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SEISMIC RETROFITTING OF SCHOOL BUILDINGS IN THE KYRGYZ REPUBLIC

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Abstract

The Kyrgyz Republic (KR) is located in one of the world’s most seismically prone regions, and it was subjected to several damaging earthquakes in the past, including the 1992 Sysamyr earthquake (magnitude 7.3). Most school buildings in the country feature unreinforced masonry construction and are highly vulnerable to earthquake effects. This paper discusses a pilot project focused on seismic retrofitting of six typical school buildings to improve both their seismic safety and energy efficiency, as a part of the World Bank’s Urban Development Project. This is the first major effort in the KR to retrofit school buildings as an earthquake risk mitigation activity; in the past, only earthquake-damaged school buildings had been retrofitted. Suitable seismic retrofitting techniques have been selected keeping in mind the capacity of local construction industry, financial sustainability, and availability of construction materials in local or easily accessible markets. School buildings which were selected for the pilot project are of unreinforced masonry construction, and the retrofit approach is to enhance lateral load-resisting capacity and ductility of existing masonry walls by jacketing using reinforced shotcrete overlays. The paper discusses design and construction challenges which the project team experienced during the project implementation, and which may be of interest to researchers and professionals engaged in seismic retrofitting of masonry buildings in countries/regions with limited experience in seismic retrofitting. Another aspect of the project, also featured in the paper, is capacity building for stakeholders in the seismic retrofit of school buildings in the KR through development of technical resources and training. The authors of this paper prepared Practical Seismic Design and Construction Manual for Retrofitting Schools in the Kyrgyz Republic for use by civil and structural engineering community in KR. The Manual (available in English and Russian) outlines seismic retrofitting techniques for masonry and reinforced concrete (RC) school buildings in KR and two illustrative design case studies, and it is also discussed in the paper.

Keywords: schools; seismic retrofitting; Central Asia; masonry buildings; precast concrete frame buildings

1. Introduction

Central Asia's earthquake activity has long been recognized as one of the highest in the world. A significant portion of the Kyrgyz Republic's (KR) territory is expected to be exposed to earthquakes of magnitude (M) of 7.5 (or higher) per Richter scale, corresponding to the shaking intensity 9 per MSK-64 scale. The KR's territory was subjected to several damaging earthquakes in the recent history, including the 1990 Baisoorun earthquake (M 6.3), the 1992 Suusamyr earthquake (M 7.3), and the 1992 Kochkor-Ata earthquake (M 6.1). In the period from June 1, 2009 to September 30, 2010, the country experienced 2,398 earthquakes with M 6 or higher. South-east part of the country was also affected by a M 6.1 earthquake in November 2014. Seismic hazard setting of the KR [1] and the Bishkek area [2] are well documented.

The official code for seismic design of new buildings and retrofit of existing buildings in the KR is SNiP KR 20-02:2018 [3] issued in 2018, which replaced previous version SNiP KR 20-02:2009 (issued in 2009). Prior to 2009, the code was developed in the former Soviet Union, starting with CH-8-57 (issued in 1957), and its subsequent versions dating back to 1962 and 1981 (SNiP II-7-81). The current code follows the force-based approach for seismic design of buildings and other structures. Design seismic forces are determined as a result of linear elastic analysis which takes into account seismic hazard parameters, type of structural system, etc. The elastic base shear force is reduced by applying a force modification factor (known as coefficient K_ψ), which accounts for expected ductility of structural system. Seismic safety of existing buildings in the KR is evaluated according to SNiP KR 22-01-2018 [4], which replaced previous version SNiP KR 22-01-98 and provides framework for seismic assessment of existing buildings.

Seismic vulnerability of school buildings in the KR is of a particular concern, because majority of school buildings in the country feature unreinforced masonry construction and are highly vulnerable to earthquake effects. As a part of an initiative to improve seismic safety of schools in the KR, the United Nations Children's Fund (UNICEF), and a few other organizations sponsored a comprehensive study in 2012 and 2013 [5]. A rapid seismic assessment of 806 kindergartens (preschools) and 2,222 schools was performed by the Kyrgyz Scientific Research and Design Institute for Seismic-Proof Construction (formerly KNIIPSS, currently State Institute on Earthquake Engineering and Design - GIISSiUIP). According to [6], all surveyed buildings were classified as Low, Medium or High Safety, depending on the seismