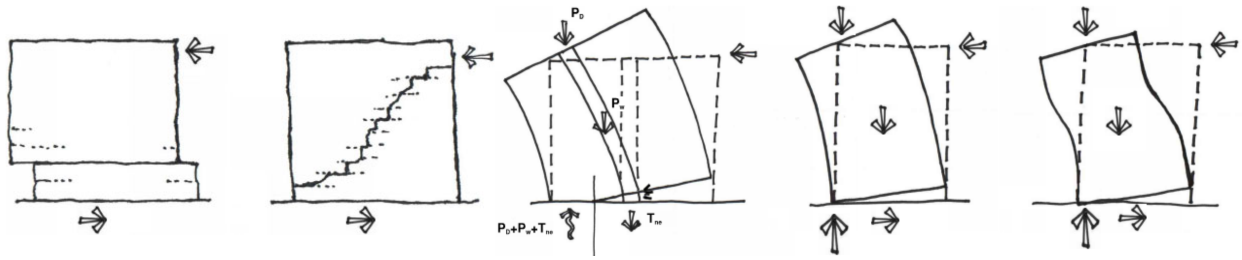

Figure 4-1 Masonry wall failure modes (left to right). Bed joint shear, diagonal shear mechanisms, flexure with toe crushing, rocking fixed-pin, and rocking fixed-fixed.

Each of these modes is represented with an associated load-displacement relationship (“backbone curve”) that can also be used to define controlling limit states. The vertical axis of a backbone curve indicates component action capacity, e.g., shear or axial force, or moment. The horizontal axis indicates deformation, e.g., drift. These curves are tabulated in ASCE/SEI 41-17 based on tests of lab specimens. Similarly, analytical models for the index buildings are coupled to cyclic nonlinear behavior of test specimens by calibration to backbone curves. Figure 4-2 illustrates the process of generating backbone curves based on structural tests.

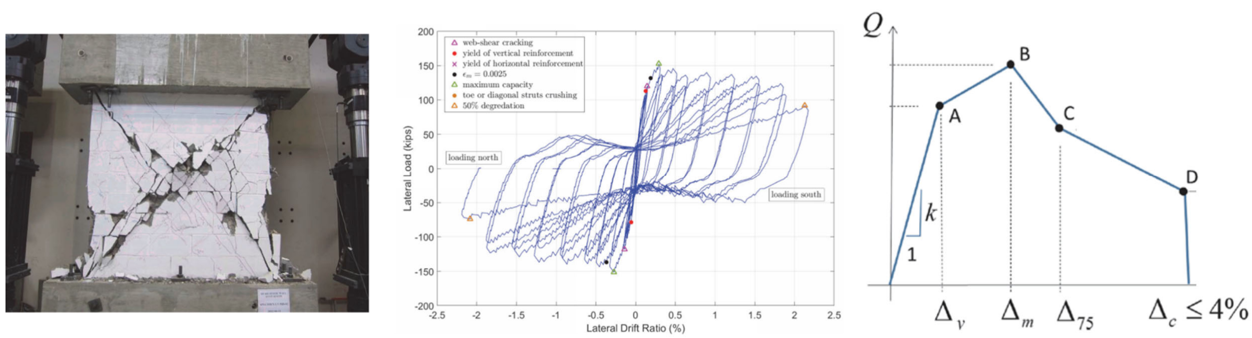

Figure 4-2 Structural testing generates a cyclic hysteretic response of the specimen. These are used as the basis to create backbone curves in ASCE/SEI 41-17.

The masonry wall buildings were analyzed using Perform 3D by Computers and Structures, Inc (CSI). Perform 3D was selected due to its suitability solving highly nonlinear problems with irregular geometry and complex failure mechanisms. The composite wall elements and piers were created with nonlinear fiber elements in combination with nonlinear springs, nonlinear hinges, and nonlinear sliders. The basic masonry wall and pier mechanisms are shown in Figure 4-3.

The wall behavior is complicated by the presence of reinforced concrete inclusions and boundaries, shown in Figure 4-4.

The nonlinear wall module is shown in Figure 4-5. This generalized arrangement of fibers, springs, hinges, and sliders can capture the complex behavior of a masonry wall with reinforced concrete inclusions or boundaries. Each of the elements (fibers, springs, hinges, and sliders) was calibrated to respond in accordance with the backbone curve for the various failure modes.

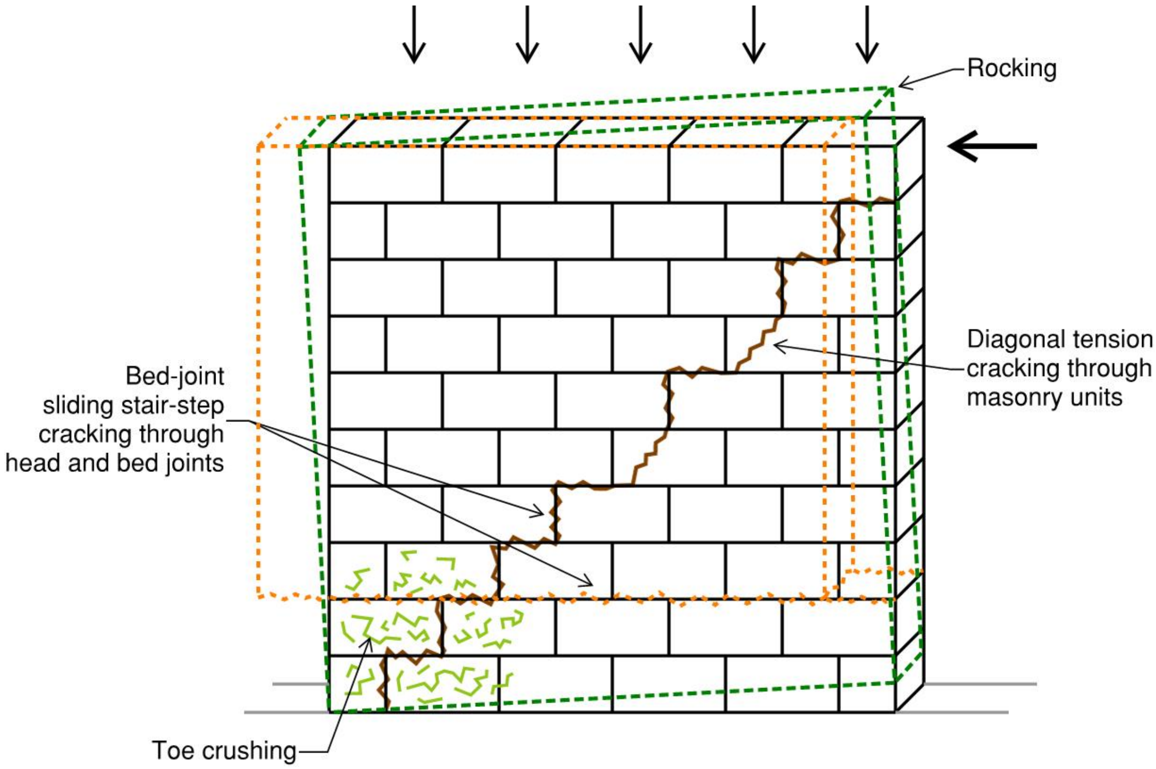

Figure 4-3 Failure mechanisms of a basic masonry wall or pier.

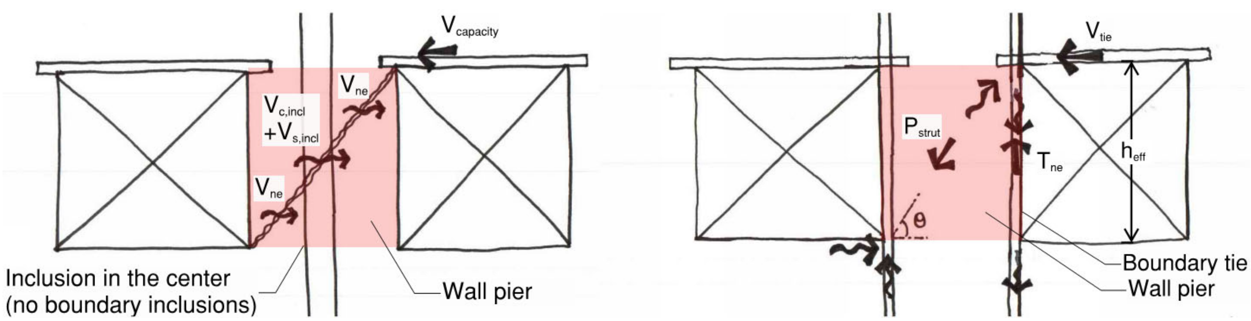

Figure 4-4 Diagonal shear mechanism with inclusions and strut-and-tie mechanism with ties from inclusions.

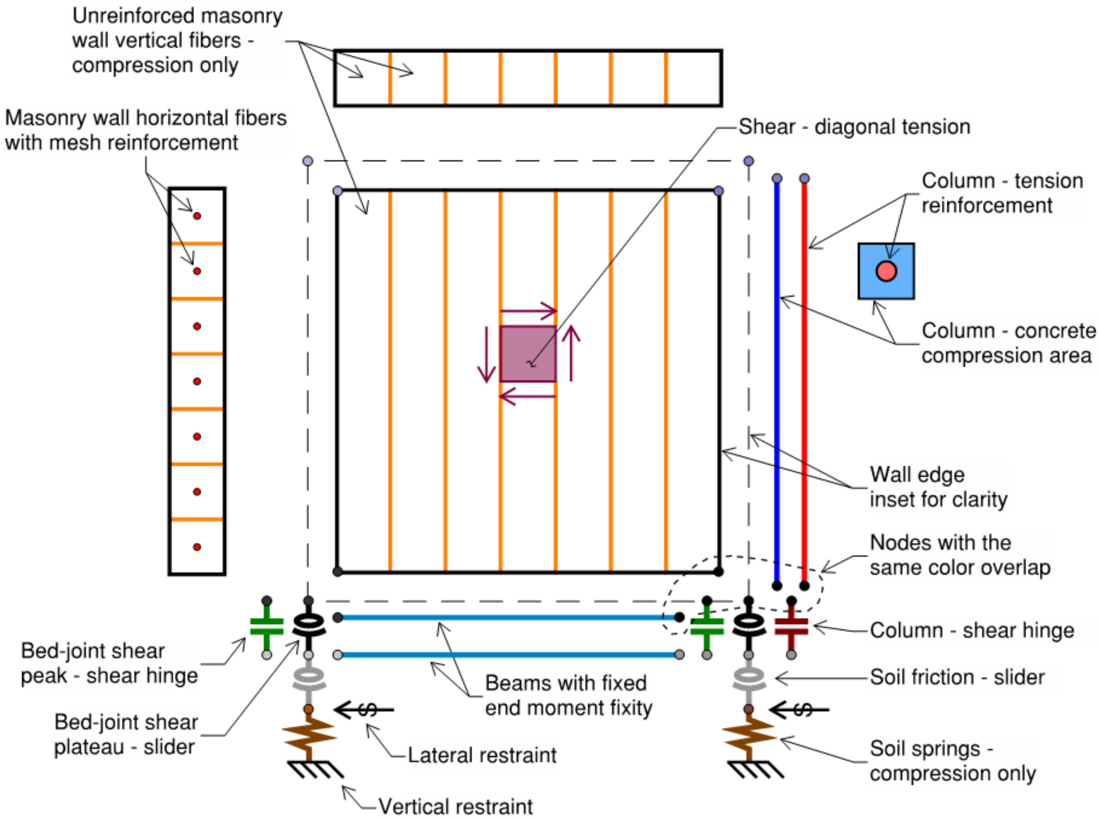

Figure 4-5 Composite nonlinear wall module. It can respond to the four masonry failures modes including the effects of reinforced concrete inclusions and boundaries.

The walls are arranged in the modeling software to form a three-dimensional structure, as shown in Figure 4-6, using a rigid diaphragm assumption. Increasing lateral forces were applied in each primary direction using loads proportional to a triangular distribution of accelerations (pushover analysis) to determine the in-plane response of walls and piers.

Figure 4-7 shows the behavior of an individual wall isolated in elevation for clarity. Lateral pushover loads are applied to the model's center of mass at each elevation. The loads are a triangular distribution in proportion to the tributary weight of each story.

Analysis shows that wall buildings (CX) and (RC2) tend to be stronger in the transverse direction, as compared to the longitudinal direction. This is due to the typology having more solid transverse walls between classrooms. Exterior longitudinal walls have smaller piers and spandrels at window openings, which are the primary source of light for classrooms. The transverse walls usually fail in diagonal shear and by yielding the soil when overturning. Retrofit strategies include strengthening walls to avoid shear failures and improving foundations to preclude soil failures. The response of longitudinal walls is often brittle as shown in Figure 4-8. Retrofit strategies include adding exterior slender reinforced concrete walls that are linked to a common base.

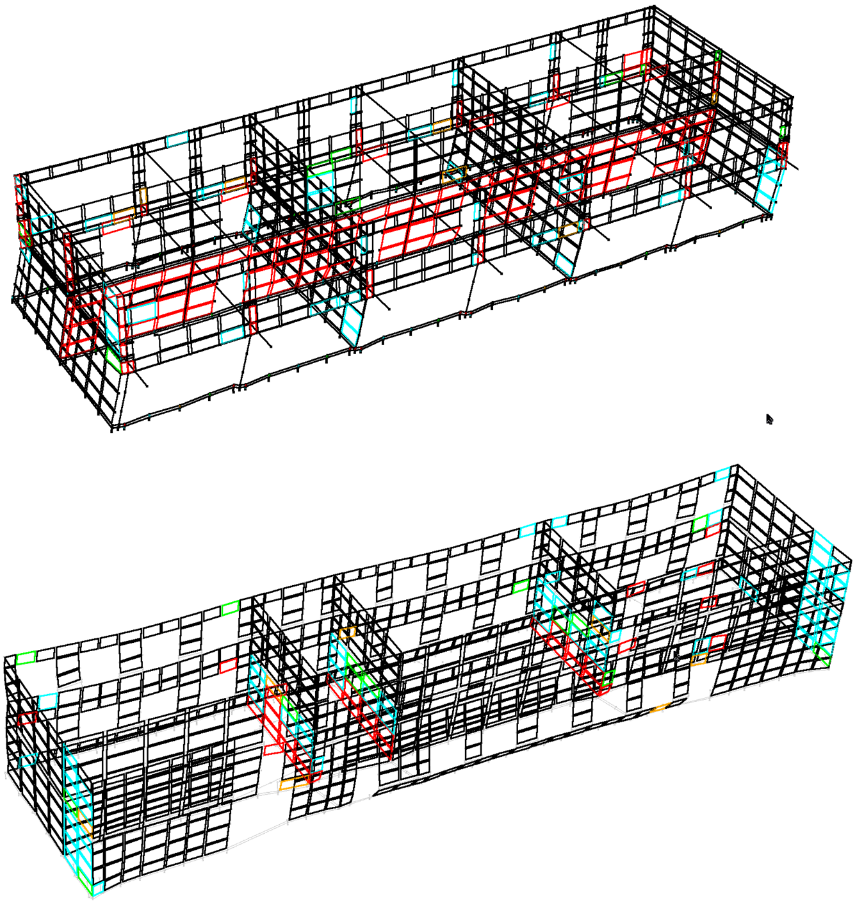

Figure 4-6 Three-dimensional nonlinear model of two-story complex masonry (CX) building below and two-story concrete frame with infill (RC2) above.

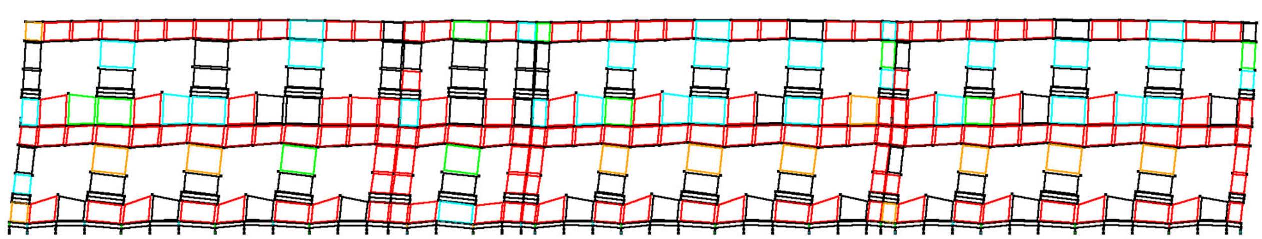

Figure 4-7 Nonlinear response of an isolated complex masonry wall elevation. The distributed failure shows damage (in red) to both piers and spandrels.

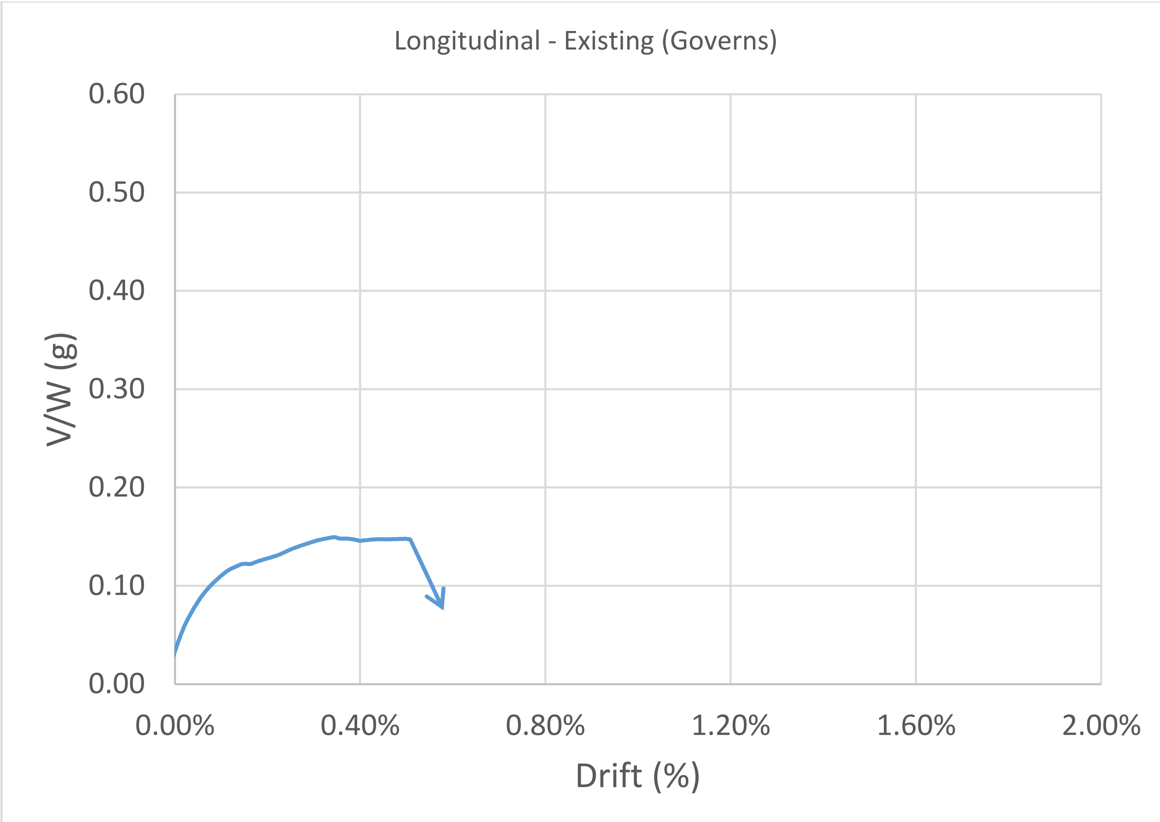

Figure 4-8 Force-displacement relationship for longitudinal wall of 2-story RC2 index building in the existing condition.

Out-of-plane wall loads were evaluated independently based on the height to thickness ratios (*h*/*t*) of the walls and the compliance criteria in ASCE/SEI 41-17.

The diaphragm is comprised of individual planks spanning the transverse direction with shear keys between members and clamped together by the surrounding belt beam and lacks a topping slab. The diaphragms need strengthening to resist the higher internal forces after retrofit.

4.2 Analysis Strategy for Frame Buildings

The strategies described below were implemented for pushover analyses of precast concrete frame (PC2) buildings. The behavior of these typologies is dominated by the flexibility and strength of the reinforced concrete frames (see Figure 4-9). Each representative frame building was analyzed using pushover analysis techniques based on nonlinear static analysis procedures in ASCE/SEI 41-17.

The information is limited to the frame member sizes, exterior precast wall panel geometries, interior partition thickness and extents, floor heights, precast floor plank thicknesses and orientations. Material properties and a general understanding of detailing are assumed, based on recommendations from the local engineers, experts, previous studies, and drawing reviews of similar PC2 buildings in the region. Foundation design values are based on the deadload pressures obtained by modeling the geometry, with the ultimate soil pressure assumed to be three times the deadload pressure. No material tests were performed.

Figure 4-9 Precast frame (PC2) on left, from an abandoned building stopped during construction. Representative precast panel connection to column, on right.

PC2 buildings are analyzed using ETABS by Computers and Structures, Inc (CSI) (Figure 4-10). ETABS is well suited for solving nonlinear frame and wall problems where failure mechanisms are well understood and the nonlinearity is less extreme in terms of rapid strength loss, as compared to masonry buildings. Frames are modeled with assumed reinforcement, and fiber elements for beams and columns, nonlinear soil springs, and rigid diaphragm assumptions. Each failure mode of the frame corresponds to a backbone curve per ASCE/SEI 41-17.

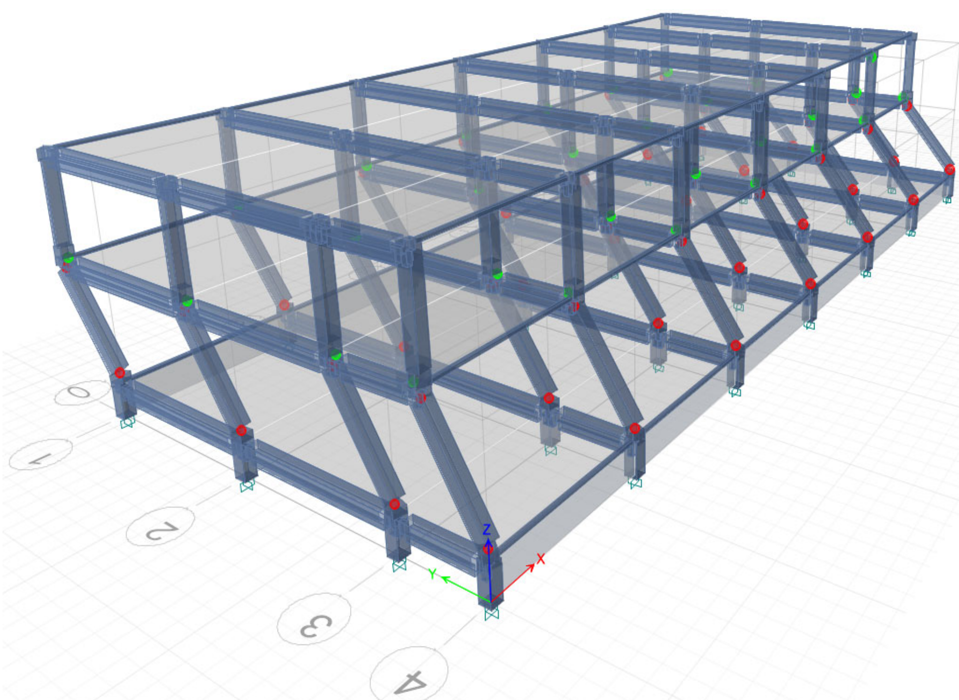

Figure 4-10 Nonlinear response of the overall frame showing column flexural hinges and story mechanism (red dots). The analysis does not model column shear.

Non-destructive investigation of column tie spacing was performed by local engineers (Figure 4-11). In many cases, for each building investigated, the spacing between column ties is approximately the column width. In these cases, the columns behave as if unreinforced for shear. Previous studies of PC2 details indicate that columns are often found to be shear critical, meaning that the column would fail in shear prior to failing in flexure. This means that the controlling failure mode of all the precast frame buildings investigated would be brittle column shear failures and most likely collapse, independent of the vertical reinforcement. As such, only frame geometry and overall weight are needed to determine the seismic capacity of the precast frame buildings.

Brittle shear failure modes of existing columns were monitored to determine the end of an analysis, rather than being modeled directly. Precast panels are detailed to not participate in the frame’s response. Except for weight, the panels are not modeled. This assumption is valid for the small displacements prior to the column shear failures. Nonstructural masonry partitions were also not modeled except for weight effects. This is because weak and brittle partitions would not prevent the column failures that control the overall capacity.

The first step in the retrofit is to jacket all the existing columns to preclude brittle shear failures and collapse. The pushover curve in Figure 4-12 shows when the preemptive column failures occur. Once the columns are stabilized, the figure shows that the frames are also weak, flexible, and susceptible to forming story mechanism. To counter this response, new walls are required to provide adequate strength and stiffness. Additional steps for the retrofit include providing collectors to transfer loads to the new walls, strengthening the diaphragms, removing brittle masonry partitions, and removing exterior precast panels.

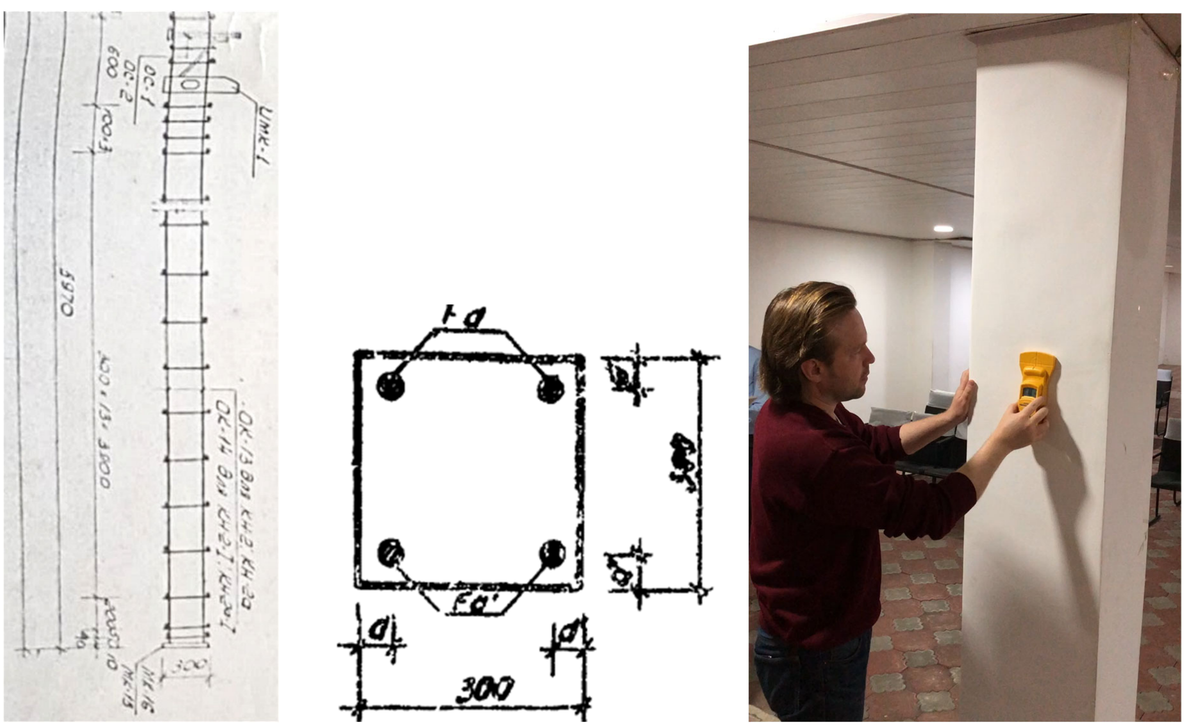

Figure 4-11 Column stirrup spacing indicating coarse tie spacing: on the left and middle, sample column drawings from a precast frame series (Series II-4), similar to index buildings; on right, investigation with metal detector.

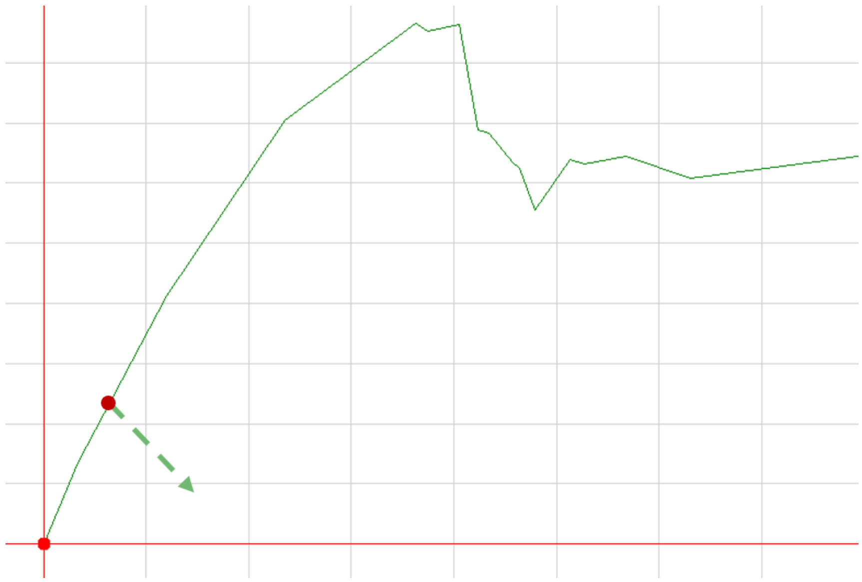

Figure 4-12 Pushover response for a PC2 index building. Base shear is plotted vertically against roof drift on the horizontal axis. The solid line is the response without shear considerations. The dashed line is the column shear response.

4.3 Seismic Retrofit Design using Performance-Based Assessment

For seismic interventions to be financed under the ERIK project, seismic retrofits must satisfy the strength requirements for new buildings designed per SNIP KR 20-02:2009 (in Russian), *Building Code of the Kyrgyz Republic, Earthquake Engineering* and SNIP KR 22-01:1998 (in Russian), *Building Code of the Kyrgyz Republic, Seismic Evaluation of Existing Buildings.*

However, for projects that may go beyond ERIK where exploration of most beneficial retrofit solutions may be an option, retrofit schemes were developed to incrementally address seismic deficiencies and incrementally reduce the associated risk.

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 additional incremental retrofit that was developed is a weaker retrofit and is 75% as strong as a new building. Many countries, including the United States, frequently target the weaker design level for retrofits. The choice is often in response to cost constraints and practical difficulties of making retrofits as strong as new buildings. The potential benefits of more efficient retrofits are an important consideration for a large program at scale, when funds may be limited. Weaker, but more efficient retrofits may allow more buildings to be improved and save more lives for a fixed amount of funds.

Both retrofit levels produce a design that is stable while the buildings undergo significant lateral displacements. Most designs share the common features of adding strength, increasing displacement capacity, strengthening the diaphragms, replacing nonstructural partitions, jacketing columns where they occur, and replacing precast panels where they occur. The biggest difference between the two retrofit levels is often avoiding foundation strengthening with the weaker retrofits.

The index buildings were evaluated for two performance points, *life safety* (LS) and *collapse prevention* (CP), in their as-is conditions and after retrofits. Life safety is a state that poses a danger for injury and 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 for injury and loss of life that could occur with a side-sway collapse of a major portion of the building.

4.4 Seismic Retrofit Strategies

This section describes typical seismic retrofit strategies implemented to reduce or remove seismic vulnerabilities identified in Chapter 3 for each structure type.

4.4.1 Column Jackets

The analysis and field investigation found that columns in frame structure types lack sufficient confinement and thus are frequently shear critical. When the building undergoes lateral displacements, internal moments and shears are generated in the columns. When the columns fail in shear, they are susceptible to sudden loss of gravity carrying capacity, leading to partial and complete collapse of the buildings. To mitigate this failure mode, supplemental shear reinforcement and confinement are required. This can be in the form of reinforced concrete jackets (Figure 4-13), which is readily available, as well as steel or fiber reinforced polymer (FRP) jackets. This deficiency is prevalent in precast frame (PC2) buildings and concrete frame with infill buildings (RC2). It also occurs in the complex masonry with concrete frame (CXCF) buildings.

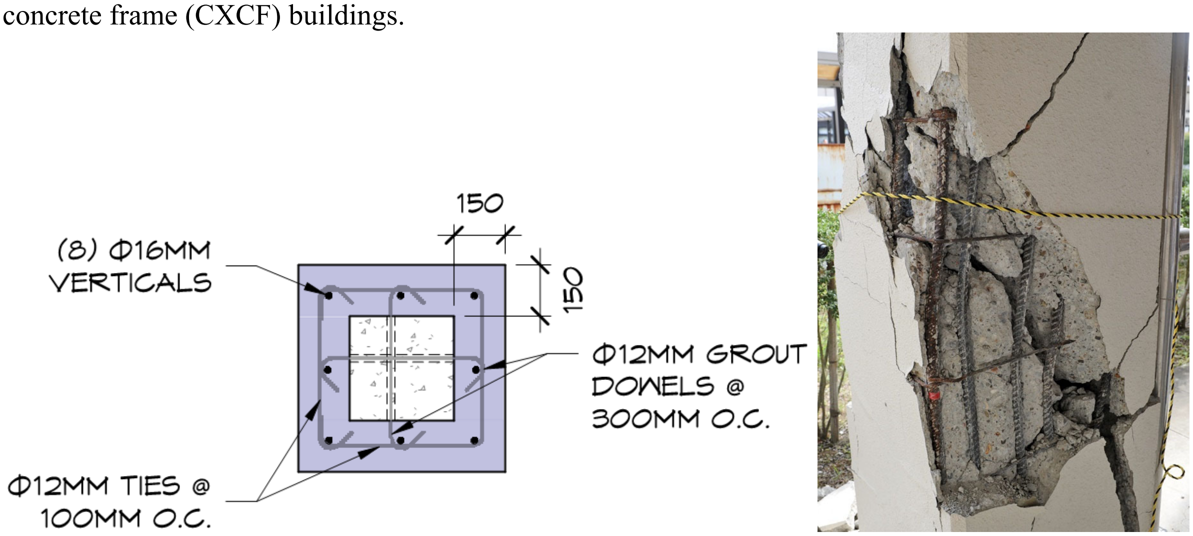

Figure 4-13 Reinforced concrete column jacket on left. Shear failure in column due to insufficient tie reinforcement.

4.4.2 Strengthening of Wall Elements

Existing masonry walls can be strengthened directly to improve performance by applying reinforced concrete jackets on each face. This option is selected when walls are failing, and the global response is inadequate or there is potential for collapse. Strengthening eliminates brittle wall failure modes (bed joint sliding, shear, toe crushing). Rocking can still occur at the foundation. Figures 4-14 and 4-15 show a section and elevation of wall strengthening, respectively.

4.4.3 Augmented Footings

Augmented footings are required to keep soil bearing pressures within the assumed plastic limits under seismic loading. Ultimate pressure is assumed to be three times the dead load pressure. Pushover results for the existing condition of the existing four-story CX index building show that the transverse walls failed in shear and crushing, and the footings failed in bearing. Figure 4-15 shows the retrofit mitigation of enlarged footings below the transverse walls that eliminate soil failure and strengthened walls at the lowest level that eliminate shear and crushing modes. The retrofitted transverse walls and footings are capable of a stable rocking response.

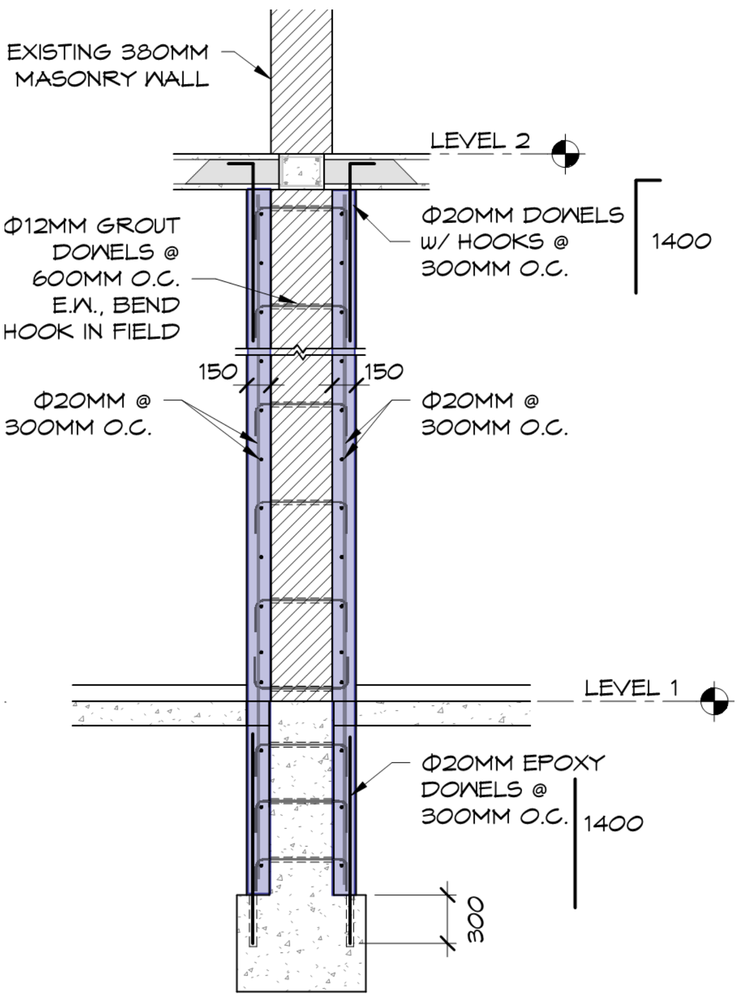

Figure 4-14 Wall strengthening by applying reinforced concrete jackets to each face of the masonry wall.

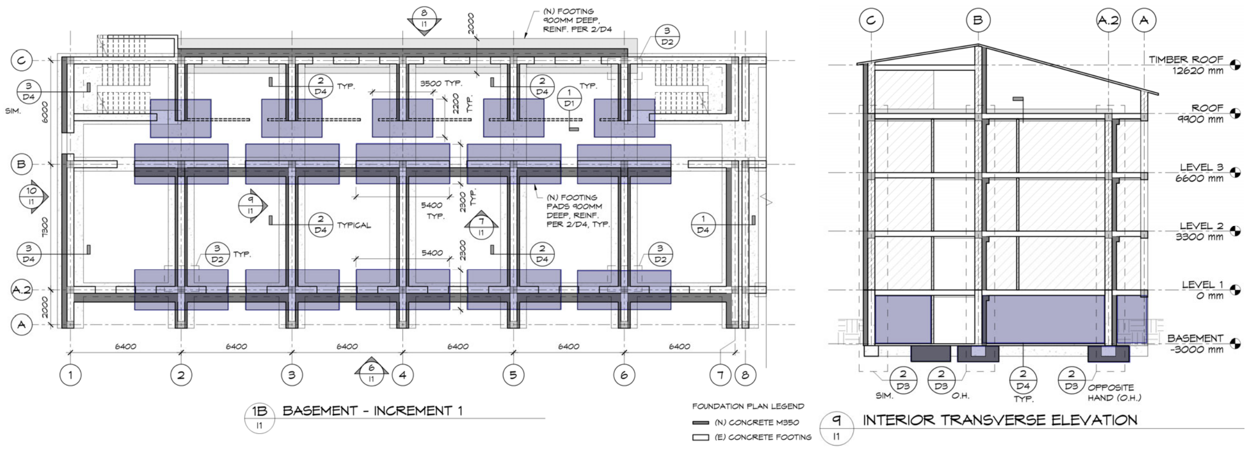

Figure 4-15 New augmented footings shown in plan and section. The lower transverse walls have been strengthened.

4.4.4 Grade Beams

New grade beams shown in Figure 4-16 are required to improve the overturning resistance of walls in order to increase the available strength of walls or to eliminate soil failure. This condition usually occurs in the transverse direction.

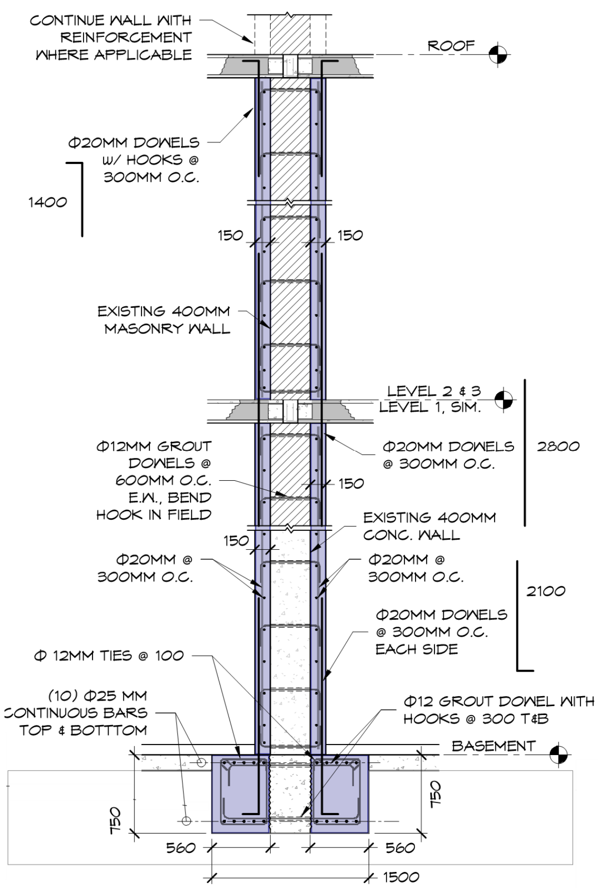

Figure 4-16 New grade beams shown in section. The lower transverse walls have been strengthened.

4.4.5 New Walls

New walls provide strength and stiffness to buildings being retrofitted (Figure 4-17). They are required to strengthen both the longitudinal and transverse directions of frame buildings due to shortcomings in strength. Walls are added to the longitudinal directions of masonry buildings, primarily to add displacement capacity. Walls need to avoid restricting the architectural function. Because the walls are relatively strong, collectors need to be added to drag loads from the diaphragms to the new walls. The walls also need new foundations to resist overturning and keep soil pressure within limits set to be three times the deadload pressures.

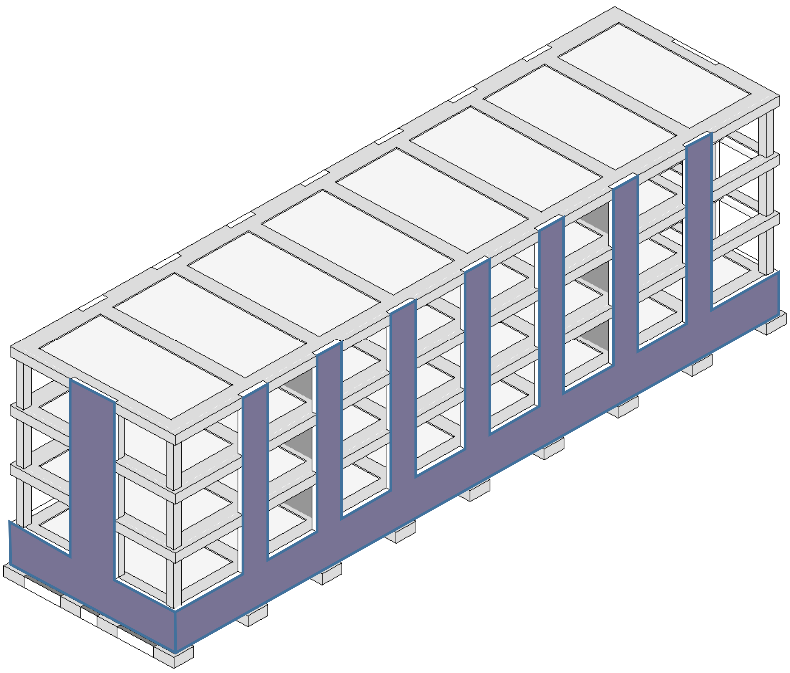

Figure 4-17 Retrofit showing new walls (in blue) added to the outside of the precast frame. The exterior panels are to be removed.

4.4.6 Collectors and Chords

Collectors are elements that drag loads that are distributed throughout diaphragms to new or existing walls. Chords are elements that reinforce diaphragm boundaries to better resist flexure. For this study, new chord and collector elements are added and are made of reinforced concrete (but steel or FRP members could also be used). These elements can be placed on top of the existing floor planks or at the perimeter of the walls, connected to existing belt beams. Both cases are shown in Figure 4-18. The collector/chord is connected to the existing belt beam and new diaphragm ties.

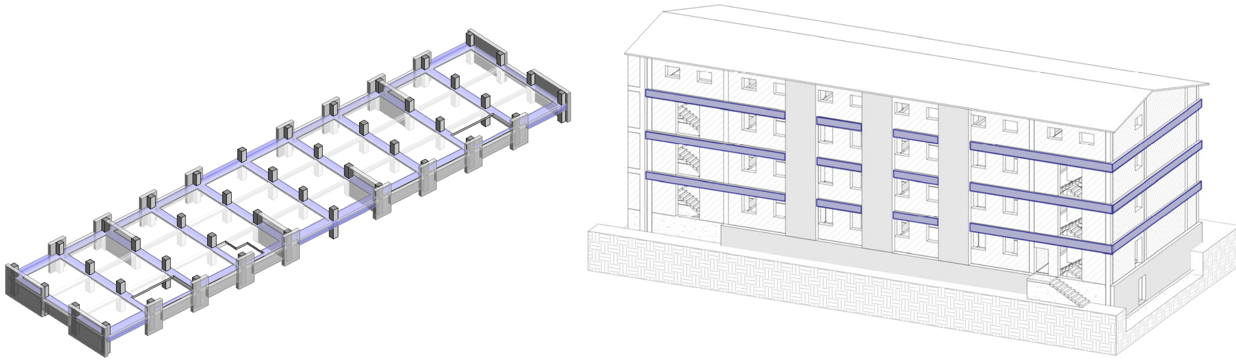

Figure 4-18 New collectors and chords at the perimeter of the diaphragm (in blue). The transverse elements in blue are added collectors where they align with walls. The blue transverse elements between the walls are required to strengthen the diaphragm.

4.4.7 Wall Ties

Wall ties resist out-of-plane forces generated in the walls. The ties shown in Figure 4-19 are designed for CX buildings and are comprised of frequently spaced steel angles, through bolts, and shear bolts grouted with cells of the hollow core concrete planks. There are different tie configurations for PC2 buildings, but they are functionally the same. When the out-of-plane wall loads act to separate the walls from the diaphragm (left image of Figure 4-19), the ties engage the floor planks, crossing joints (right image of Figure 4-19), until the opposite wall is engaged. The ties keep the diaphragm stitched together.

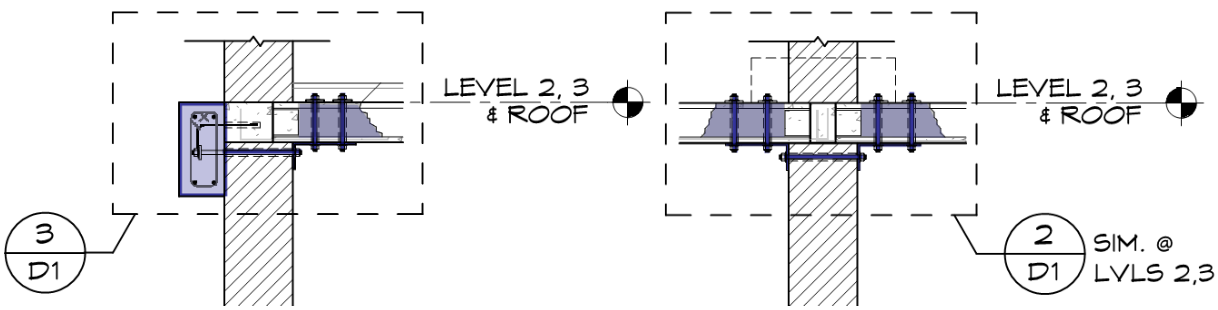

Figure 4-19 Wall ties consisting of angles and grouted bolts (in blue). They transfer out-of-plane wall forces through the diaphragm, from one side of the building to the other, keeping the diaphragm stitched together. The tie on the left is anchored into the new collector/chord.

4.4.8 Partition Replacement

Most of the index buildings studied have unreinforced or lightly reinforced masonry partitions that appear to be poorly anchored. These elements are susceptible to in-plane failure due to imposed drift of the primary structure and out-of-plane failure to accelerations, creating falling hazards. The partitions can also negatively interact with the primary structure, because abrupt changes in strength due brittle failure exacerbate potential story mechanisms where the partitions failed. It is recommended to replace them with light-weight partitions made with metal studs and gypsum wallboard. This eliminates the falling hazard and the interaction problem, in addition to reducing the seismic mass of the building. Alternatively, the partitions can be strengthened and secured.

4.4.9 Precast Panel Replacement

PC2 buildings have precast panel systems attached to the exterior. They are designed to not participate in the seismic response and are with limited capacities for unencumbered frame drift. This study recommends removing and replacing panels. This is primarily due to the practical constraints of jacketing the exterior columns. As is shown in the right image in Figure 4-9, there is very little room between the column and the panel.

4.5 Cost Estimate Approach

4.5.1 Structural Costs

Cost estimates were developed for each of the conceptual retrofit increments based on current construction rates and construction norms for Kyrgyz Republic. Structural costs were calculated by directly accounting for labor and materials shown for each retrofit. The cost needed for the removal and restoration of finishes in kind was determined for different typologies by performing a detailed take-off and estimate of finish costs. In addition, general expenses and profit were estimated to be around 28% based on advice from local experts and value added taxes (VAT) as 15%. The seismic strengthening impacted significant portions of the typologies. Due to the scale and extent of the expected work, there would be opportunities to make other practical improvements, such as better energy efficiency and water supply, in addition to seismic safety.

4.5.2 WASH and EE Costs

Cost estimates for intervention to water, sanitation, and hygiene (WASH) and energy efficiency (EE) systems were developed by UNISOM. The estimates vary from block-to-block based on selected variables. It is noted that efficiencies can be benefited from when conducting WASH and EE interventions at the same time at the same block.

Chapter 5
Development of Fragility and Vulnerability Functions

This chapter describes the methodology for development of fragility and vulnerability functions for the prevalent structural typologies identified in Chapter 3.

5.1 Calculation of Fragility and Vulnerability Functions

The methods described in *Glosi Fragility and Vulnerability Assessment Guide* (World Bank, 2019c) were adapted for use with the buildings studied. The *Glosi Guide* describes a fragility function (illustrated in Figure 5-1) as follows:

"[A fragility function] establishes the probability of reaching or exceeding a particular damage state given a hazard intensity parameter. Damage states are usually defined in terms of global or local parameters, which identify the loss of physical integrity and structural capacity of the building. In an analytical fragility assessment, the damage states are defined with respect to damage thresholds, i.e., specific values of an Engineering Demand Parameter (EDP), such as roof or inter-story drift, which characterize the onset of a particular damage state."

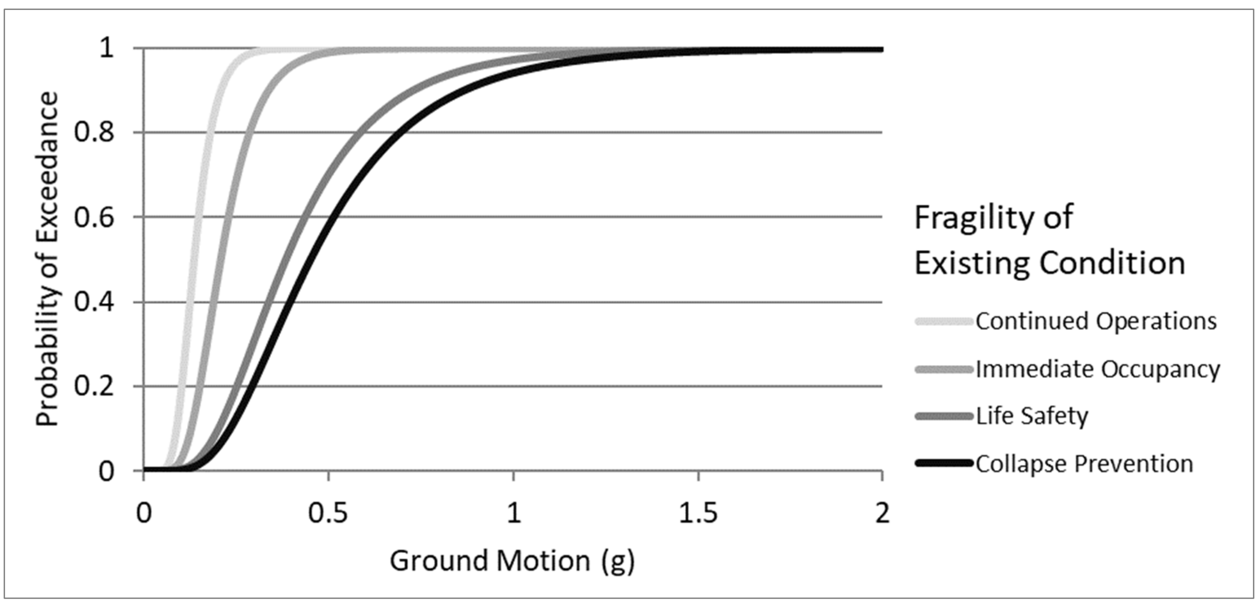

Figure 5-1 Typical representation of a fragility function.

Glosi Guide describes a vulnerability function (illustrated in Figure 5-2) as follows:

> "[A vulnerability function] correlates the Mean Damage Ratio (MDR) and its variance with a hazard intensity parameter. The MDR is usually expressed in economic terms, as the ratio of the expected total repair cost to the total replacement cost of the building. Within the GLOSI library, the total replacement cost of the building has been defined as the actual reconstruction cost of the building according to local price conditions in the country or zone under analysis."

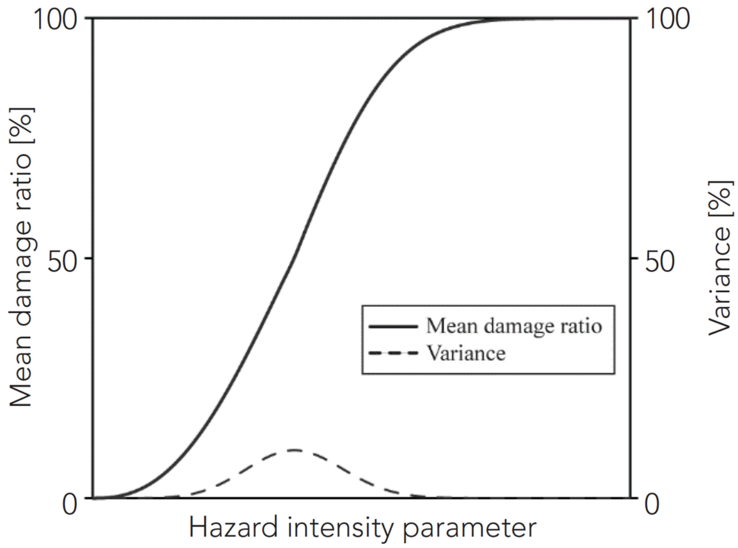

Figure 5-2 Typical representation of a vulnerability function (World Bank, 2019c).

Figure 5-3 presents the process followed for derivation of fragility and vulnerability functions and safety benefits for index buildings identified in Chapter 2. Note that the vulnerability functions referred to in Figure 5-3 are in terms of expected fatalities, not mean damage ratio as shown in Figure 5-2, although they are derived from the fragility curves in the same manner. This allows for computation of safety benefits in terms of expected lives saved due to retrofit.

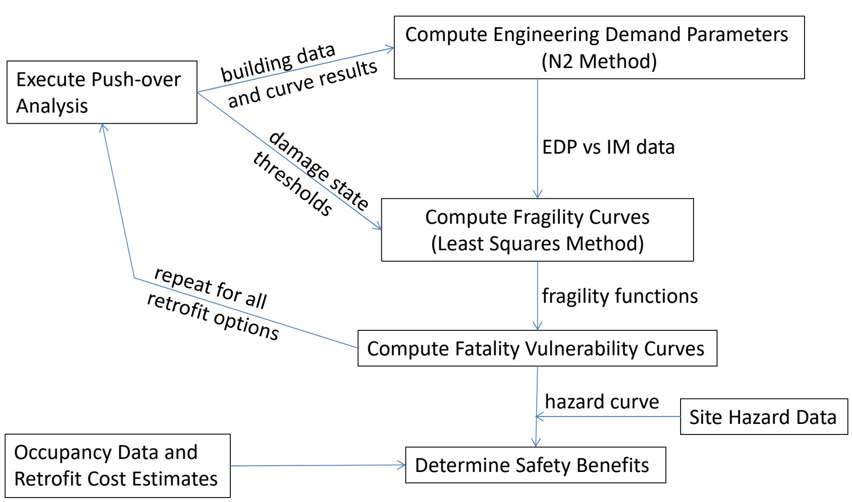

Figure 5-3 Process for calculation of fragility and vulnerability functions and safety benefits.

The process illustrated in Figure 5-3 includes the following primary steps:

- Implement the *N2* simplified non-linear static seismic performance methodology, based on D'Ayala et al. (2015), to generate engineering demand parameter versus intensity measure (EDP vs. IM) data. The method utilizes an idealized bilinear representation of the building capacity curve derived from the push-over analysis described in Chapter 4. For the seismic demand, a suite of ground motions is used, each represented by a scaled set of response spectra. For each scaled response spectrum, the analysis method of Fajfar (2000) is used to compute the performance point, which is the EDP (in terms of horizontal roof displacement) at the given IM (seismic demand in terms of spectral acceleration).
- Use the *Least Squares Method*, based on D'Ayala et al. (2015) with EDP vs. IM data to compute the fragility curve parameters. The method performs a piece-wise regression over four distinct bins of the EDP vs. IM data to compute a mean and variance of the data in each bin, assuming a lognormal distribution. The bins are defined by the thresholds of horizontal roof displacement (EDP) associated with the onset of each of the four damage states: slight, moderate, extensive, and complete damage. The resulting mean, μ, and variance, β, parameters were reviewed and adjusted as necessary to preserve the proper shape of fragility curves and to ensure that the four curves did not cross each other at low levels of ground motion. Figure 5-4 shows fragility curves indicating four damage states for one index building (2-story CX).

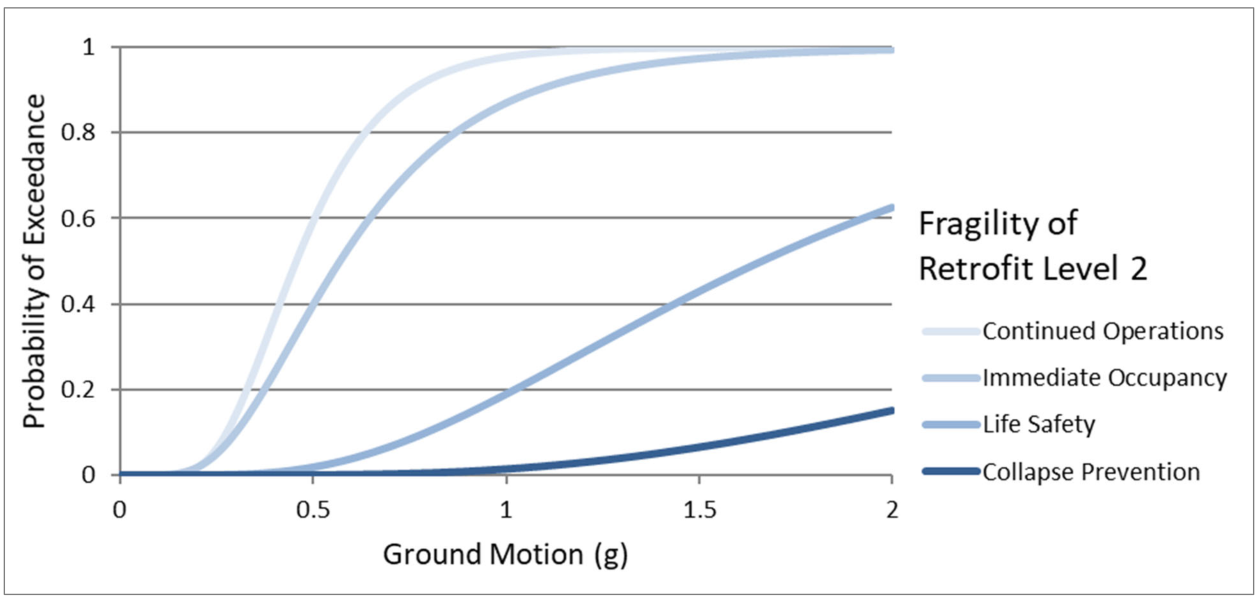

Figure 5-4 Fragility curves showing four damage states.

- Compute fatality vulnerability curves from the fragility curves using the method described in the ATC-142 report (World Bank, 2019a). In this method, fatality rates associated with extensive and complete damage are applied to the probability of extensive and complete damage computed from the fragility curves. The resulting vulnerability curve is expressed in terms of expected fatality rates versus ground motion intensity. Figure 5-5 shows the fatality vulnerability curves for different retrofit levels for one index building (2-story CX). For example, if the building illustrated in Figure

5-5 is occupied by 100 people at any given time, an earthquake with shaking equivalent to 1g spectral acceleration (a rare event, shown in dashed red line) would be expected to kill about 28 occupants (0.28×100) in its current condition. With a weak retrofit (Retrofit Level 1), the expected fatalities would decrease to 6 occupants (0.06×100) and with a strong retrofit (Retrofit Level 2), the expected fatalities would decrease to less than 1 occupant (0.007×100). Note that for a more moderate event, with shaking equivalent to 0.5g spectral acceleration, Figure 5-5 shows that both retrofit levels achieve a similar fatality rate that is significantly smaller than the existing condition.

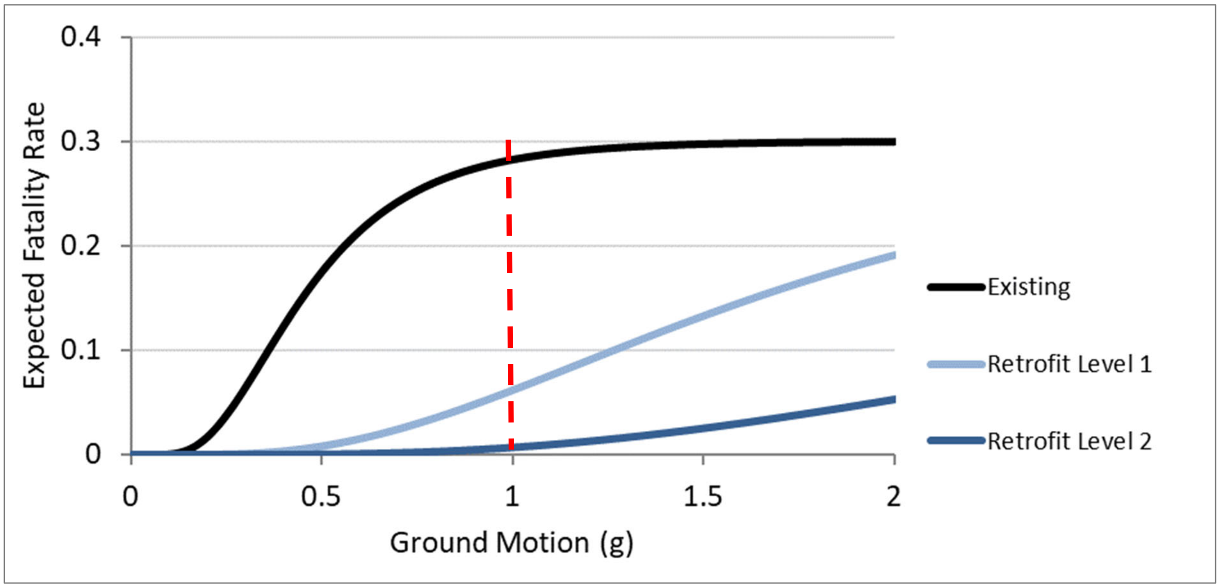

Figure 5-5 Expected Annual Loss (in terms of fraction of occupants killed) for different retrofit levels.

- Compute the expected annual loss (EAL) in terms of an expected fatality rate for the building (fraction of occupants killed on an annual basis) from the probabilistic seismic hazard curve at the site of the building and the fatality vulnerability curve described above. The EAL is on a per occupant basis, and it uses the actual time-weighted building occupancy to estimate expected fatalities. The safety benefits are computed from the change in EAL (reduction in expected annual fatalities) due to the retrofit, as described in the ATC-142 report, and briefly summarized in the following section.

5.2 Development of Fragility and Vulnerability Functions to Represent School Infrastructure Database

During the conduct of this and prior phases of this work, structural analyses were conducted for most of the structural typologies prevalent in the school infrastructure database. These are listed in Table 5-1. These analyses resulted in pushover curves that are necessary to implement the procedure described in the previous section. The information for URM4 typology was obtained from *Glosi* documentation.

Table 5-1 Structural Typologies for which Pushover Information is Available

Typology	*Number of Stories*
Complex Masonry (CX)	1 2 4 Gym
Precast Frame with Exterior Precast Panels (PC2)	2 3 4 Gym
RC Frame with Infill Walls (RC2)	2
Complex Masonry with Concrete Frame (CXCF)	3

To develop a complete suite of fragility and vulnerability functions used in the seismic risk prioritization framework, pushover curves for the remaining prevalent structural typologies were derived by extrapolation, since drawings were not available. The judgement-based extrapolation considered the architectural configurations, expected weights, stiffnesses, and component deflection limits of the typologies to derive the relative strengths and pushover capacities. Table 5-2 summarizes method of derivation for all prevalent structural typologies. The use of extrapolated fragilities is suitable for these studies since the purpose of the project is to assign *relative* risks to schools within the inventory, in order to prioritize interventions to improve safety based on efficiency.

For example, the observed complex masonry typologies have similar architectural forms, with the longitudinal wall configurations of piers and windows, responding to light and air requirements of the classrooms. The 1-story CX has a similar wall length to floor area as that of a 2-story CX. The relatively higher capacity of the one-story CX is explained due to its lower seismic weight. This pattern of wall length to floor area to seismic weight, was used to extrapolate the capacity of the 3-story CX. The results are deemed reasonable to derive *relative* capacities, especially considering that all these typologies are short period structures where the response is not greatly influenced by the small effects of stiffness. Moreover, the overall displacement capacity tends to be limited and the damage tends to be concentrated at the lowest level.

For the CXCF typology, the only reasonably complete set of drawings available for analysis was from a 3-story school. Accordingly, the fragilities for the 1-, 2-, and 4-story typologies had to be extrapolated from their CX counterparts. The strengths were deemed to be the same as the corresponding CX. However, because the CXCF typology is distinct, due to free standing concrete columns, the drifts at *life safety* and *collapse prevention* were limited to that expected for shear critical columns.

Similar processes to those described for CX and CXCF were used to determine the fragilities for the 1-story PC2, and the 1- and 3-story RC2.

For low-rise URM4 schools, the fragility information provided in Glosi was used. This is a very weak, informal building made with clay bricks set in mud mortar. The same fragility was used for schools of adobe construction, because the mud mortar is expected to control and the strength of the adobe wall. The Adobe fragility from Glosi was not used since it suggests significantly more capacity than URM4.

Table 5-2 Method of Derivation for all Prevalent Structural Typologies

Typology	*Number of Stories*	*Analyzed*	*Glosi*	*Extrapolated*
Complex Masonry (CX)	1	X		
	2	X		
	3			X
	4	X		
	Gym	X		
Precast Frame with Exterior Precast Panels (PC2)	1			X
	2	X		
	3	X		
	4	X		
	Gym	X		
RC Frame with Infill Walls (RC2)	1			X
	2	X		
	3			X
Complex Masonry with Concrete Frame (CXCF)	1			X
	2			X
	3	X		
	4			X
Adobe				X
URM4	Low-rise Mid-rise		X	

Chapter 6

Risk-Based Prioritization Framework

This chapter describes the implementation of the analytical framework developed to prioritize schools in Kyrgyz Republic for seismic retrofit.

6.1 Overview

The prioritization framework is based on the methodology described in the ATC-142 report and 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.
- 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 (as described in Chapter 5).
- Prioritization indices and benefit-cost ratio are calculated.

Results of application of the framework to the eligible schools list is presented in Chapter 7.

6.2 Determine Seismic Hazard

For each school site identified by a latitude and longitude, the full seismic hazard is evaluated for the peak ground accelerations (PGA) and the 5% damped spectral acceleration at a period of vibration of 0.2 seconds, $S_a(0.2)$. Annual exceedance rates for different levels of PGA and S_a (0.2) were obtained by running a full earthquake hazard analysis in the Kyrgyz Republic using the OpenQuake software. The study recreated the hazard estimates from the Global Earthquake Model (GEM) Global Hazard Model for Central Asia. Fault geometries, magnitude recurrence rates, and the logic tree with corresponding ground motion prediction equations (GMPE) were obtained from GEM documentation (https://hazard.openquake.org/gem/models/CEA/). Soil conditions that can potentially amplify the shaking intensity at the school sites were obtained from the Global slope-based V_s30, the time-averaged shear-wave velocity to 30 m depth, by the U.S. Geological Service (https://earthquake.usgs.gov/data/vs30/).

The validity of the seismic hazard model was confirmed by comparing the results with the shaking intensity for the only two return periods (475 and 975 years) publicly available for the Kyrgyz Republic from the Kyrgyzstan Disaster Risk Data Platform at http://geonode.mes.kg/, generally referred to here as Geonode. Figure 6-1 shows the hazard map for PGA.

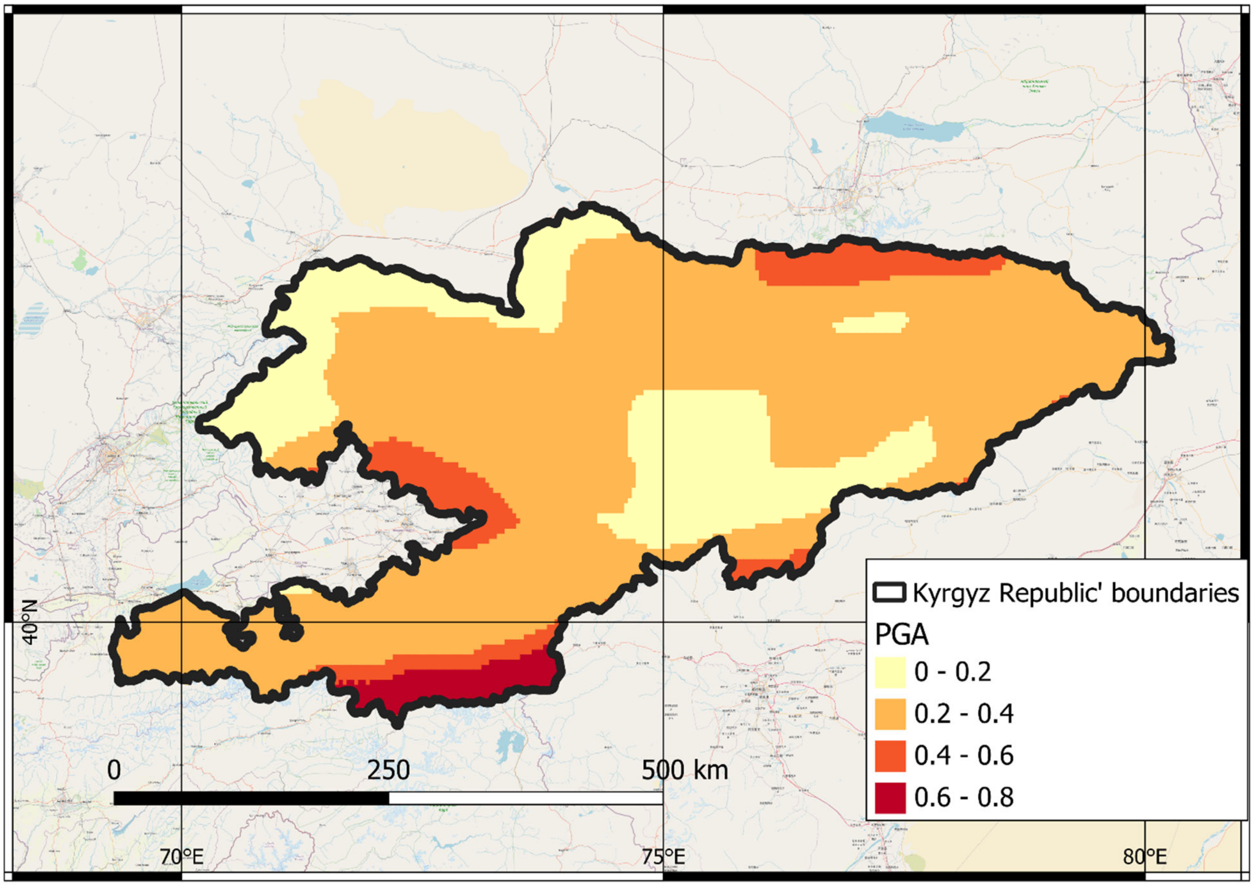

Figure 6-1 Seismic hazard map of Kyrgyz Republic showing the distribution of PGA with 10% probability of exceedance in 50 years, i.e., return period of 475 years.

6.3 Calculation of Safety Benefits

The Safety/Benefits index, A_1, is computed from the change in EAL (reduction in expected annual fatality rate) due to the retrofit, as described in Section 6.7.1 of the ATC-142 report (World Bank, 2019a) and reproduced below.

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

$$A_1 = \frac{B_r}{V} = \left(\frac{EAL}{V} - \frac{EAL_r}{V} \right) \times t \quad (6\text{-}1)$$

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

$= Occs \times h$ (6-2)

where:

$Occs$ = actual number of occupants during school hours

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

$$= \frac{5 \frac{school\ days}{week} \times 7 \frac{school\ hr}{day}}{7 \frac{calendar\ days}{week} \times 24 \frac{hr}{day}} \tag{6-3}$$

$$= 0.21$$

$$\frac{EAL}{V} = \int_{x=0}^{\infty} y(x) \left| \frac{dG(x)}{dx} \right| dx \tag{6-4}$$

$$\frac{EAL_r}{V} = \int_{x=0}^{\infty} y_r(x) \left| \frac{dG(x)}{dx} \right| dx \tag{6-5}$$

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 in existing condition

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

t = expected remaining useful life of the structure. Absent better information, t is taken as 75 years, in agreement with NIBS (2018).

This index uses the time-weighted occupancy of the building to estimate the total number of lived saved over the remaining life of the building (assumed to be 75 years unless otherwise known). The time-weighted occupancy represents the estimated time-averaged population of occupants at the building, i.e., accounting for nighttime and weekend hours during which the building is unoccupied. For blocks with the assigned occupancy of classroom and auditoriums, the assumptions for time weighting are the same as those in the ATC-142 project, based on the fraction of the week during which school is occupied based on a 7-hour school day 5 days a week, resulting in $V = 0.21$. These blocks are considered to have high density of students for a majority part of the school day. In contrast, blocks with an assigned occupancy of gymnasium, library, and bathrooms where a lower density of students are present for a limited time, the calculation of estimated time-averaged occupancy in the building, V, is adjusted to 0.07, and for blocks with very limited service time, such as canteen and transition blocks, the occupancy is adjusted to 0.03.

6.4 Calculation of Cost Efficiency

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

$$A_{2,r} = \frac{Occs}{C_r} \tag{6-6}$$

where:

$Occs$ = actual number of occupants during school hours

C_r = cost of retrofit r, presented in Chapter 3. The cost might be a square-meter value multiplied by the area of the building.

6.5 Calculation of Benefit-Cost Ratio

The benefit-cost ratio is calculated as a combination of two prioritization indices previously described.

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

$$BCR_r = A_{1,r} A_{2,r} h = \frac{B_r}{C_r} \tag{6-7}$$

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.

6.6 Implementation of Seismic Risk-Based Prioritization Framework

Due to the large size of the school infrastructure database and necessity of computational needs, the framework was implemented on an opensource, high-level programing language, Python, resulting in the development of the Seismic Risk Tool (SRT). SRT works with input files provided as excel files and output is also provided in an excel file that allows viewing of results in a variety of ways.

It is expected that over time, improved information will be available on the input data, especially the infrastructure database (additional surveys may be conducted, especially to data points that were brought over from UNICEF) and the cost estimates.

In addition, SRT also allows for adjustment of selected levers to serve as a useful tool to decision makers to investigate potential changes to results based on policies they are considering. For example, the default value of triggering a replacement is set to when a retrofit intervention cost estimate exceeds 50% of an estimated cost for new school construction, given as 500USD. The user can choose to adjust the cost estimate for new school construction for changing market values or investigate the effects of adjusting the 50% trigger value.

SRT estimates the best intervention for each block in the school portfolio according to their benefit-to-cost ratios, BCR_r. Then, it estimates a global BCR_r at the school level using the best interventions at the block level. SRT ranks the schools according to their global BCR_r and recommends interventions on the schools at the top of the list.

Chapter 7

Findings and Recommendations

7.1 Development of a Risk-Based Prioritization Strategy in Kyrgyz Republic

There is a significant risk of loss of life in schools in the areas of highest seismic hazard in Kyrgyz Republic. Seismic evaluation of existing buildings found that none of the representative building types satisfy current code requirements, and the precast frame type is especially fragile and at risk of collapse. Given the importance of the education sector for the resilience and safety of communities and the potential scale of the problem, a risk-based prioritization strategy that aims to maximize safety benefits, cost-efficiency, and benefit-cost ratio for spending available funds is recommended for the Kyrgyz Republic.

Education facilities are buildings where the children of the nation spend a substantial amount of their time, and children continuing school is critical to the recovery of a community. Variation in the damage pattern of an earthquake may leave some schools in a region still functional, and if any single school is damaged, other schools in the region could be utilized despite the costs of more difficult transportation, overcrowding, and additional shifts, allowing some students to temporarily relocate to continue their education. These considerations have not been addressed in this study, but it would be recommended to expand this type of assessments towards understanding the capacity of the school infrastructure network to cope with disruptive events and devise integrated solutions to ensure that educational services can continue during a time of emergency or disaster.

The presented retrofits are effective in driving down the fatality rates. However, the estimated retrofit costs are high, with all the building types analyzed exceeding the 50% replacement cost threshold. The decision to retrofit or replace any particular building is a policy decision and should be informed with consideration beyond just cost. Each building is unique and will differ in important ways from the representative building types considered here. Because of these differences, the ultimate cost and benefits of the retrofit will vary from the estimates presented here.

Investment decisions to reduce the vulnerability of school facilities are not only about physical interventions described in this report. The social and institutional environment, among others, are also important considerations. However, a risk-based prioritization approach founded on technical considerations will always be a key tool for efficient use of available funds to ensure saving the most lives.

7.2 Seismic Evaluation Results

Analytical evaluations of representative masonry wall and concrete frame buildings observed at selected facilities identified the following key vulnerabilities present in the buildings studied:

- Low lateral strength manifested in shear critical columns in precast and cast-in-place concrete frame structures
- Low lateral displacement capacity in at least one direction of all typologies
- Lack of diaphragm connectivity to transfer in-plane loads and out-of-plane loads
- Low out-of-plane masonry wall capacities due to anchorage deficiencies
- Low displacement capacities of precast panels due to connection limitations
- Presence of nonstructural falling hazards, e.g., masonry partition walls, masonry gables, and precast exterior panels

Overall, precast concrete frame structures were found to be the most dangerous due to their weak and brittle behavior. Masonry wall structures that are most prevalent in the country are moderately strong, however, they are brittle with limited displacement capacity. No study buildings met the expected performance objective of providing life safety, i.e., structure is damaged but retains a margin against the onset of collapse, in their existing conditions. Accordingly, seismic retrofit designs were developed for index buildings utilizing strategies such as column jacketing, strengthening of wall elements, augmented footings, installation of new walls, collectors, chords, wall ties, and replacement of partitions and precast panels, where applicable.

7.2.1 Differences in Performance by Typology

Seismic evaluations of representative buildings show that precast buildings are the most dangerous building type studied. They are weak and brittle, primarily due to the limited shear capacity of poorly detailed columns. Because of the limited ductility (brittleness), the capacity is primarily controlled by strength. Table 7-1 shows that the base shear capacity of precast reinforced concrete frames with exterior precast reinforced concrete wall panels (PC2) typology in different configurations is between $0.06W$ and $0.07W$, where W is the building weight, indicating relatively low strengths. The reinforced concrete frame with masonry infill (RC2) typology is nearly twice as strong as the strongest PC2 building, with a base shear of $0.16W$. Representative buildings with complex masonry (CX) typology have even higher base shear capacities of $0.24W$.

Table 7-1 Base Shear Capacity of Typologies in Existing Condition

Building	*Base Shear in Building Weight, W*
2-story PC2	0.06*W*
PC2 Gym	0.07*W*
2-story RC2	0.16 *W*
2-story CX	0.24*W*
CX Gym	0.24*W*

7.2.2 Effects of Occupancy

The number of occupants in the building at a given time has a significant impact on the vulnerability of a typology. Schools are assumed to be occupied five days a week, seven hours a day, resulting in a time-averaged population factor of 0.21 (21%); meaning that a school facility is empty 79% of the time. A gymnasium occupies a large area on a school facility, but only a low density of students can be present to exercise. In addition, the same occupancy factor is applied to the average population of a gymnasium (assumed to be 32 kids each hour).

Figure 7-2 shows the expected annual losses in terms of fatalities per area for a PC2 gym and a 2-story PC2 classroom. Figure 7-1 includes consideration for the occupants present in the building at a given time and shows that the danger posed by the PC2 gym is lower than the classroom building. The same effect would be observed for the CX classroom versus gymnasium, as well.

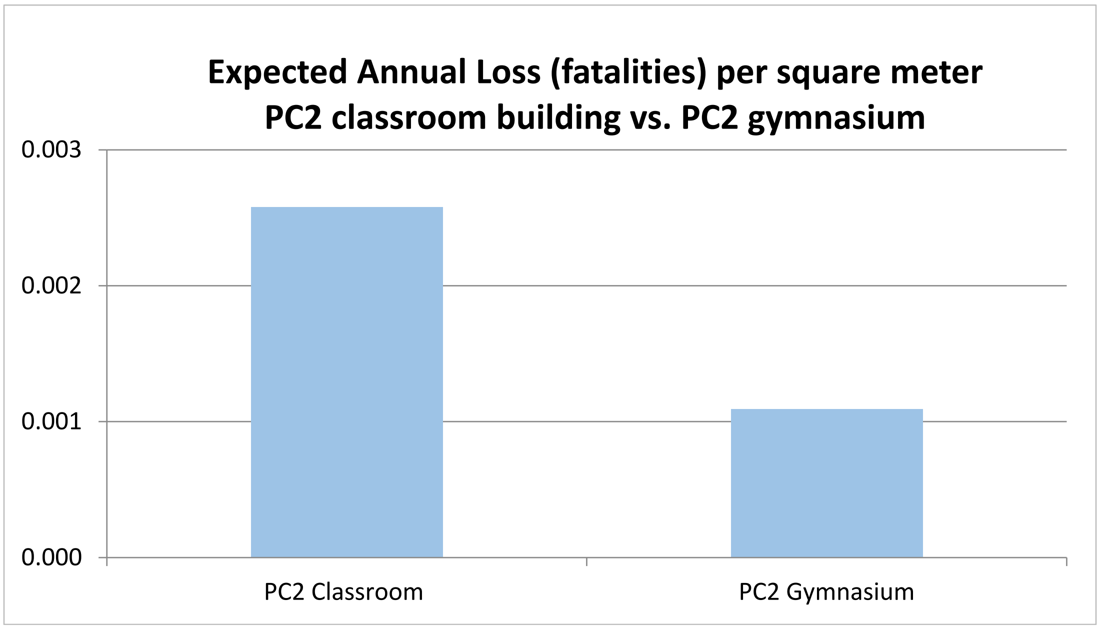

Figure 7-1 Expected annual losses for 2-story PC2 classroom and PC2 Gym per square meter of area. This presentation normalizes the floor area for each representative building. There are 106 occupants (time-weighted) in a 1,080 sq. meter block, and 7 occupants (time-weighted) in a 327 sq. meter gym.

7.3 Cost Estimate Results

Cost estimates for seismic retrofits were developed on a square meter basis and include demolition of elements required for construction of seismic retrofit and work related to heating, water supply, electrical systems, as well as replacement of affected finishes for capital repair.

Figure 7-2 shows cost estimates per unit area (square meter) ranked by building height for CX, RC2, and PC2 typologies.

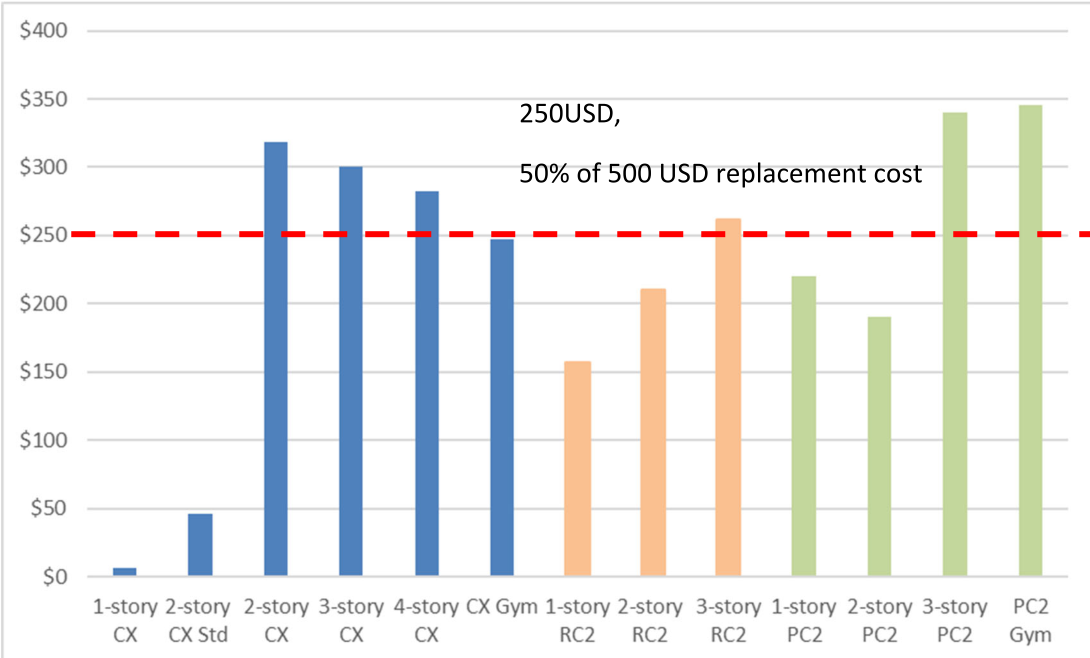

Figure 7-2 Relative costs per square meter for seismic retrofits to full code. The red line is the replacement threshold, set per policy at 50% of an estimated 500 USD replacement cost.

The final cost of retrofit for each typology is a complex product, driven by many factors including the particular set of deficiencies and the existing capacity. There is no single trend that uniformly explains the final cost differences, but the following are observations and explanations for the trends in Figure 7-2:

- 1-story CX is a relatively small building with low seismic weight, relative to its larger counterparts. The observed CX typologies have similar wall configurations, with the capacity controlled by the piers of the longitudinal elevations. The single-story CX has a similar wall length to floor area as that of the 2-story CX, but with a much lower seismic weight. Consequently, the typology is relatively much stronger than its taller counterparts, and minimal seismic retrofit is required, at only 6USD per square meter.
- If a typology requires foundation work as part of the recommended seismic retrofit, the costs are shared by the entire building area. Consequently, smaller typologies such as the PC2 Gym and 2-story CX have relatively higher unit costs. In contrast, the 2-story PC2 and the CX Gym typologies reflect relative savings due portions of the existing structures not needing retrofit: The 2-story PC2 did not require new walls or footings in the transverse direction once the existing frame was improved; similarly, the CX Gym did not need wall strengthening or new footings for two of the four sides.
- 2-story CX standard building typology (for 150 students) is a design that was developed in 2009. Even though it has seismic vulnerabilities, it is stronger than older buildings that may have been designed to lower code requirements. Because of the typology’s greater strength, it is expected to have a higher lateral capacity than its older counterparts. The retrofit adds displacement capacity, and this was accomplished without new foundations. Accordingly, the cost to retrofit the standard building design to comply with the new building code expected performance is less onerous (46USD per square meter).

A common threshold is to replace a building if expected retrofit costs exceed 50% of new construction costs, which was given as 500USD per square meter. Figure 7-2 includes a dashed red line at the value of 250USD.

The values shown in Figure 7-2 pertain to structural costs related to seismic retrofits only. The calculation of intervention costs related to water, sanitation, and hygiene (WASH), and energy efficiency (EE) were calculated on a block-by-block basis. For reference, the average cost for EE upgrades is 124USD per square meter (which includes finishes and heating), and WASH upgrades is 11USD per square meter. Accordingly, if average WASH and EE costs are included in Figure 7-2, only 1-story CX and 2-story CX standard school typologies would remain beneath the 50% threshold and all other typologies would trigger replacement costs.

The decision to retrofit or replace any particular building is a policy decision and should be informed by considering the following:

- A replacement building has the potential for improved structural performance.
- A replacement building may provide a better architectural fit for planned programming and community needs.
- An important consideration is the potential loss of use of facilities during construction. If land is available for placement of the new building, new construction avoids the loss of use. However, if land is not available, new construction may take more time than retrofit, resulting in a longer loss of use and education.

7.4 Safety Benefits of Seismic Retrofits

Figure 7-3 shows the expected fatality rate versus ground motion for the existing condition and the full code retrofit. It illustrates the reduction in fatalities when a building is retrofitted. The variation in the horizontal axis shows that seismic retrofits lower the fatality rates for all earthquake intensities, including moderate levels of shaking (upto 0.5g) that are much more prevalent than higher levels of shaking.

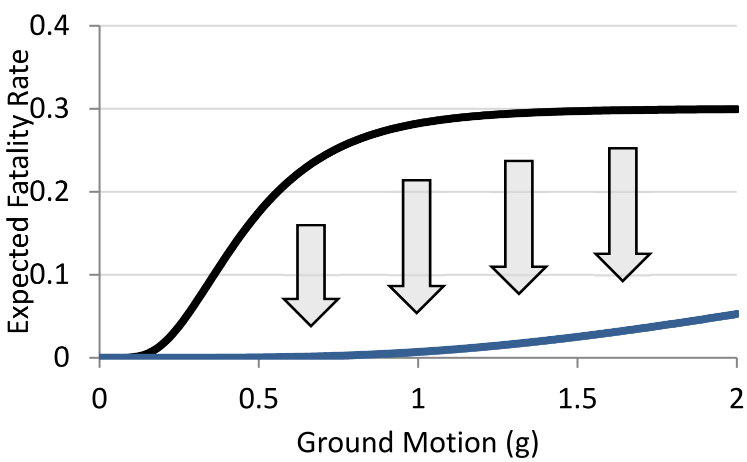

Figure 7-3 Safety benefits of retrofit for different ground motion levels, as measured with the reduction in the fatality rate.

The effectiveness of seismic retrofit is shown in Figure 7-4 with a comparison of rate of expected annual losses (per time-weighted occupancy) for two-story classroom buildings and gymnasiums before and after retrofit. For all typologies, the reduction in fatalities relative to the existing condition is so large that it is difficult to see when plotted on the same scale.

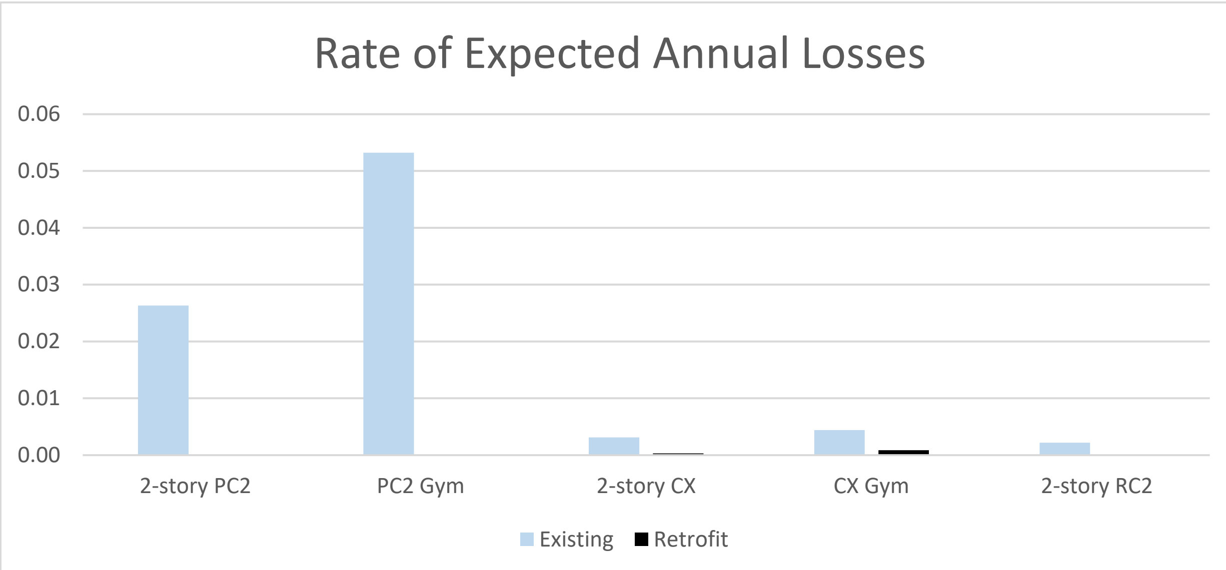

Figure 7-4 Expected annual loss per time-weighted occupancy for selected two-story classroom and gym typologies, in existing (blue) and retrofit (black) conditions. All typologies have low expected losses after retrofit (black) and large safety benefits.

Retrofits for all typologies are effective for increasing safety. However, when considering a benefit-cost ratio (BCR) where the improvement in seismic safety through reduction in fatalities is divided by the retrofit cost, a difference in efficiency rankings is observed. One driver for this change is the fragility of the typology in its existing condition. Since the retrofits for all buildings are set to full code, the improved capacities are similar among typologies. Thus, typologies that are weaker in the existing condition have greater safety improvements (benefit) from retrofit.

Figure 7-5 shows a comparison of benefit-cost ratios for selected two-story classroom and gym typologies. In this comparison, 2-story PC2 classroom typology has the highest BCR, with PC2 gym having the second highest value. This is consistent with Figure 7-4 where the two PC2 configurations had displayed the largest expected annual loss, confirming that improving the capacity of these weak typologies has the most impact on safety. Another driver for a high BCR is the cost of the retrofit. The 2-story PC2 school retrofit is the least inexpensive of the typologies in Figure 7-5, and thus, it has the highest BCR. Accordingly, the order of the 2-story classroom and gym typologies are reversed in Figure 7-5. Further, 2-story PC2 also has higher occupancy than a PC2 gym.

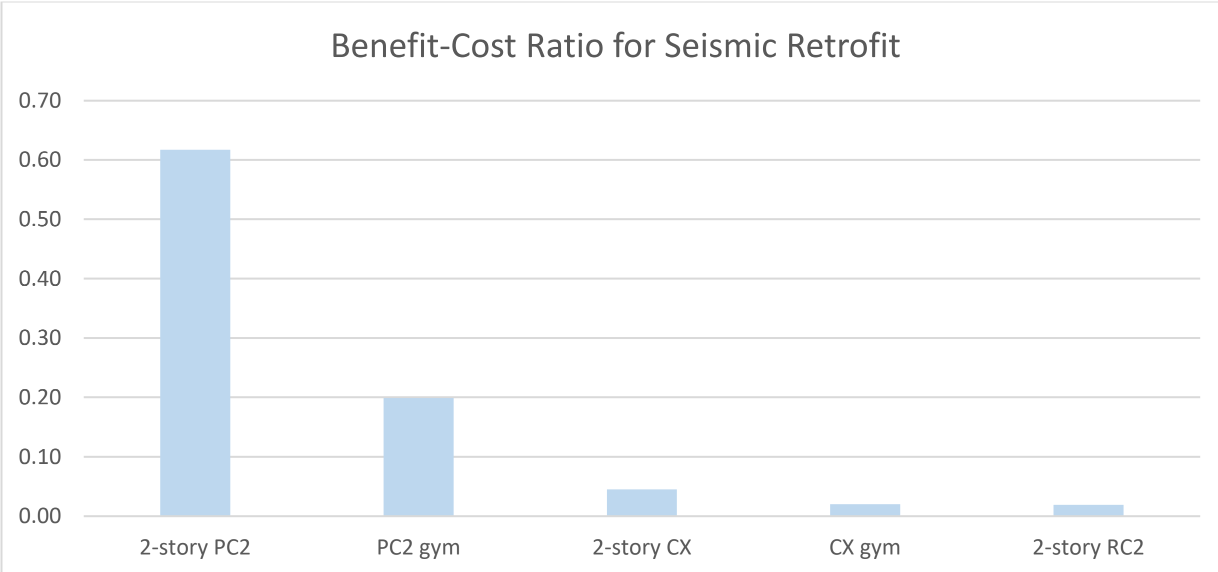

Figure 7-5 Benefit-cost ratios for selected two-story classroom and gym typologies. Although gyms have the highest time-weighted losses (see Figure 7-4), the overall risk is somewhat reduced because of the lower occupancy relative to classrooms.

7.5 Implementing the Risk-Based Prioritization Strategy

The risk-based seismic prioritization strategy described in this report was implemented on the school infrastructure database developed in Chapter 2 with the Seismic Risk Tool (SRT) described in Section 6.6. This section presents commentary on preliminary results obtained with SRT and describes next steps for implementation of SRT as part of ERIK project.

7.5.1 Preliminary Results Discussion

As described in Section 6.6, SRT outputs a list of school facilities prioritized based on the benefit-cost ratio considering safety benefits. The graphics presented in this section were developed based on SRT output. To present patterns, the presentation includes results pertaining to the top 30 school facilities and the top 100 facilities. Top 30 facilities comprise 125 blocks and top 100 school facilities comprise 439 blocks.

Figure 7-6 are histograms showing the distribution of the top 30 (left) and top 100 (right) school facilities among oblasts in Kyrgyz Republic. Figure 7-7 shows the geographic distribution on a map. The distribution shows proposed interventions in areas with high seismic hazard in the country (see Figure 6-1), as well as the Bishkek City area where there is a high concentration of PC2 blocks.

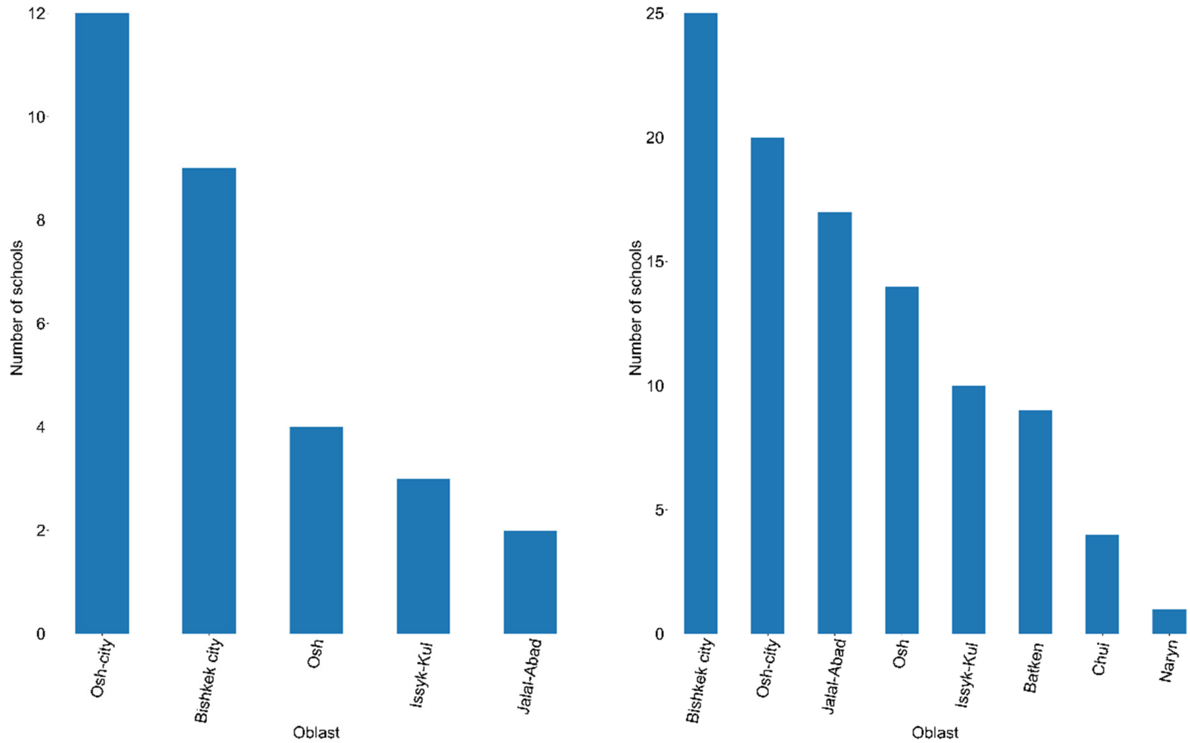

Figure 7-6 Histograms showing geographic distribution of top 30 (left) and top 100 (right) school facilities.

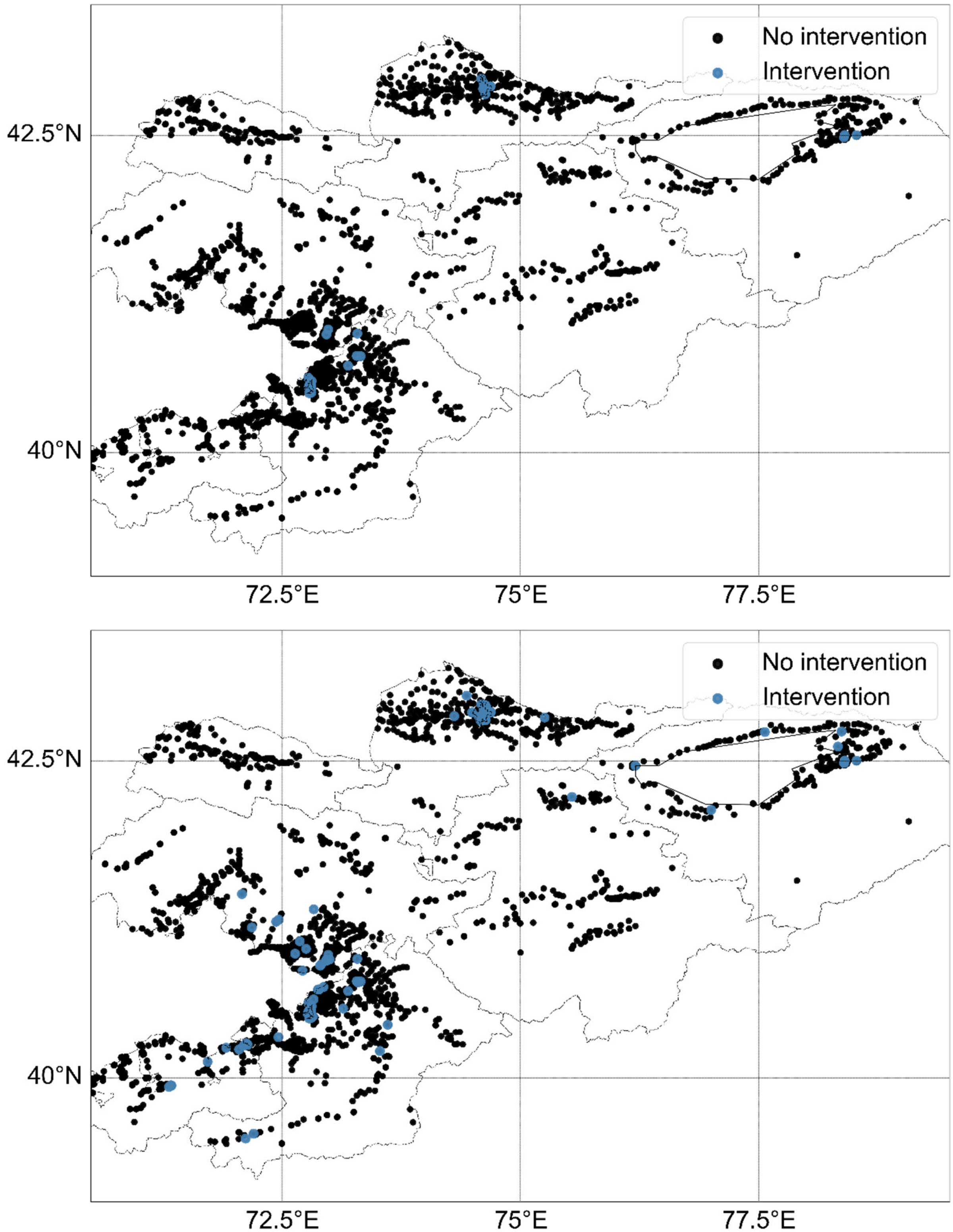

Figure 7-7 Maps of Kyrgyz Republic showing geographic distribution of top 30 (top) and top 100 (bottom) school facilities.

Figure 7-8 are histograms showing the number of blocks that require seismic intervention in the form of replacement versus retrofit for top 30 (left) and top 100 schools (right). In both cases, majority of seismic interventions are replacements. This is due to intervention costs for most typologies exceeding the 50% threshold of the 500USD replacement cost set by policy (see Section 7.3). Blocks for which retrofit is selected are the relatively less expensive 1-story CX and CX standard design typologies.

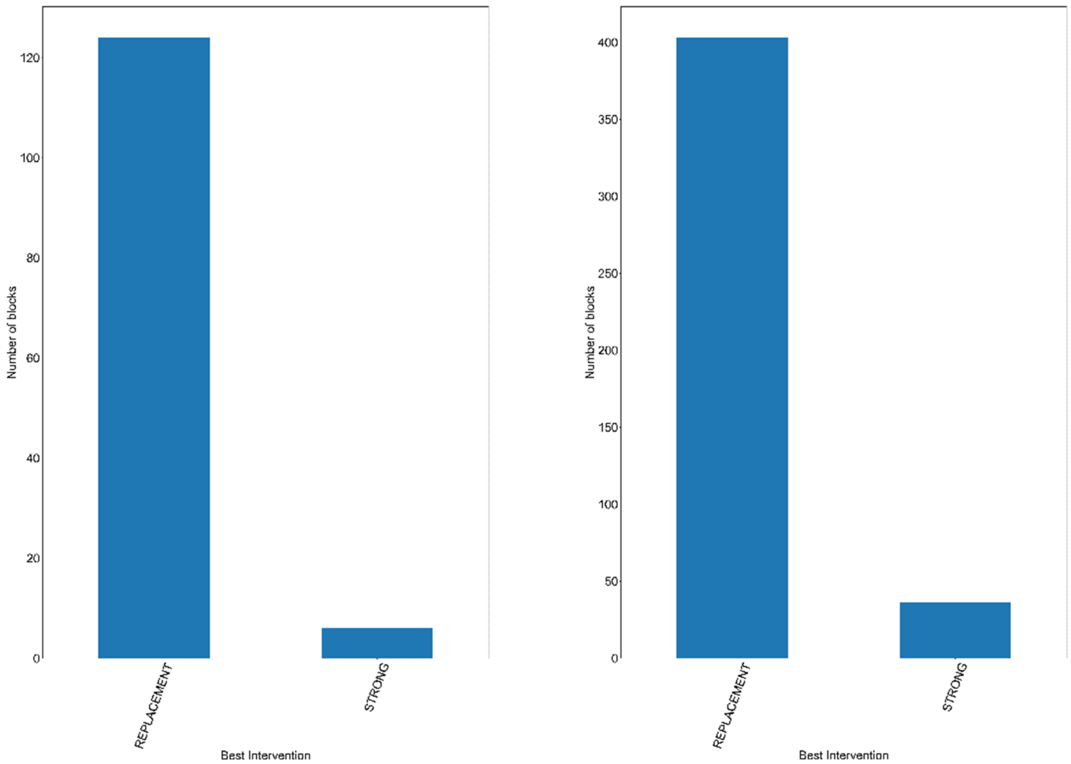

Figure 7-8 Histograms of seismic intervention methods (replacement vs. strong retrofit) for blocks of top 30 (left) and top 100 (right) schools.

Figure 7-9 presents histograms showing the prevalence of structural typologies requiring seismic intervention for replacement or retrofit for the top 30 (left) and the top 100 schools (right). In both cases, majority of seismic interventions are for 2-story PC2 classrooms, with PC2 gym and 3-story PC2 classrooms also being frequently intervened. This observation is consistent with the safety benefits discussion of Section 7.4 noting that PC2 typologies are so extremely dangerous that replacement of existing conditions provides a great benefit to safety, and consequently high benefit-cost ratios.

Top 30 school facilities include a considerable number of interventions required for 1-story URM4 and adobe structures, as well. This is due to intervention ranking that is on a school basis. An individual school may have a mix of typologies among the blocks.

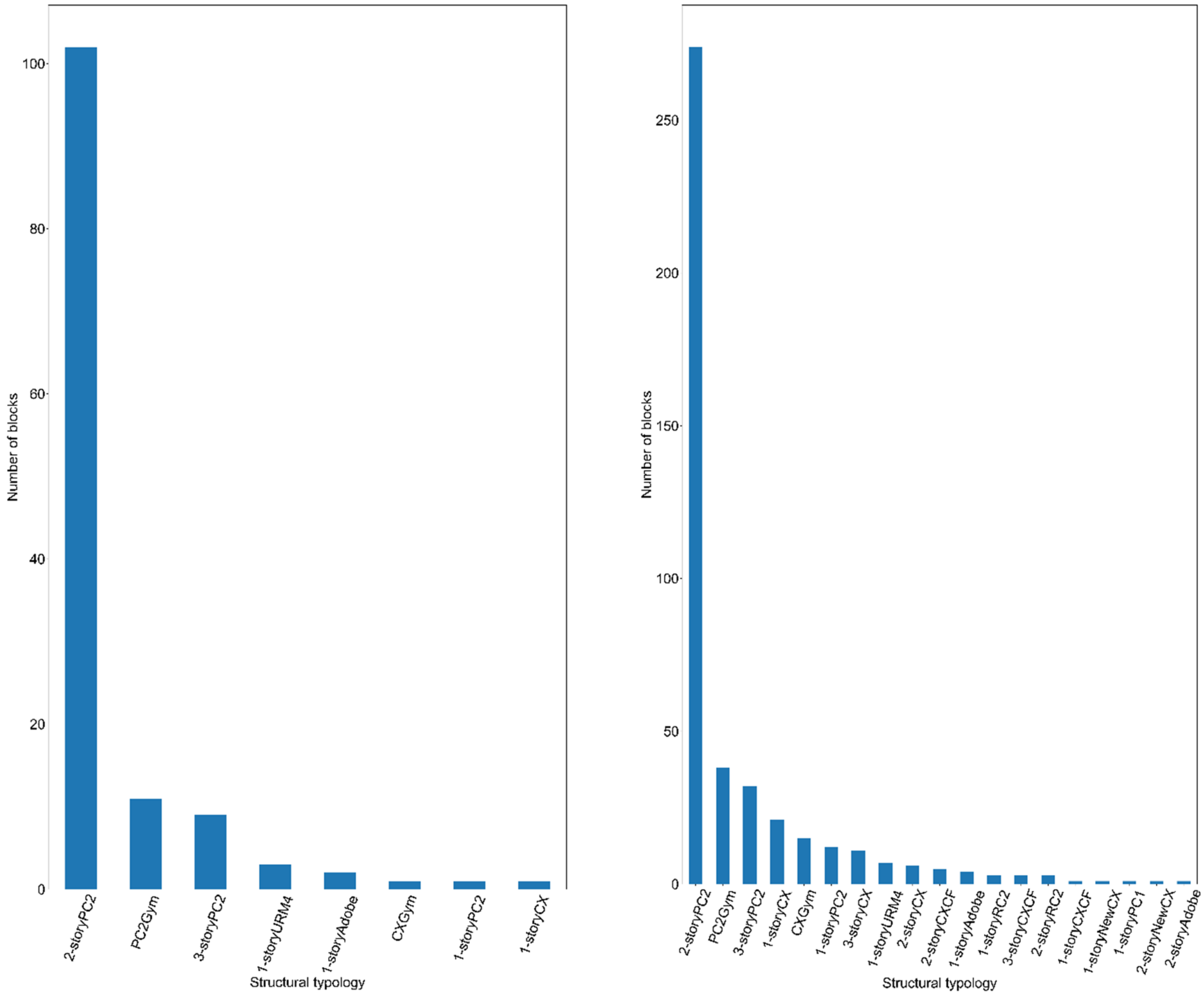

Figure 7-9 Histograms of prevalence of structural typologies requiring seismic intervention for top 30 (left) and top 100 (right) schools.

7.5.2 Next Steps

Preliminary results of implementing the framework provide a great starting point for informing the investment plan. However, the underlying data have important limitations (see Section 7.6) that can be mitigated so that any investment decisions could be made with higher confidence. The recommendation of 100 schools is intended to be the pool for the eventual selection of the top 30 schools. Accordingly, it is critical for detailed surveys to be conducted of selected 100 schools. Information from the surveys can be used to validate input for the prioritization tool. For example, if a school has more students than initially reported, it will move up the list. If additional classrooms have been added since the initial survey, it would move down the list. Once data have been verified or corrected, the priority order should be recalculated. Only after this validation step should feasibility studies be initiated to help plan seismic interventions.

7.6 Study Limitations and Suggested Refinements and Adjustments

The risk-based framework presented in this report is intended to be used iteratively to refine results. Moreover, the framework allows policy makers to expand the scope of study or make changes to the intervention strategy. The process of pooling candidate schools, then validating the data with re-inspection is consistent with the intended use and essential for quality results.

The tool is intended to be adaptable to many possible changes. These include changes in market information, updates to retrofit costs to align with the real outcomes, and the discovery of new typologies. There is also the possibility of refining the retrofit policy by changing the replacement threshold or allowing retrofits that are weaker than new code designs, consistent with design practice in the United States, if these provide more efficient retrofits with higher benefit cost ratios.

Expected changes should come from updates to the database. For example, the database in this current study is known to be incomplete and needs updating. As noted in Chapter 2, information was not available for 559 preschool sites, approximately 35% of the inventory identified on the Ministry of Preschool Education database in 2020. Additionally, typology information for many of the buildings was deduced from limited and outdated information from the UNICEF database.

Another potential area of refinement is the fragility information for the underlying typologies. The premise of the ranking is that the studied typologies will reasonably reflect the behavioral trends of the various schools throughout the country. The structural analyses used for the pushover curves are based on limited information from individual buildings. In many cases, drawing sets were incomplete and material properties were assumed. As more information becomes available, fragility information could be updated, and new typologies could be added as needed.

The requirement for replacement schools is a great opportunity to provide enhanced seismic resilience at lower cost by using performance-based design. A similar potential for innovation can apply to many aspects of the replacement schools, including energy efficiency and architectural configuration for improved educational outcomes.

Appendix A
Selection and Prioritization Criteria

This Appendix provides a copy of the decree (in Russian) issued in March 2018 by the Kyrgyz Republic Government on the subject of the Selection and Prioritization criteria for the ERIK project.

КЫРГЫЗ РЕСПУБЛИКАСЫНЫН
ӨЗГӨЧӨ КЫРДААЛДАР
МИНИСТРЛИГИ

МИНИСТЕРСТВО
ЧРЕЗВЫЧАЙНЫХ СИТУАЦИЙ
КЫРГЫЗСКОЙ РЕСПУБЛИКИ

MINISTRY OF EMERGENCY SITUATIONS OF THE KYRGYZ REPUBLIC

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19.03.2018 №02-27/1724
На исх.№11-1/1505 от 07.03.2018г

Министерство образования и науки
Кыргызской Республики

Министерство чрезвычайных ситуаций Кыргызской Республики, рассмотрев «Руководство по проведению оценки в соответствии с критериями отбора средних школ для включения в перечень работ по капитальному ремонту, реконструкции и усилению школьных зданий», замечаний и предложений не имеет.

Статс – секретарь **А.М.Мамбетов**

Исп. Шаршенов Б.
Тел: 439113

«Одобрено»	«Одобрено»	«Одобрено»
Директор Государственного агентства архитектуры, строительства и жилищно-коммунального хозяйства при ПКР	Министр образования и науки Кыргызской Республики	Министр чрезвычайных ситуаций Кыргызской Республики
____________ Б. Абдиев	____________ Г. Кудайбердиева	____________ К. Боронов
«___»____________2018 г.	«___»____________2018 г.	«19» 03 2018 г.

Методические рекомендации
по отбору средних школ для включения в состав работ по капитальному ремонту, реконструкции и модернизации

Межведомственная рабочая группа:

Усеналиев М.	Начальник Управления дошкольного, школьного и внешкольного образования МОН КР;	____________
Рысбеков Б.	Заведующий сектором НПА Управления дошкольного, школьного и внешкольного образования МОН КР;	____________
Шаршенов Б.	Начальник отдела обследования опасных природных процессов Департамента мониторинга МЧС КР;	____________
Исаева Н.	Заведующая отделом мониторинга и планирования Департамента жилищно-гражданского строительства ГААС ЖКХ при ПКР;	____________
Субакеева Ж.	Главный специалист Отделом государственный закупок МОН КР	____________

Руководство по проведению оценки в соответствии с критериями отбора средних школ для включения в перечень работ по капитальному ремонту, реконструкции и усилению школьных зданий

г. Бишкек – март 2018 года

Введение

Настоящее Руководство по оценке содержит общие критерии отбора и определения приоритетности среди средних школ в Кыргызской Республике для выполнения капитального ремонта, реконструкции и усиления школьных зданий с целью снижения сейсмического риска в рамках Проекта «Повышение устойчивости к стихийным бедствиям в Кыргызстане», финансируемого Всемирным банком («ERIK»). Данные критерии эффективны и применимы к планированию работ по капитальному ремонту, реконструкции и усилению зданий средних школ в Кыргызской Республике.

В основе критериев отбора и определения приоритетности лежит цель Проекта ERIK, заключающаяся в максимальном увеличении численности учеников школ, защищенных от землетрясений. Таким образом, для достижения такой цели предлагается использовать процесс принятия решений, основанный на оценке риска. Как следствие, Проект фокусируется на школах, расположенных в района с наибольшей вероятностью землетрясений самой высокой магнитудой; в рамках проекта определяется приоритетность школьных зданий с наименьшей сейсмоустойчивостью и с самым высоким уровнем концентрации учеников. Исследование «Оценка сейсмических рисков в Кыргызской Республике», проведенное организацией ARUP International (2017) при финансировании Всемирного банка – самая последняя имеющаяся в стране информация о сейсмическом риске школьной инфраструктуры. По результатам таких исследований было определено двенадцать районов с наивысшим уровнем риска. Краткое изложение данных результатов представлено в Приложении I. Процесс принятия решений, в ходе которого учитывается наиболее актуальная информация о сейсмическом риске в стране, позволяет максимизировать стоимость вложений в части защиты жизни учащихся и снижения риска, т.е. достигать максимальной пользы на благо детей.

Проект ERIK в своей работе основывается на ранее предпринятых в стране попытках по обеспечению более безопасных школ. Проект разработан в контексте Государственной программы «Безопасные школы и дошкольные образовательные учреждения». С учетом суммы в размере 12 млн. долларов США, выделенной на реализацию данного компонента, в рамках Проекта могут быть реализованы интервенции в ограниченном количестве школьных зданий (согласно предварительным оценкам от 10 до 15 школ), а также будут установлены рамки, сформирован институциональный потенциал, разработана стратегия интервенции и план вложений в целях репликации интервенций по всей стране, т.е. в целях реализации решения в большем масштабе.

Между критериями отбора и критериями определения приоритетности проводится отличие. Критерии отбора применяются для выявления группы подходящих школ, а критерии определения приоритетности - для определения окончательного перечня отобранных школ на основе показателей, учитывающих такие факторы как, повышение безопасности, эффективность затрат и аспекты социальной справедливости (эффективного распределения социальных затрат).

Критерии отбора и критерии определения приоритетности не включают в себя определение интервенций (т.е. замена здания на вновь построенное (новое строительство), реконструкция, капитальный ремонт, усиление школьных зданий). Объем интервенций будет определен посредством тщательного анализа, в основе которого лежит инженерно-конструкторский анализ повышенного уровня сложности и анализ эффективности затрат.

При соблюдении критериев определения приоритетности будет учитываться возможность выполнения требований к энергоэффективным улучшениям, созданию благоприятных условий для образования, использованию современных строительных материалов и оборудования.

Процесс принятия решений по отбору и определения приоритетных школ

Процесс составления окончательного перечня школ, которые будут финансироваться в рамках Проекта ERIK, включает два основных решения. В группе школ, расположенных в областях и городах с высоким уровнем риска, критерии отбора применяются для составления короткого перечня группы отвечающих критериям школ, которые должны соответствовать всем критериям. Второе решение касается определения окончательного перечня школ, которые будут профинансированы в рамках Проекта ERIK, с помощью критериев определения приоритетности. При применении последних, отвечающие критериям школы ранжируются от самого высокого до самого низкого приоритета. Только школы с высоким уровнем приоритетности будут финансироваться в рамках Проекта ERIK с учетом имеющихся денежных средств.

Критерии отбора

При отборе отвечающих критериям школ должны применяться следующие критерии. В настоящем контексте под термином «школа» понимается учреждение, имеющее одно или более школьных зданий.

a. Только государственные школы могут участвовать в отборе;

b. Критерий максимального повышения общественной пользы (направлен на максимальное увеличение численности учеников школ, защищенных от землетрясений):

   b1. могут участвовать только школы с общей численностью учеников, равной 500 или больше (городские школы) или 100 и выше (сельские школы);
   b2. могут участвовать только школы с общей численностью учеников за 2017 год, равной 70% или выше от общей численности учеников, на которую рассчитана школа.

c. Критерий максимальной масштабируемости Государственной программы (направлен на охват репрезентативной группы различных типов школьных зданий, требующих различные виды интервенций, результаты которых могут масштабироваться в целях их учета в национальных стратегиях):

   c1. не могут участвовать школы, чьи здания были построены до 1970 года;

c2. из общей группы отвечающих критериям школ в минимум 70% зданий школ должны быть проведены инженерные работы.

d. Критерий максимизации преимуществ сокращения риска (направлен на определение приоритетных регионов с высоким сейсмических риском):

d1. Общая группа отвечающих критериям школ расположена в областях и городах с наивысшим уровнем сейсмического риска. В данных областях и городах ожидается самое большое количество смертных случаев при землетрясениях. Такие области и города будут определены по результатам самой последней вероятностной оценки сейсмического риска в стране (см. более подробную информацию в Приложении I);
d2. Группа отвечающих критериям школ должна включать школы из нескольких отвечающих критериям областей;
d3. Группа отвечающих критериям школ должна включать школы из обоих городов Бишкек и Ош;
d4. Группа отвечающих критериям школ должна включать школы из городской и сельской местностей.

Критерии определения приоритетности

При составлении окончательного перечня отобранных школ, которые будут профинансированы в рамках Проекта ERIK, должны быть использованы следующие критерии. Для составления такого перечня, приоритетность школ, попавших в короткий перечень, будет определяться с точки зрения защиты жизни учеников, эффективности и социальной инклюзивности вложений. Для количественного выражения и сочетания данных показателей будет проведен инженерный анализ повышенного уровня сложности и анализ эффективности затрат по различным типам школьных зданий. Окончательное количество отобранных школ будет зависеть от суммы имеющихся денежных средств.

a1. Показатель повышения безопасности: данный показатель оценивает пользу интервенций в части снижения сейсмической уязвимости. Цель данного показателя – быть применимым к школам, большая часть зданий которых отличается высоким уровнем уязвимости.

a2. Показатель эффективности затрат: данный показатель оценивает эффективность вложений посредством количественного выражения численности учеников, которые получат пользу от интервенций, по сравнению с общим объемом потребностей школьного комплекса во вложениях. Цель данного показателя – быть применимым к школам с самым большим количеством учеников, которые получили пользу от интервенции на одну единицу вложений.

a3. Показатель социальной справедливости: данный показатель оценивает уровни бедности и этнический состав районов, где расположены отвечающие критериям школы. Цель данного показателя – быть применимым к школам, где учатся дети бедных слоев населения, и при этом обеспечивается репрезентативность различных этнических групп.

Приложение I

Определение районов с наивысшим уровнем сейсмического риска по результатам национальной вероятностной оценки сейсмического риска

Основные выводы национальной вероятностной оценки сейсмического риска

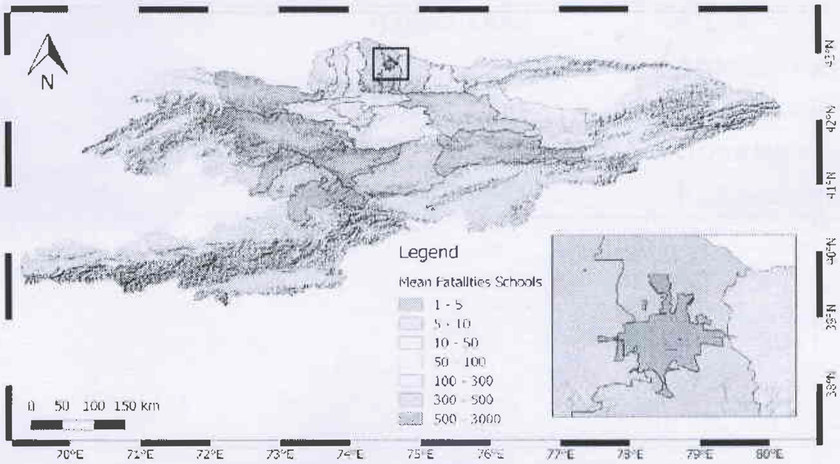
В ходе национальной вероятностной оценки сейсмического риска, завершенная в 2017 году[i], проведена оценка сейсмического риска школ во всех районах Кыргызской Республики. Жизнь человека и экономические убытки получили количественное выражение по всем районам с учетом сейсмоопасности, количества лиц, находящихся в школах, концентрации школьных зданий в каждом районе. Среди всех потенциальных сценариев землетрясений в стране, по результатам оценки был сделан вывод, что землетрясение силой 7,5 баллов в Ферганской долине и землетрясение силой 7,3 баллов, вызванное Иссык-Атинским разломом – наиболее вероятные сценарии, которые могут привести к смертельным случаям и экономическим убыткам. Заключения по результатам национальной оценки кратко изложены ниже:

1. Самое высокое количество смертельных случаев и экономических убытков может вероятней всего иметь место в школах г. Бишкек и Ферганской долины;
2. В целом, с учетом количества ожидаемых смертельных случаев при вышеуказанных сценариях землетрясений, наивысший уровень сейсмического риска наблюдается в 12 районах, где спроектированное количество смертей превышает 300 учеников.

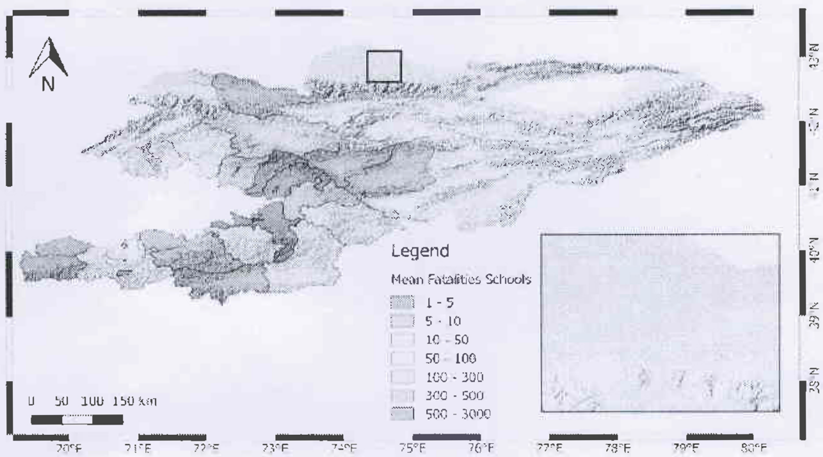
Сейсмический риск в г. Бишкек и Ферганской долине

По результатам вероятностной оценки сейсмического риска было определено, что сейсмический риск неравномерно распределен по стране – он сконцентрирован в г. Бишкек и Ферганской долине. Предполагается, что в случае землетрясения эти зоны подвергнутся наибольшему уровню потери человеческих жизней и экономических убытков. На рисунке 1 показано распределение среднего количества потенциальных смертельных случаев в школе (на уровне районов) при землетрясении магнитудой 7,5 баллов в Ферганской долине и при землетрясении магнитудой 7,3 баллов, вызванном Иссык-Атинским разломом. Так, к примеру, в Ферганской долине количестве смертей среди учителей и учеников школ может достичь максимального показателя в 11 4000, а сумма экономических убытков составит свыше 268 млн. долларов США.

Рисунок 1. Распределение потенциальных смертельных случаев при соответствующих сценариях землетрясений



Среднее количество потенциальных смертельных случаев в школах (на уровне районов) при сценарии землетрясения магнитудой 7,3 баллов, вызванного Иссык-Атинским разломом



Среднее количество потенциальных смертельных случаев в школах (на уровне районов) при сценарии землетрясения магнитудой 7,5 баллов, вызванного разломом в Ферганском долине

Определение районов с наивысшим уровнем сейсмического риска

Согласно критерию d1 Критериев отбора, школы, имеющие право на получение финансирования по Проекту, должны располагаться в областях или городах с наивысшим уровнем сейсмического риска. Это области и города, где ожидается наибольшее количество смертельных случаев в случае землетрясений. Учитывая результаты оценки риска по самым критическим сценариям, можно прийти к выводу, что районы с наивысшим уровнем сейсмического риска – это районы, в школах которых количество смертельных случаев при землетрясении может достичь 300. В целях извлечения максимальной пользы от реализации Проекта в части защиты жизни учеников, в рамках Проекта будут отобраны школы из указанных в перечне районов с наивысшим уровнем сейсмического риска, как показано в таблице 2 ниже.

Таблица 2. Районы с наивысшим уровнем сейсмического риска в Кыргызской Республике

Сценарий землетрясения, вызванного Иссык-Атинским разломом		**Сценарий землетрясения в Ферганской долине**	
Район	**Область**	**Район**	**Область**
г. Бишкек	Чуйская	Базар-Коргонский	Джалал-Абадская
Аламединский	Чуйская	Сузакский	Джалал-Абадская
Сокулукский	Чуйская	Кара-Суйский	Ошская

Кочкорский	Нарынская	г. Ош	Ошская
		Араванский	Ошская
		Узгенский	Ошская
		Ноокенский	Джалал-Абадская
		Кадамжайский	Баткенская

Термины и определения

Капитальный ремонт здания	означает интервенции, необходимые для восстановления здания до его первоначального состояния (т.е. до его первоначального состояния сейсмической уязвимости), и включают ряд строительно-инженерных работ по устранению физического и функционального износа, не предполагающих каких-либо изменений в основных технических и экономических показателях здания или структуры, включая, если необходимо, замену некоторых или всех элементов конструкции (за исключением не подлежащих замене)
Спроектированное здание	означает здание школы, спроектированное для образовательных целей в соответствии с техническими стандартами и правилами.
Новое строительство	означает полную замену всего здания школы посредством строительства нового здания. Новое строительство осуществляется в соответствии с современными техническими стандартами и правилами. Ожидается, что новое школьное здание будет соответствовать действующим стандартам безопасности и функциональным стандартам.
Не спроектированное здание	означает здание школы, не спроектированное в соответствии с техническими стандартами и нормативами и/или здание школы, которое первоначально не было спроектировано для образовательных целей. Предполагается, что не спроектированное здание должно полностью подлежать замене новым строительством.
Элементы конструкции, не подлежащие замене	означает все несущие элементы конструкции такие как, стены, колоны, балки, фундаменты.
Реконструкция здания	означает интервенции, необходимые для снижения сейсмической уязвимости и улучшения функциональности здания. Большое значение отдается повышению безопасности исходной конструкции.
Усиление здания	означает интервенции, необходимые для улучшения функциональных условий зданий (вода и санитария, электричество, отопление и др.).
Школа	означает всю территорию школы, где может располагаться

	одно или несколько зданий школы.
Средняя школа	означает общеобразовательное учреждение в Кыргызской Республике, где учащиеся получают общее образование, готовятся к общественной и практической деятельности, а также к учебе в учреждениях высшего и профессионального образования.

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[i] ARUP, CAIAG, GEM, GFZ, World Bank, Measuring Seismic Risk in Kyrgyz Republic: Seismic Risk Reduction Strategy, 2017 [Оценка сейсмического риска в Кыргызской Республике: Стратегия сокращения сейсмического риска].

КЫРГЫЗ РЕСПУБЛИКАСЫНЫН ӨКМӨТҮНҮН АППАРАТ ЖЕТЕКЧИСИ - МИНИСТР

РУКОВОДИТЕЛЬ АППАРАТА ПРАВИТЕЛЬСТВА - МИНИСТР КЫРГЫЗСКОЙ РЕСПУБЛИКИ

БУЙРУК РАСПОРЯЖЕНИЕ

2020-жылдын 8-сентябры, № 96

Кыргыз Республикасында мектеп инфраструктурасынын коопсуздугун жогорулатуу боюнча чараларды иштеп чыгуу максатында, Кыргыз Республикасынын Өкмөтүнүн 2013-жылдын 10-июнундагы № 341 токтому менен бекитилген Кыргыз Республикасынын Өкмөтүнүн Регламентинин 35 жана 36-пункттарына ылайык:

1. Кыргыз Республикасында мектеп инфраструктурасынын коопсуздугун жогорулатуу боюнча чараларды иштеп чыгуучу ведомстволор аралык жумушчу топ тиркемеге ылайык курамда түзүлсүн.

2. Ведомстволор аралык жумушчу топ 2020-жылдын 1-декабрына чейинки мөөнөттө төмөнкүлөрдү иштеп чыгып, Кыргыз Республикасынын Өкмөтүнүн Аппаратына киргизсин:

- Кыргыз Республикасында мектеп инфраструктурасынын коопсуздугун жогорулатуу боюнча иш-чаралар планынын долбоорун;

- Дүйнөлүк банктын "Кыргызстанда табигый кырсыктардын тобокелдигине туруктуулукту жогорулатуу" долбоорунун "Мектеп инфраструктурасынын коопсуздугун жана иштешин жакшыртуу" компонентинин алкагында жалпы билим берүү уюмдарын тандоо критерийлерин;

- жогоруда аталган тандоо критерийлеринин негизинде жалпы билим берүү уюмдарынын артыкчылыктуу тизмесин;

- Кыргыз Республикасынын Өкмөтүнүн 2015-жылдын 31-июлундагы № 551 токтому менен бекитилген Кыргыз Республикасынын Өкмөтүнүн "2015-2024-жылдарга Кыргыз Республикасында коопсуз мектептер жана мектепке чейинки билим берүү уюмдары" программасын өркүндөтүү боюнча сунуштарды.

3. Ведомстволор аралык жумушчу топ иш процессинде келип чыккан маселелерди чечүү үчүн зарыл болгон учурда министрликтердин, мамлекеттик комитеттердин, административдик ведомстволордун, жергиликтүү мамлекеттик администрациялардын, жергиликтүү өз алдынча башкаруу органдарынын (макулдашуу боюнча), бизнес ассоциацияларынын жана эксперттик коомчулуктун (макулдашуу боюнча) адистерин белгиленген тартипте ишке тартууга жана маалыматтарды сурап алууга укуктуу экендиги белгиленсин.

КЫРГЫЗ РЕСПУБЛИКАСЫНЫН ӨКМӨТҮНҮН АППАРАТ ЖЕТЕКЧИСИ - МИНИСТР

РУКОВОДИТЕЛЬ АППАРАТА ПРАВИТЕЛЬСТВА - МИНИСТР КЫРГЫЗСКОЙ РЕСПУБЛИКИ

БУЙРУК РАСПОРЯЖЕНИЕ

от 8 сентября 2020 года № 96

В целях разработки мер по повышению безопасности школьной инфраструктуры в Кыргызской Республике, в соответствии с пунктами 35 и 36 Регламента Правительства Кыргызской Республики, утвержденного постановлением Правительства Кыргызской Республики от 10 июня 2013 года № 341:

1. Образовать межведомственную рабочую группу по разработке мер по повышению безопасности школьной инфраструктуры в Кыргызской Республике в составе согласно приложению.

2. Межведомственной рабочей группе в срок до 1 декабря 2020 года разработать и внести в Аппарат Правительства Кыргызской Республики:

- проект плана мероприятий по повышению безопасности школьной инфраструктуры в Кыргызской Республике;

- критерии отбора общеобразовательных организаций в рамках компонента «Улучшение безопасности и функциональности школьной инфраструктуры» проекта Всемирного банка «Повышение устойчивости к рискам стихийных бедствий в Кыргызстане»;

- приоритетный перечень общеобразовательных организаций на основании вышеуказанных критериев отбора;

- предложения по совершенствованию Программы Правительства Кыргызской Республики «Безопасные школы и дошкольные образовательные организации в Кыргызской Республике на 2015-2024 годы», утвержденной постановлением Правительства Кыргызской Республики от 31 июля 2015 года № 551.

3. Установить, что межведомственная рабочая группа имеет право в установленном порядке, при необходимости, запрашивать информацию и привлекать специалистов министерств, государственных комитетов, административных ведомств, местных государственных администраций, органов местного самоуправления (по согласованию), бизнес-ассоциаций и экспертного сообщества (по согласованию) для решения вопросов, возникающих в процессе работы.

4. Руководителям министерств, государственных комитетов, административных ведомств, главам местных государственных администраций и органов местного самоуправления (по согласованию) в

4. Министрликтердин, мамлекеттик комитеттердин, административдик ведомстволордун, жергиликтүү мамлекеттик администрациялардын жана жергиликтүү өз алдынча башкаруу органдарынын (макулдашуу боюнча) жетекчилери ведомстволор аралык жумушчу топтун суроо-талабы боюнча ыкчам тартипте зарыл болгон маалыматты беришсин жана анын ишине ар тараптуу көмөк көрсөтүшсүн.

5. Ведомстволор аралык жумушчу топтун жумушчу органы болуп Кыргыз Республикасынын Билим берүү жана илим министрлиги аныкталсын.

6. Ушул буйруктун аткарылышын контролдоо Кыргыз Республикасынын Өкмөтүнүн Аппаратынын билим берүү, маданият жана спорт бөлүмүнө жүктөлсүн.

Өкмөттүн Аппарат жетекчиси - министр **Т.А.Темиралиев**

оперативном порядке представлять необходимую информацию по запросу межведомственной рабочей группы и оказывать всемерное содействие ее деятельности.

5. Определить рабочим органом межведомственной рабочей группы Министерство образования и науки Кыргызской Республики.

6. Контроль за исполнением настоящего распоряжения возложить на отдел образования, культуры и спорта Аппарата Правительства Кыргызской Республики.

Руководитель Аппарата Правительства – министр **Т.А.Темиралиев**

Тиркеме

Кыргыз Республикасында мектеп инфраструктурасынын коопсуздугун жогорулатуу боюнча чараларды иштеп чыгуучу ведомстволор аралык жумушчу топтун курамы

Джусупбекова Надира Сынташевна	-	Кыргыз Республикасынын Билим берүү жана илим министринин орун басары, ведомстволор аралык жумушчу топтун төрагасы;
Борубаев Самат Нарматович	-	Кыргыз Республикасынын Өкмөтүнө караштуу Архитектура, курулуш жана турак жай-коммуналдык чарба мамлекеттик агенттигинин статс-катчысы, ведомстволор аралык жумушчу топтун төрагасынын орун басары.

Ведомстволор аралык жумушчу топтун мүчөлөрү:

Мамбетов Азамат Муратович	-	Кыргыз Республикасынын Өзгөчө кырдаалдар министрлигинин статс-катчысы;
Саралаева Жанна Урматовна	-	Кыргыз Республикасынын Өкмөтүнүн Аппаратынын билим берүү, маданият жана спорт бөлүмүнүн башчысы;
Карыбеков Залкарбек Арзыбекович	-	Кыргыз Республикасынын Өкмөтүнүн Аппаратынын курулуш, транспорт жана коммуникациялар бөлүмүнүн эксперти;
Усеналиев Марат Жолдошбекович	-	Кыргыз Республикасынын Билим берүү жана илим министрлигинин мектептик жана мектептен сырткары билим берүү башкармалыгынын начальниги;
Абдылдаева Чолпон Жолдошбековна	-	Кыргыз Республикасынын Өзгөчө кырдаалдар министрлигинин эл аралык кызматташтык башкармалыгынын начальнигинин милдетин аткаруучу;
Кадыркулов Бакыт Акылбекович	-	Кыргыз Республикасынын Билим берүү жана илим министрлигинин мамлекеттик сатып алуулар жана мектеп инфраструктурасы бөлүмүнүн башчысы;

Приложение

Состав
межведомственной рабочей группы по разработке мер по повышению безопасности школьной инфраструктуры в Кыргызской Республике

Джусупбекова Надира Сынташевна	-	заместитель министра образования и науки Кыргызской Республики, председатель межведомственной рабочей группы;
Борубаев Самат Нарматович	-	статс-секретарь Государственного агентства архитектуры, строительства и жилищно-коммунального хозяйства при Правительстве Кыргызской Республики, заместитель председателя межведомственной рабочей группы.

Члены межведомственной рабочей группы:

Мамбетов Азамат Муратович	-	статс-секретарь Министерства чрезвычайных ситуаций Кыргызской Республики;
Саралаева Жанна Урматовна	-	заведующая отделом образования, культуры и спорта Аппарата Правительства Кыргызской Республики;
Карыбеков Залкарбек Арзыбекович	-	эксперт отдела строительства, транспорта и коммуникаций Аппарата Правительства Кыргызской Республики;
Усеналиев Марат Жолдошбекович	-	начальник управления школьного и внешкольного образования Министерства образования и науки Кыргызской Республики;
Абдылдаева Чолпон Жолдошбековна	-	исполняющая обязанности начальника управления международного сотрудничества Министерства чрезвычайных ситуаций Кыргызской Республики;
Кадыркулов Бакыт Акылбекович	-	заведующий отделом государственных закупок и школьной инфраструктуры Министерства образования и науки Кыргызской Республики;

Каримжанов Жумабай	- Кыргыз Республикасынын Өкмөтүнө караштуу Архитектура, курулуш жана турак жай-коммуналдык чарба мамлекеттик агенттигинин Турак жай-жарандык курулуш департаментинин директорунун орун басары;
Кенжетаев Камчыбек Исмаилович	- Кыргыз Республикасынын Өкмөтүнө караштуу Архитектура, курулуш жана турак жай-коммуналдык чарба мамлекеттик агенттигинин алдындагы Жер титирөөгө туруктуу курулуш жана инженердик долбоорлоо мамлекеттик институтунун директорунун орун басары;
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Токторбаева Жылдыз Айтбековна	- Кыргыз Республикасынын Өзгөчө кырдаалдар министрлигинин алдындагы долбоорлорду ишке ашыруу бөлүмүнүн директору (макулдашуу боюнча);
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Appendix B

Updated Glosi Taxonomy Guide

This Appendix provides a copy of the updated Glosi Taxonomy Guide that was used to for field surveys in Kyrgyz Republic.

The Global Library of School Infrastructure GLOSI

Training material:

Taxonomy guide

GLOBAL PROGRAM FOR SAFER SCHOOLS – GPSS

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Contents

Global Library of School Infrastructure

The World Bank's Global Program for Safer Schools (GPSS) launched in 2019 the Global Library of School Infrastructure (GLOSI). The GLOSI is a live global repository of evidence-based knowledge and data about school infrastructure and its performance against natural hazard events, as shown in Figure 1. A one-stop-shop with open access to global indicators on school infrastructure exposure and risk to natural hazards, taxonomy of school buildings, catalog of building types, fragility and vulnerability information, case studies on vulnerability reduction solutions applied around the world, and data collection tools. In-country data is also available with restricted access. The GLOSI is updated over time through World Bank-funded safer school projects and contributions from development partners with interest in this field.

Why do we need GLOSI?

Safer school projects have taught us that there are three main challenges to global dissemination of knowledge surrounding school building performance: communication to decision makers, the lack of a common language, and facilitation of quantitative risk assessment.

Global knowledge about school infrastructure performance needs to reach decision makers

The engineering community has achieved immense progress in the past few decades towards understanding building performance against natural hazards and devising scalable risk-reduction solutions. However, this knowledge has not reached decision makers nor has it been used to drive school infrastructure investments. Without this knowledge, the opportunity to maximize benefits from intervention and optimize investments in school safety can be lost.

The first objective is to create a universal "language"

School buildings tend to follow standard designs, yet buildings with similar vulnerability are still difficult to identify in different countries, or even within a country. This is largely due to the lack of a systematic classification system and consistent vulnerability assessment framework. The GLOSI offers a solution by making a taxonomy and vulnerability assessment framework for school buildings globally applicable, and oriented to produce quantitative risk information that will inform large investments in school safety and resilience.

The GLOSI is a tool to mainstream quantitative risk assessment in investment planning

By using a systematic taxonomy, the GLOSI includes a catalog of typical school building types found in different parts of the world with the respective vulnerability data needed to conduct quantitative risk assessments. Countries can map their school facility portfolios with the catalog and use the GLOSI data to perform quantitative risk assessments or vulnerability analyses to identify cost-efficient retrofitting solutions. The availability of this information will ensure that results are scalable across countries and safer school engagements in each country begin with a solid existing technical foundation.

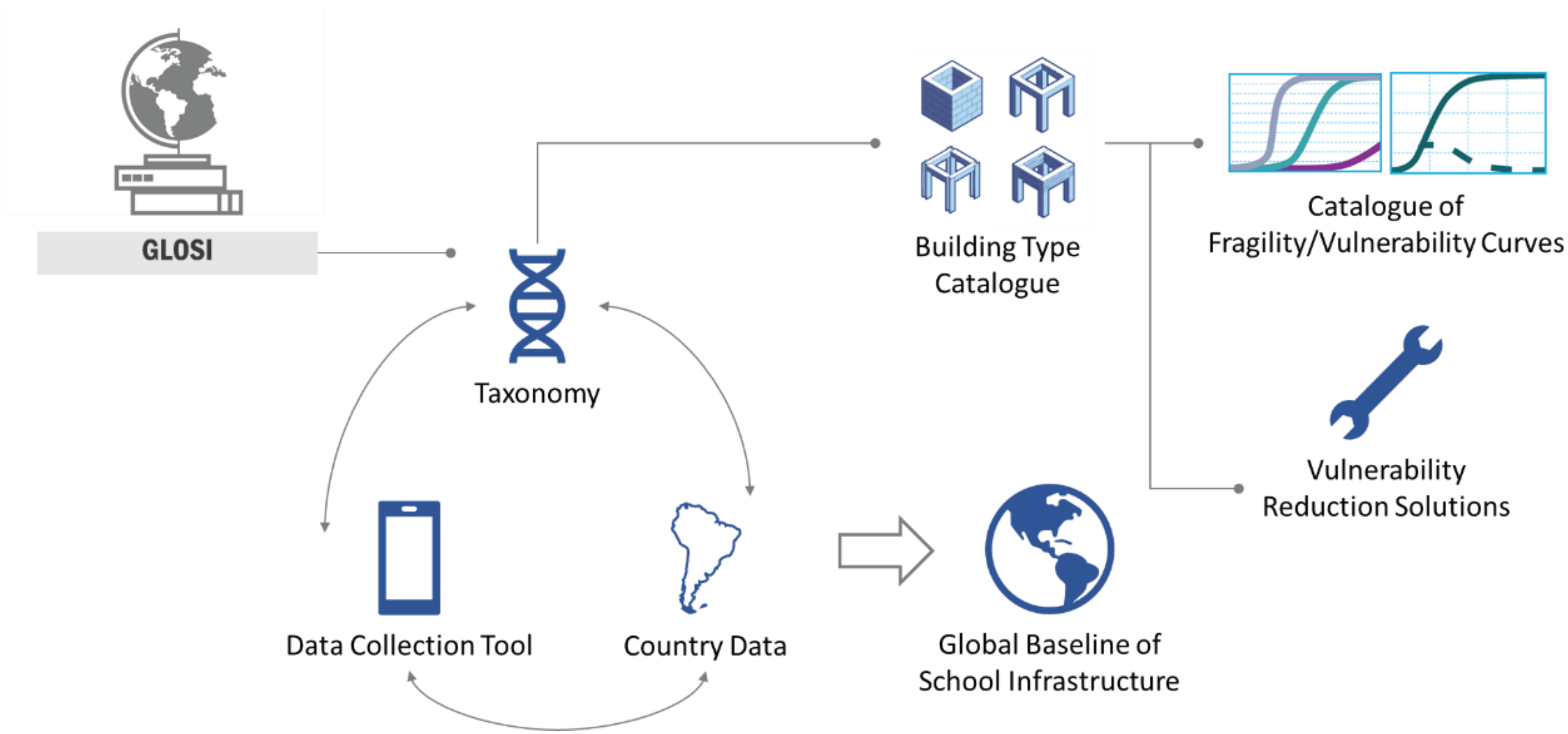

Figure 1. Global Library of School Infrastructure

1 Taxonomy – Classification of Seismic Safety

1.1 Building types classify seismic performance

The performance of a building construction during an earthquake depends not only on the intensity of the earthquake, but also on its construction characteristics, including the main structural system, lateral load resisting mechanisms, materials used, building height, and quality of construction. Different characteristics help categorize constructions into different types. There is enough statistical evidence from past destructive earthquakes to conclude that some types of construction are more vulnerable than others. For example, adobe buildings are likely to experience more damage than brick masonry buildings given the same seismic intensity. Since it is not possible to study the seismic vulnerability of individual buildings one by one, buildings which share similar construction characteristics (i.e. main structural system, building height and seismic design level) are classified into distinct categories called building types.

1.2 The taxonomy supports seismic vulnerability/risk assessments

A building type represents a large class of buildings bearing similar attributes of the main construction characteristics (i.e. main structural system, height range and seismic design level), yet showing a variation in the attributes of other construction characteristics such as diaphragm type, or structural irregularities. The full classification system based on all the attributes of the construction characteristics is termed as taxonomy. The construction characteristics can also be termed as taxonomy parameters. The identification and selection of the representative attributes of these characteristics result in one or more index buildings for a building type. An index building is a representative building of a building type which has fixed attributes for all the construction characteristics. Through detailed seismic analyses of the index buildings for a building type, the seismic performance of the building type can be collectively defined. The development of a structural taxonomy is of great importance, as it enables the identification of index buildings, seismic vulnerability/risk assessment, and school infrastructure risk reduction planning/implementation for safer communities.

Most school buildings worldwide are made of load bearing masonry (LBM) (unreinforced, partially reinforced, confined, reinforced, etc.) and reinforced concrete (RC) (moment resistant frames with or without masonry infills, combined systems, etc.) construction. Other construction types like steel framed, timber framed, or prefabricated structures are also locally present in some countries or regions but not at a global level. Some of these buildings are very old and show very poor seismic performance, while others have been recently designed and constructed using the most up-to-date building codes and practices, leading to a very good expected seismic behavior. Thus, the development of a taxonomy will make it easier to distinguish each school building in terms of its seismic performance and assist in the overall process of seismic risk assessment and intervention prioritization.

1.3 Objectives of taxonomy development

- A common language for seismic vulnerability and risk communication with respect to school infrastructure
- Identification of the distinct global construction types of school buildings
- Ranking of the vulnerability parameters from generic to specific, and also by relative importance based on the definition and characterization of the seismic response
- Identification and description of various taxonomy parameters (and their associated attributes) that affect the seismic performance of school buildings
- Characterization of different school building types
- Identification and definition of different index buildings representing different building types for the seismic vulnerability assessment of a population of school buildings
- Acceleration of the school infrastructure risk assessment process by using the results of some building types that have already been thoroughly studied in the past
- Development and adoption of the possible economical retrofitting options of school buildings per building type

2 How to Build the GLOSI Taxonomy?

Since there are many different school building construction types along with several variations in construction characteristics within a country and/or in different countries, the development of a global taxonomy for the building classification of these buildings is a complex process. For this reason, it should be comprehensive, yet comprised of simple steps. The overall steps to develop the GLOSI taxonomy are shown in Figure 1, and each of them is discussed in detail in the following sub-sections.

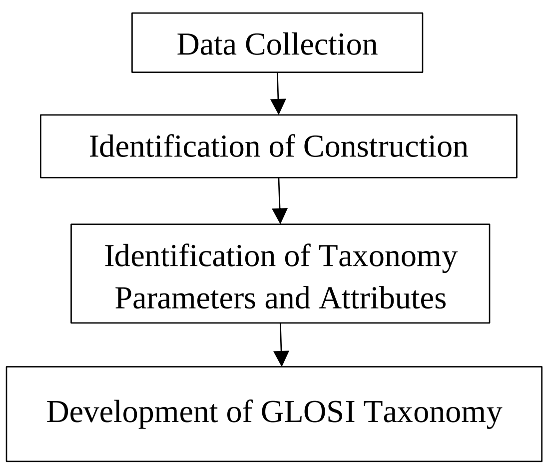

Figure 1 Steps to develop the GLOSI taxonomy.

The first step involves the data collection and analysis of school building construction characteristics at a national level in each country, and the comparison of construction types along with similarities and regional differences (if any). This allows the identification of the main global construction types of school buildings. Under GLOSI, the data collection tools are designed based on the taxonomy parameters, requiring different efforts depending on the level of information available and the level of detail required. The data collection tools under GLOSI are consistent and standardized for both the initial building type and the more detailed index building characterization, which ensures:

- A flexible format for the data collection template which can apply to a large number of building types;
- A relatively short process to limit time on site;
- To record observable quantities, which are not subject to judgement and interpretation (to avoid implicit biases by the surveyor).

The next step involves the identification and definition of the taxonomy parameters that affect the seismic performance of these school construction types. In each taxonomy parameter, the possible variations and ranges of attributes at a global level are also identified and summarized in the following section 2.1. The final step involves the development of the comprehensive taxonomy (section 2.2) with all the taxonomy parameters which appropriately indicate associated attributes, resulting in a specific taxonomy string for each school building. This taxonomy string will then define the building classification of the school construction.

2.1 GLOSI: Taxonomy Parameters

The taxonomy parameters (i.e. seismic vulnerability parameters) are the construction and functional characteristics of a building structure that affect the seismic performance of the structure. Based on literature and experiences, 12 taxonomy parameters which affect the seismic performance of school buildings have been identified in GLOSI. These parameters can be broadly categorized into the following three types:

a) Primary parameters
b) Secondary parameters
c) Intrinsic parameters

Primary parameters

The primary parameters are the main parameters that highly affect and govern the expected seismic behavior of a school building. The attributes associated with the primary parameters collectively define a building type. The three primary parameters, which will be discussed in greater detail in the following sub-sections 2.1.1 – 2.1.3, are listed below:

- *Main structural system*: It defines fundamental aspects of the expected seismic behavior, such as the flexibility, lateral strength, and ductility (i.e. the capacity of inelastic deformation) of the structural system.
- *Height range*: The height of the building controls the vibrational characteristics of the building structure.
- *Seismic design level*: It corresponds to the quality of construction materials, level of workmanship, structural detailing, and integrity of the structural elements in the construction of the building in terms of earthquake resistance. A poorly designed building will certainly perform less than a well-designed one given the same seismic event.

Secondary parameters

The secondary parameters are a group of characteristics that will play a key role in modifying the usual expected behavior of a building type, which is classified according to the three main parameters. These are: diaphragm type, structural irregularity, wall panel length/span length, wall openings/pier type, foundation type and flexibility, seismic pounding risk, structural health condition, and non-structural components. A more detailed discussion can be found in sub-sections 2.1.4 – 2.1.12.

Intrinsic parameters

The intrinsic parameters are the building-specific characteristics, like the geometrical dimensions, architectural layout, and mechanical properties of the construction materials/structural elements. Even though they are not explicitly included in the taxonomy string, these parameters are required for the complete definition of index buildings and the development of reliable analytical models. The seismic analysis of these index buildings allows the assessment of the seismic capacity with respect to different levels of earthquake intensity. The analysis and assessment will then support the derivation of representative fragility/vulnerability functions of different building types.

Twelve different taxonomy parameters (3 primary and 9 secondary parameters) are listed in Table along with a brief description of each parameter. They are further discussed in the sub-sections 2.1.1 to 2.1.12.

Table 1. GLOSI taxonomy parameters for building classification

No.	Parameter Category	Taxonomy Parameter	Description
1	Primary	Main Structural System	Deals with the main construction material and lateral load resisting system
2		Height Range	Deals with the dynamic response of the structure and its fundamental period of vibration
3		Seismic Design Level	Deals with the quality of construction materials, level of workmanship, structural detailing and the inclusion of seismic enhancement measures
4	Secondary	Diaphragm Type	Deals with the roof/floor diaphragm behavior (flexibility)
5		Structural Irregularity	Deals with the abrupt changes in strength or stiffness in plan and elevation
6		Wall Panel Length/Span Length[1]	Deals with the unrestrained wall panel length between two cross-walls/buttresses in LBM construction Deals with the horizontal clear span of the typical bay in RC framed structures
7		Wall Openings/Pier Type[1]	Deals with the size and number of openings (e.g. windows and doors) within a typical wall panel in LBM construction Deals with the vertical elements (e.g. columns) in the lateral load resisting system in RC construction
8		Foundation Type	Deals with the material and type of foundation structure as well as the soil type
9		Seismic Pounding Risk	Deals with the susceptibility to damage due to the different vibrational characteristics of adjacent buildings with insufficient spacing between
10		Effective Seismic Retrofitting	Deals with whether the structure has effectively been retrofitted in the past or not
11		Structural Health Condition	Deals with the condition of the building in terms of damage or deterioration
12		Non-Structural Components	Deals with the vulnerability/hazardousness (e.g. falling, overturn, etc.) of non-structural components (e.g. gables, overhangs, roof covering, partitions, bookshelves, etc.)

[1] These parameters have different definitions and attributes depending on the main construction type (i.e. LBM or RC).

2.1.1 Main Structural System

The main structural system is the first parameter in the classification system. The structural system determines the structural behavior (brittle or ductile) and the collapse mechanisms. In LBM constructions, the unit and binding agent of the masonry fabric (e.g. field stone in mud mortar, bricks in cement mortar, etc.) greatly affect the seismic performance and vulnerability. For example, a field stone in mud mortar masonry construction has a poor seismic performance compared to brick in cement mortar masonry construction. Mud mortar is generally weaker than cement sand mortar and provides low tensile, cohesion and frictional resistance. Both bricks and concrete blocks have a regular rectangular shape and size, so the two are collectively known as a rectangular block, differentiated from dressed stone which often has a larger and varying shape and size.

For RC framed structures, the collapse mechanisms are primarily affected by the presence or absence of stiff infill walls. Also, if the infills are not full story height, the configuration may cause a failure mechanism known as short column failure, or captive column. When the structural system is combined (reinforced concrete walls and frames), the behavior is likely to be different. In those cases, a ductile collapse mechanism is expected. The last case relates to RC constructions with no clear definition of structural systems, usually non-engineered and built by non-professional builders.

Other typologies derived from lateral load resisting systems such as precast reinforced concrete, timber and steel frames are included. Also, in very specific cases mixed systems can be present in which the lateral load resisting system changes in each direction (longitudinal and traverse).

There are two considerations of the application of the GLOSI taxonomy:

1. In the case of retrofitted buildings, they should be classified according to their current characteristics and the retrofit interventions should be specified in the Parameter 10.
2. Taxonomy classification also applies to buildings that are under construction.

The main structural systems for the GLOSI taxonomy are summarized and described in detail below.

Parameter 1: Main Structural System		
Type	**Attribute**	**Description**
LOAD BEARING MASONRY	**A** - Adobe	Earthen bricks/blocks or compressed stabilized soil bricks/blocks in mud mortar.
	UCM/URM - Unconfined/ Unreinforced Masonry	These are masonry school buildings with unconfined/unreinforced masonry walls in the main lateral load resisting system. They are sub-divided into different categories depending on the type of units and mortar material used in the masonry, considering that different combinations of different units and mortars result in different seismic performance of the building: • **UCM-URM1** - Dry stone masonry (without mortar) • **UCM-URM2** - Rubble (or field) stone in mud mortar • **UCM-URM3** - Dressed stone in mud mortar • **UCM-URM4** - Bricks/blocks in mud mortar • **UCM-URM5 -** Rubble (or field) stone in cement mortar • **UCM-URM6** - Dressed stone in cement mortar • **UCM-URM7** - Bricks/blocks in cement mortar
	CX – Complex masonry	Complex masonry buildings mainly consist of masonry walls (burnt clay bricks or concrete block in cement mortar) with vertical RC confining elements (inclusions) located at the wall intersections. These inclusions usually have smaller cross-sectional dimensions than masonry walls (wall thickness ranges from 380 to 510 mm). Due to rather large spacing of cross walls (more than 8.0 m in some instances) the effect of confinement provided by vertical elements is expected to be insignificant. Masonry walls in CX buildings are usually reinforced with horizontal bars embedded at mortar bed joints.
	CXCF - Complex masonry walls and concrete frames	CXCF buildings mainly consist of confined masonry walls (burnt clay bricks or concrete block in cement mortar) with interior RC columns and beams. These RC elements are placed in an irregular pattern and don't act like an RC moment frame. CXCF buildings usually have complex floor plans.
	CM - Confined masonry with bricks/blocks in cement mortar wall with horizontal and vertical RC elements	These are confined masonry school buildings in which the masonry walls are confined with RC columns and beams (known as tie-columns and tie-beams) of a relatively small cross-section to improve the integrity of the walls. The level (density) of confinement can vary within a country or at a regional level, which affects the seismic performance. For example, in confined masonry school buildings in El Salvador, the confinement is applied around the openings as well as walls; while in India, this school building construction type commonly lacks confinements around the openings.
	RM1 - Reinforced Masonry with Rectangular Block in Cement Mortar Wall	Buildings mainly consist of hollow concrete blocks in cement mortar with internal vertical and horizontal steel reinforcement. Vertical reinforcement in hollow concrete blocks is embedded into mortar grout, and horizontal reinforcement is embedded into mortar bed joints.

Parameter 1: Main Structural System		
Type	**Attribute**	**Description**
LOAD BEARING MASONRY (Continuation)	**RM2** - Reinforced masonry with bricks/blocks and horizontal RC bands	Buildings mainly consist of clay/concrete bricks/blocks in cement mortar with internal vertical and horizontal steel reinforcement. It also contains RC horizontal bands placed at plinth, sill, lintel, and floor/roof level.
	SFM – Light Steel Frame with LBM walls	This school building construction type has a light steel framed structure with load bearing masonry walls. This construction type is further sub-divided into different categories depending on the type of load bearing masonry walls, and considering that different load bearing wall types result in different seismic performance of the building. • **SFM1** - Light steel frame with stone in mud mortar walls • **SFM2** - Light steel frame with bricks/blocks in mud mortar walls • **SFM3** - Light steel frame with stone in cement mortar walls • **SFM4** - Light steel frame with bricks/blocks in cement mortar walls • **SFM5** - Light steel frame with confined masonry walls • **SFM6** - Light steel frame with reinforced masonry walls
	TFM - Lightweight gravity timber frame with URM walls	Lightweight gravity timber frame with URM walls
CAST-IN-PLACE REINFORCED CONCRETE	**RC1** - Bare Frame	Reinforced concrete moment resistant frames with/without infill walls that do not contribute to lateral stiffness. Masonry infill walls are well separated from the columns by expansion joints. Joints are usually filled with elastic sealer. Also, in some cases, partitions are made using light and/or flexible infills such as drywall.
	RC2 - Infilled Frame	Reinforced concrete moment resistant frame with infill walls as a stiffening element. In this kind of structure, the masonry walls usually go from the floor to the roof. The walls may have window openings. Infill walls are not separated from the RC structure. Since the masonry walls are not attached to the columns and usually have no internal reinforcement, walls may present an out-of-plane type failure.
	RC3 - Short Column Frame	Reinforced concrete moment resisting frames with masonry infill walls in contact with the structure. Masonry walls include uniform openings along the longitudinal direction of the building generating the possibility of a “short column” type of failure (“captive column”). This type of failure occurs when the lateral displacements are concentrated in the free portion of the column, generating greater shear forces and hence an anticipated column failure mechanism. Since the masonry walls are not attached to the columns and usually have no internal reinforcement, walls may present an out-of-plane failure mechanism.

Parameter 1: Main Structural System		
Type	**Attribute**	**Description**
CAST-IN-PLACE REINFORCED CONCRETE (Continuation)	**RC4** - Dual or Combined Frame	Reinforced concrete combined or dual system. These are structures which include two different main lateral load resisting systems. It is usually a reinforced concrete moment frame with steel braces or reinforced concrete walls to increase the stiffness of the system. The moment resistant frame can be designed to withstand only gravity loads or gravity loads and a percentage of lateral loads.
	RC5 - Non-Engineered Frame	Non-engineered reinforced concrete structure. It usually includes a certain distribution of columns that may not be continuous in all floors. Slabs usually consist of a solid slab or one-way joists without beams or girders. The structural elements may not conform to standard or continuous moment resistant frames. Partition walls and facades are usually built with unreinforced masonry in contact with the structural elements, providing some initial apparent stiffness but with a potential out-of-plane type failure.
PRECAST REINFORCED CONCRETE	**PC1 -** Precast large panel reinforced concrete wall system	Precast reinforced concrete systems conforming structural walls as the main loadbearing system. These buildings consist of precast wall panels connected to precast panel (hollow-core or ribbed) floors/roofs with/without attic.
	PC2 - Precast reinforced concrete frames with exterior precast reinforced concrete wall panels	Precast reinforced concrete systems conforming beams and columns connected by means of welded connections. The floor/roof structure usually consists of precast hollow-core or ribbed panels. There are exterior prefabricated wall panels welded to the columns.
TIMBER	**TF** - Timber frames	Structural system that corresponds to a composition of columns, beams and walls made of wood. Floors and roof structures is also made of wood elements. Usually a non-engineered construction.
	TW - Timber walls	Structural system that corresponds to a composition of structural walls made of wooden plank or log. Floors and roof structures is also made of wood elements. Usually a non-engineered construction.
STEEL FRAMES	**SF1** - Steel moment resisting frame with masonry infill walls	Moment resisting steel frame (standard elements) with RM, CM or precast as infills.
	SF2 - Steel moment resisting frame with lightweight infill panels	Moment resisting steel frame (standard elements) with lightweight timber or steel framed panels as infills.
	SF3 - Braced steel frame	Braced steel frame (standard elements) with RM, CM or precast panels as infills.

2.1.2 Height Range

Building height is one of the most important characteristics of a building as it controls the dynamic behavior during earthquake ground motions. It affects the natural period of vibration and mode shapes of vibration of a building during earthquakes. Under similar seismic intensity, high-rise buildings of similar design are subjected to more deformation (they are more flexible) and higher modes come into play during seismic excitation (they are susceptible to a wider range of seismic spectrum and therefore subjected to more earthquake energy, leading to larger acceleration/drift response), which makes them more vulnerable.

The LBM school buildings are mostly single-storied, while a few 2 – 5 story masonry school buildings are also present, especially in urban areas. Most RC school buildings are usually 2 stories, but some could be up to 6 stories or more.

The table below lists the categorization of the number of stories according to GLOSI.

Parameter 2: Height Range	
Attribute	**Description**
LR(1) - Low Rise	Single story.
MR() - Mid Rise	2 to 3 stories. Specify the number of stories inside the brackets.
HR() - High Rise	4 or more stories. Specify the number of stories inside the brackets.

2.1.3 Seismic Design Level

The seismic design level of a building structure highly affects its seismic performance. In the present classification systems, the seismic design level of a building structure represents the overall quality (workmanship) of construction, quality of materials used, level of connectivity within the individual elements, and integrity of the overall structure. This is often prescribed in seismic design codes as fundamental to attain a given level of seismic capacity.

For LBM buildings, even though there might not be explicit seismic code provisions, if the building standards and good construction recommendations or bylaws are followed, a building is considered as a well-designed structure. Specifically, a well-designed LBM building needs to meet the following conditions: good workmanship in the construction of individual walls; walls are properly connected to each other; and horizontal components (floors/roof) have sufficient in-plane stiffness as well as good connections to the walls.

Based on literature, here are some examples of good seismic design features for LBM buildings:

- Walls having good quality mortar, provision of strong type of bond pattern of brick/stone, minimum openings, proper connection between wall leaves (e.g. using thorough stone in stone masonry) and other similar features
- Connections between the walls using corner quoins or vertical reinforcements at the cross-wall corners, using seismic bands (ties) such as sill bands, lintel bands, floor bands, etc.
- Diaphragm connections of horizontal structures (floors, roof) with the walls having proper anchorage, ties, pegs, etc.

For RC buildings, the seismic design level is defined as follows:

- Poor design: structures with no seismic design (only gravity loads), expected with a low lateral capacity and a fragile collapse mechanism
- Low design: structure designed for a low seismic hazard level (e.g. PGA<0.1g) but no seismic detailing is provided, expected with a low lateral capacity and a fragile collapse mechanism
- Medium design: structures designed for a medium hazard zone (e.g. PGA<0.2g) with some reinforcement detailing, expected with a major lateral capacity and a ductile collapse mechanism
- High design: structures designed for a high seismic hazard zone (e.g. PGA>0.25g) with conservative reinforcement detailing, expected with a major lateral capacity and a ductile collapse mechanism.

Another important thing to note is the date of construction. Although it is often used as a proxy for the seismic design level, there are also other factors to be considered to identify the seismic design level. Indeed, the date of construction can be used as an indication of the seismic design codes enforced in the country at the time the building was built. A good understanding of the seismic building culture of the country and its evolution is essential.

As seismic code provisions have improved over time, it is generally assumed that more recent buildings will have better seismic design and will therefore perform better than older buildings. Take Nepal, as an example, where there are many older school buildings (especially LBM constructions) which were not designed for seismic resistance or were designed following earlier (now outdated) seismic design codes. However, in many cases local seismic enhancement measures (such as the use of through stones, timber tying elements, infill wall isolation, concrete wall addition, etc.) have been included in these older constructions. Such local seismic enhancement measures should be accounted for in the assessment of the seismic design level.

In countries like Nepal or Perú, it has been found that school buildings had been mostly constructed by local communities without adherence to published seismic codes or guidelines. If so, the date of construction may not be adequate to define the seismic design level. Thus, several other factors influencing the seismic design level should be assessed before assigning a design level class to a specific building, such as the designer and contractor (e.g. government, community, private contractor etc.), code enforcement capacity in the country, workmanship, and level of quality control during construction.

Parameter 3: Seismic Design Level	
Attribute	**Description**
PD - Poor Design	A poor seismic design level is considered when one or multiple of the following apply: • Non-engineered building or designed only for gravity loading. • Pre-code buildings. • Poor quality of construction materials and workmanship.
LD - Low Design	A low seismic design level is considered when one or multiple of the following apply: • Designed according to a force-based seismic code, which does not include capacity design approach and ductile seismic design provisions. • Low quality of construction materials and workmanship. • No seismic enhancement measures.
MD - Medium Design	A medium seismic design level is considered when one or multiple of the following apply: • Designed according to a force-based seismic code, which does not include capacity design approach and ductile seismic design provisions. • Medium quality of construction materials and workmanship. • Seismic enhancement measures.
HD - High Design	A medium seismic design level is considered when one or multiple of the following apply: • Designed according to the latest seismic code with design provisions reflecting state-of-the art seismic design practice of ductile detailing for good seismic performance, as evidenced by structural drawings. • High quality of construction materials and workmanship. • Seismic enhancement measures.

2.1.4 Diaphragm Type

A rigid diaphragm generates in the roof/floor system and provides an equal redistribution of the lateral forces among all structural elements in proportion of their stiffness. Hence the structures are best suited to resist the lateral forces and have a robust behavior. It plays an important role in controlling the global box-type seismic behavior, in which the in-plane displacements of the elements from the lateral load resisting system are equivalent. This effect is highly correlated to the in-plane stiffness of the roof/floor system, and its connection to the lateral load resisting system. Considering that in some cases the factors that influence in the development of a rigid diaphragm may vary, the table below describes the levels of diaphragm.

Parameter 4: Diaphragm Type	
Attribute	**Description**
ND – No diaphragm	A building without diaphragms, e.g. a single-storey building with a timber roof but without a horizontal bracing or a ring beam (bond beam).
FD - flexible diaphragm	Timber floor/roof supported by LBM walls, presence of ring beam.
SRD - Semi-rigid diaphragm	Prefabricated hollow core slabs without reinforced concrete topping
RD - Rigid diaphragm	A rigid diaphragm is developed when the roof/floor structure has: • Short spans between vertical load-resisting elements that contributes to in-plane stiffness • Continuity within the floor • Good connection to the lateral load resisting system e.g.: Reinforced concrete slab or composite steel and RC slab at least 75 mm thick; prefabricated RC hollow-core slabs with RC topping

2.1.5 Structural Irregularity

Horizontal and vertical structural irregularities tend to make structures more vulnerable than simple and regular structures. Horizontal (plan) irregularity refers to the building's irregular (e.g. rectangular long, T-, C- or H-shaped) footprint or unsymmetrical positioning of lateral load resisting elements. Vertical irregularity includes the variation in story height/mass/stiffness over building height. A common deficiency is the torsional effect introduced in seismic shear increments during earthquakes, which is because the building plan shape is irregular/longer in one direction or that openings are distributed unevenly.

Parameter 5: Structural Irregularity	
Attribute	**Description**
NI - No irregularities	
HI - Horizontal	If the plan shape is different from rectangular/square such as: • H-shaped • L-shaped • U-shaped • T-shaped • Asymmetrical • Other
VI - Vertical	If one of the followings is present: • Soft or weak Story • Discontinuity in vertical elements • Variation in story mass and/or stiffness • Setback irregularity
HV - Both Horizontal and Vertical	

2.1.6 LBM: Wall Panel Length; RC: Span Length

This taxonomy parameter is considered separately for LBM and RC as follows:

LBM

In LBM buildings, wall panels are susceptible to out-of-plane damage under seismic loading. Their vulnerability is directly proportional to the unrestrained length of a wall. This is mainly due to the low moment resistance (i.e. flexibility) of the wall along the out-of-plane direction under the two-way bending introduced by an earthquake. For example, in the 2008 Wenchuan earthquake, the main building of a primary school collapsed, while the adjacent dormitory of the same construction type survived as it had smaller rooms and therefore more cross-walls to provide more constraints along the length of the wall.

Masonry walls are generally restrained by cross-walls, piers or buttresses. Several studies and seismic design codes (see reference list) have thus suggested a limit on the permissible length as a function of thickness of the URM walls (usually less than 12 times the wall thickness). Similarly, for confined masonry, it is recommended to be less than 4 m. Thus, the unrestrained wall panels are categorized into two types: long panel and short panel. In stone masonry school buildings, the wall is generally thicker (more than 400 mm), usually resulting in short panels. On the other hand, in brick masonry construction where the wall thickness is generally low (250 mm to 400 mm), similar lengths of walls make them long panels.

However, attention needs to be paid to the connection of the masonry leaves (i.e. layers of masonry units) across the thickness of the wall for stone masonry walls. Indeed, if there are several leaves and they are not well connected with regularly spaced through stones, then the wall slenderness should be computed with reference to one leaf instead of the whole thickness of the wall. For LBM walls, the unrestrained wall panel length thus has two possible attributes: Short Panel or Long Panel, as presented in **Error! Reference source not found.**.

RC

The span length in RC structures is a very important indicator of general dimensions and vulnerability. It measures the distance between columns and classifies the flexibility of the frame by its beam length. It should be noted that short span beams tend to be stiffer and are more likely to attract higher levels of shear, leading to potential failure in shear (brittle) rather than bending (ductile). Conversely, beam with long spans tend to be very deformable and fail in bending. This parameter classifies span length as Short Span (SS) or Long Span (LS). Clear spans below 6 meters length are considered to be short span.

Parameter 6: Structural Irregularity		
Type	**Attribute**	**Description**
LOAD BEARING MASONRY	**SP** - Short Panel **LP** - Long Panel	If the wall length is less than 12 times the effective wall thickness, it is an SP, otherwise LP.
REINFORCED CONCRETE	**SS** - Short Span **LS** - Long Span	If the span length is less than or equal to 6 m, it is a SS, otherwise LS.

2.1.7 LBM: Wall Openings; RC: Pier Type

This taxonomy parameter is also considered separately for LBM and RC as follows:

LBM

The size, number and distribution of openings in masonry walls largely affect the seismic behavior of an URM building. This is due to the fact that the openings divide the wall into piers (vertical elements of the wall) and spandrels (horizontal elements of the wall), and determine the shape and size of piers and spandrels and their relative stiffness and capacity. The presence of openings in an LBM wall reduces the in-plane capacity and stiffness, causing damage concentration in the areas around openings. The out-of-plane vulnerability also increases due to the presence of openings, as the cracks initiating around the openings can easily trigger partial collapses.

Recent studies (see reference list) find that openings in a wall cause an easier development and propagation of diagonal shear cracks, which is more pronounced when the openings are of different size and irregular distribution.

An irregular distribution of openings often induces concentration of drift demands and damage in some particular regions of the wall, which causes an increased seismic vulnerability. This has been commonly observed in past earthquakes and experimental studies (see reference list), as in the case of the 2002 Molise earthquake, 2007 Cameli earthquake, and 2009 L'Aquila earthquake. To limit the seismic damage, openings need to be located at a specified minimum clear distance from the ends and top of the walls and should be reinforced if large/irregular openings are unavoidable.

Here, the openings are categorized into either small or large. The opening is small if the combined width of the openings on a wall between two consecutive cross-walls is less than 50% of the wall length and is large when that is equal to or more than 50% of the wall length. This decision is based on the analysis of the opening characteristics in the school buildings from some country case studies.

RC

In RC structures, the columns are equivalent to the masonry piers, and play a key role in the stiffness and capacity of the structure. Building codes usually limit column and beam minimum dimensions (ASCE 7-16 & ACI 318-14). Here, the minimum size of the column is recorded as an indicator of the building behavior and the capacity of the column in relation to the beams. Taking this into account, the Pier Type parameter allows to classify the structure in terms of its propensity to develop a weak floor collapse mechanism. Two classes are considered:

- Slender or weak columns (SW): their moment of inertia and cross-sections are smaller than that of the beam cross-section. This can generate a weak or soft story and trigger a failure mechanism controlled by the columns instead of the beam, leading to a soft story collapse.
- Regular columns (RO): the column dimensions should be at least equal to the depth of the beam. In this case the frame is likely to comply with the Strong column-weak beam requirement. In this case a failure mechanism controlled by the beams in the upper stories is more probable, which would present a more ductile type of failure.

Parameter 7: Wall openings/Pier type		
Type	**Attribute**	**Description**
LOAD BEARING MASONRY	**SO** - Small Openings **LO** - Large Openings	If the opening width in a wall between two consecutive cross-walls is less than 0.35 and 0.25 times the wall length in single- and multi-story buildings, respectively, it is considered a SO; otherwise a LO.
REINFORCED CONCRETE	**SW** - Slender-Weak Column **RO** - Regular Column	RO criteria meet when: • The column depth is at least the same as the beam • Three times the length divided by the depth of the column is less than 22 (ACI 318-14)

2.1.8 Foundation Type

The type of foundation influences the seismic performance of a building by controlling the settlements, cracking, deformations and overturning at the base of the main lateral load resisting systems. In fact, all the foundation structures have some flexibility. Depending on the foundation structure and the underlying soil properties, a foundation structure can be categorized as flexible or rigid compared to the flexibility of the superstructure. A rigid type foundation usually prevents large foundation deformations as well as anticipated failures. On the other hand, flexible foundations contribute to the horizontal deformations of the building, generating the possibility of anticipated failures both at the foundation level and in upper structural elements.

Masonry walls usually have continuous stone masonry, a brick masonry strip type foundation, or reinforced concrete strip footings below the ground level. These foundation structures are usually thicker than the masonry walls. If these foundations are at least 1 m deep and the site soil is medium or hard, the foundation can be categorized as a rigid foundation type.

In the case of RC buildings, the foundation is usually built in reinforced concrete. Their behavior depends greatly on the soil type and on the presence of foundation beams. The most common foundation is isolated footings, which may be very rigid in hard soils but flexible in soft soils. On the other hand, a deep mat foundation can be considered rigid in hard or soft soil. **Error! Reference source not found.** summarizes the various types of foundations for both LBM and RC structures and classifies them into either flexible or rigid.

Parameter 8: Foundation Type	
Attribute	**Description**
FF - Flexible Foundation **RF** - Rigid Foundation	The foundation type depends on two factors: 1. The foundation details: materials, structure and depth below the ground level • The material can be RC, Brick Masonry or Stone Masonry or Dry-Stone Masonry • The structure type can be Isolated Footing, Combined Footing, Strip Footing, Mat Foundation, etc. • Foundation depth can be Shallow, Medium or Deep 2. The soil type in the site, which can be soft, medium or hard The combination of these two factors determines the type of foundation. For example, a RC Mat foundation in a hard soil is considered as a rigid foundation.

2.1.9 Seismic Pounding Risk

Seismic pounding occurs when two adjacent building which have different vibration characteristics collide with each other during earthquakes. Although this is not a significant issue in the case of low-rise building structures, if the gap between the buildings is very small, it can cause damage to structural or non-structural elements of the building due to hammering, and eventually cause partial collapse. The minimum gap recommended by FEMA (see reference list) and other codes is at least 4% of the height of the shorter building.

Parameter 9: Seismic Pounding Risk	
Attribute	**Description**
PR - Pounding Risk **NP** - No Pounding	Seismic gap between buildings is at least 4% of the critical height. Critical height is the height of the shorter building where the expected collision occurs.

2.1.10 Effective Seismic Retrofitting

Effective seismic retrofitting is a process of strengthening a building structure, by which its seismic resistance is increased. Seismic strengthening can be mainly categorized into two types: the strengthening of the vertical load resisting system, and the strengthening of horizontal structures. The strengthening of vertical load resisting elements includes the different measures to increase the strength and ductility of the vertical members (e.g. walls or frames), or improving the connections among the vertical load resisting elements. The jacketing of LBM walls or RC columns and the installation of bracings are examples of these interventions. On the other hand, the strengthening of horizontal structures entails increasing the in-plane stiffness or floors/roof and improving the connections of these with the vertical load resisting system.

These retrofitting interventions can improve the seismic performance of poorly designed school buildings in future earthquakes. For example, several retrofitted LBM school buildings in Nepal survived without any damage during the 2015 earthquake. In the studied countries, the retrofitting interventions had been applied to very few school buildings.

As the retrofitting work is usually covered (with non-structural elements like plaster), it is often necessary to talk to the school administrators to know more about the seismic retrofitting history of the school building.

It is also important to note that for each school building, the main structural system and all other taxonomy parameters will be classified for the retrofitted structures. The knowledge of previous retrofitting works helps recognize that this particular building is not of the same quality as an equivalent new one.

Parameter 10: Effective Seismic Retrofitting	
Attribute	**Description**
OS - Original Structure **RS -** Retrofitted Structure	If a building has been retrofitted effectively so that the seismic behavior improved considerably with respect to its original situation, it is a retrofitted structure (RS). Minor non-structural improvements and/or maintenance do not make it a retrofitted structure.

2.1.11 Structural Health Condition

The structural health condition describes a building's current physical condition with respect to the material deterioration and existing damages in the structure. Masonry materials such as brick and mortar can deteriorate over time. Similarly, steel reinforcement bars in confined, reinforced masonry or reinforced concrete may get corroded or exposed over time due to the disintegration of the concrete cover. Existing damages (e.g. building out of plumb, delaminated walls, corner separation, cracks in the walls/columns etc.) contribute more to the seismic vulnerability of a building. Based on these analyses, buildings can be categorized in terms of the health condition as good or poor.

Examples of factors that determine the structural health condition of LBM buildings are:

- Deteriorated materials (units and mortar)
- Deteriorated connections among structural and non-structural elements (e.g. between walls and floors/roofs, between roof structure and roof covering tiles/sheets)
- Exposed reinforcement bars or corrosion in the reinforcement bars in reinforced or confined masonry
- Existing structural damages (cracks in the walls, corner separation, tilted building/walls etc.)

Examples of factors that determine the structural health condition of RC buildings are:

- Disintegration/deterioration of concrete
- Exposed rebars
- Corroded rebars
- Existing cracks

Parameter 11: Structural Health Condition	
Attribute	**Description**
PC - Poor Condition **GC -** Good Condition	Engineering judgement is required to evaluate the health condition of the building which may affect its structural behavior.

2.1.12 Non-Structural Components

In school buildings, several forms of non-structural components, such as gables, heavy roof covering (e.g. tiles), parapets, in-class furniture and others, may impose special vulnerability conditions during earthquakes. For example, if not secured properly, heavy masonry gables are one of the most vulnerable non-structural components, since they act like cantilever walls and are subjected to larger inertia force from higher levels of acceleration.

The vulnerability can be reduced using light gable materials (such as CGI sheet) or tying masonry gables using RC tie beams. Also, the proper tying of the roof tiles to the purlins greatly reduces the hazard that is inherent to the unsecured roof tiles during a seismic event. Unsecured furniture, blackboards, covers, divisions, equipment, pipes, installations or windows can topple down during earthquakes, which can be hazardous to the building occupants.

The presence, location, self-weight and connection details of non-structural elements may be assessed and rated as Vulnerable or Non-Vulnerable.

Parameter 11: Structural Health Condition	
Attribute	**Description**
VN - Vulnerable Non-Structural Components **NN -** Non-Vulnerable Non-Structural Components	This refers to components that can produce economic losses or human casualties like parapets, ceilings, tiles, and pipe infill. This parameter is rather qualitative, and the selection of associated attributes depends on the assessment of all the non-structural components with respect to the location, self-weight, connection to the main structural elements, etc.

2.2 Building the GLOSI Taxonomy String

The 12 GLOSI taxonomy parameters discussed above will make it easier to systematically and clearly classify school buildings into categories of different seismic characteristic. The classification using GLOSI provides a specific taxonomy string to each school building. The string consists of the 12 taxonomy parameters, starting with primary parameters and moving to secondary parameters, with an increasing influence on the seismic performance of the school building.

For example, an old low-rise adobe school building with no seismic enhancement features and a flexible diaphragm is identified with a string containing the corresponding attributes of the taxonomy parameters, ultimately resulting in a taxonomy string given as: A/LR(1)/PD/FD/……

The length of the string depends on the extent of information on the building characteristics. The strings become longer as more information is gathered. Additionally, when limited information is available, any element in the string can be omitted or truncated depending on the availability of the information, or priorities given to different taxonomy parameters. More detailed examples can be found under “Learn How to Apply the Taxonomy”.

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Appendix C

ERIK Field Survey Summary

This Appendix provides a copy of a presentation by GPSS on the ERIK Field Surveys.

Enhancing Resilience in Kyrgyzstan – ERIK

February 2020

WORLD BANK GROUP

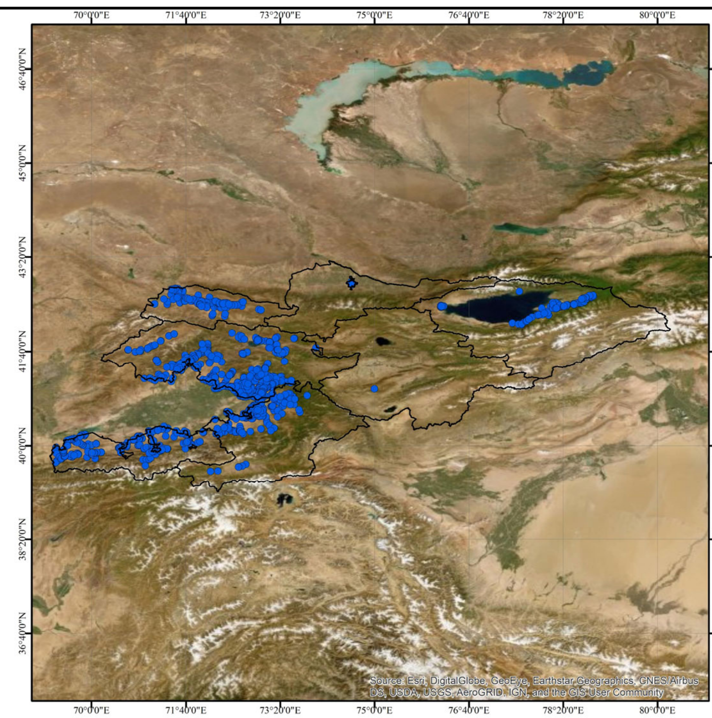
GFDRR

Global Facility for Disaster Reduction and Recovery

1

Field inspection campaign nationwide

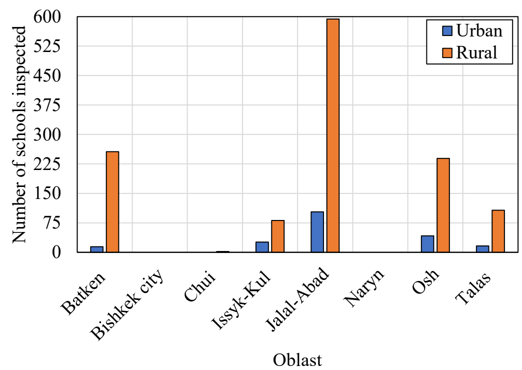
- 1,480 schools and 4,512 buildings (Feb 14,2020)
- Participation of four institutions:
  - Osh Technological University (OshTU)
  - Kyrgyz State University Of Construction, Transport and Architecture (KSUCTA)
  - International University of Innovation Technologies (IntUIT)
  - GISSIP



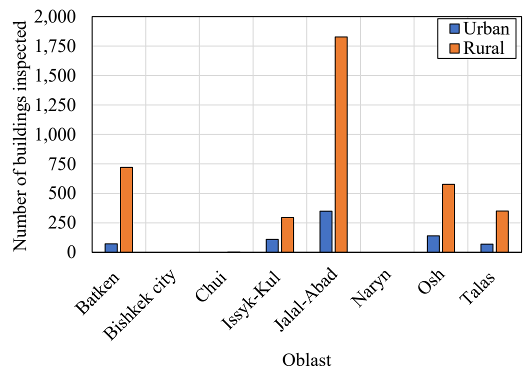
2

Distributions of data collected in oblasts

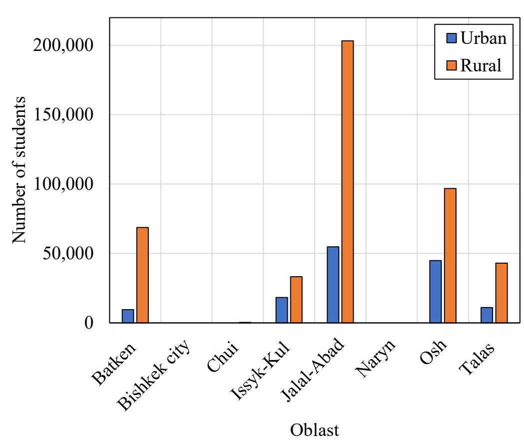
Schools inspected

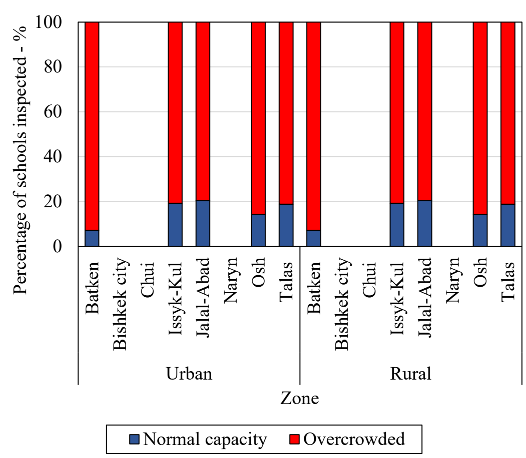


Buildings inspected



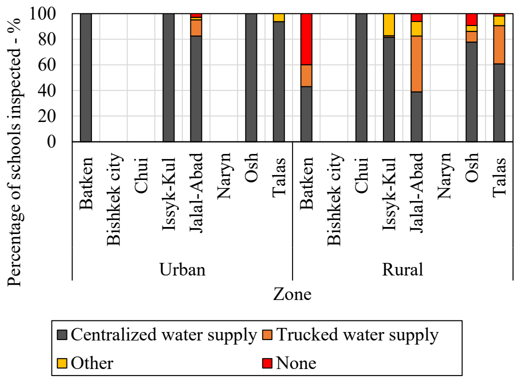
Distribution of students per oblast



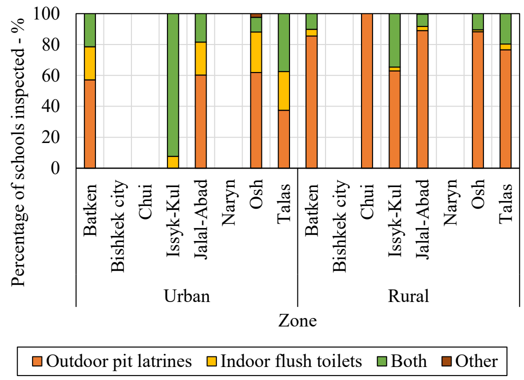


Distribution of functional characteristics per oblast

Water supply



Toilet type

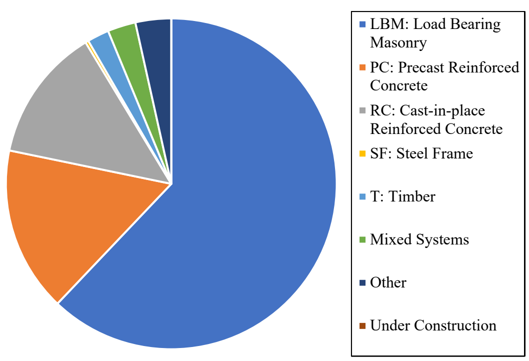


5

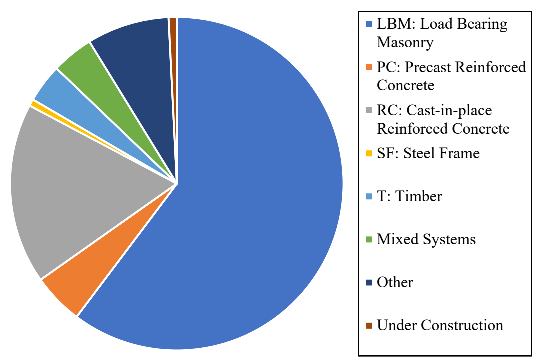
WORLD BANK GROUP GFDRR Global Facility for Disaster Reduction and Recovery

Category of structural typologies

Urban area



Rural area



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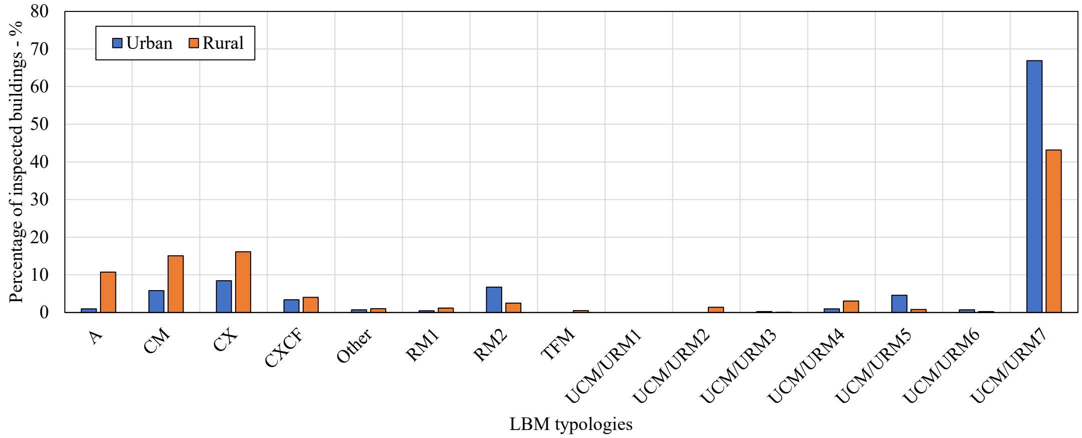
Category of LBM typologies



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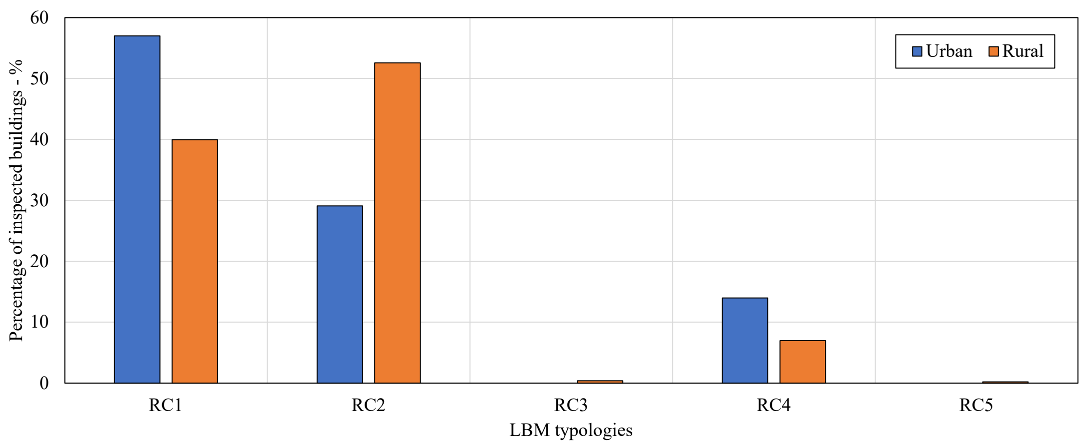
Category of RC typologies



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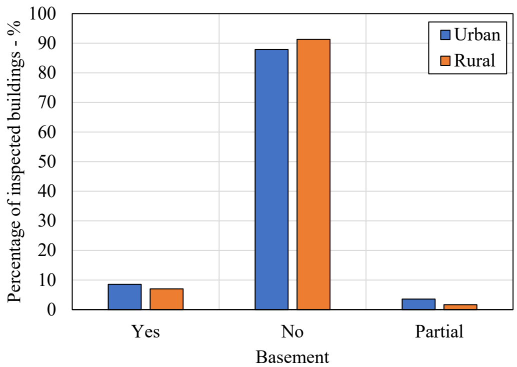
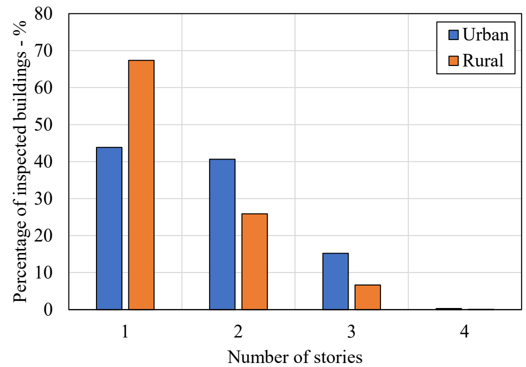
Basement



Number of stories



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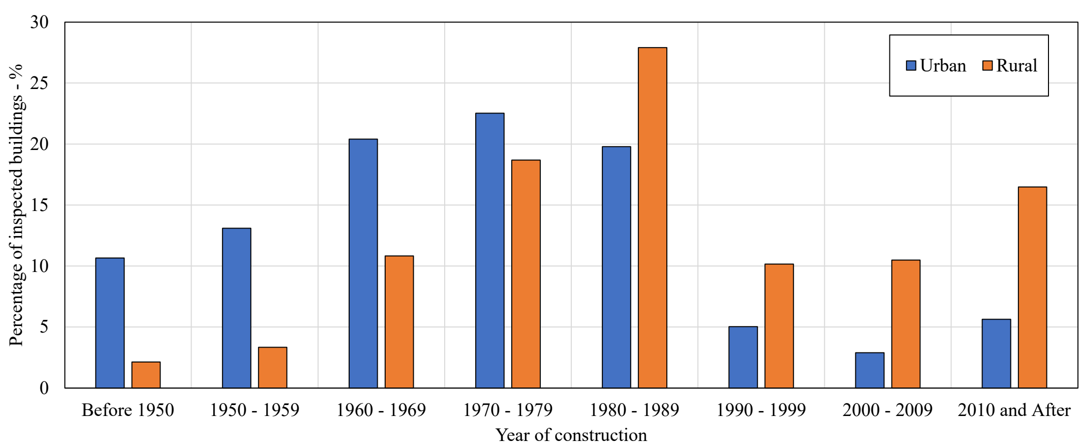
WORLD BANK GROUP GFDRR

Distribution of year of construction



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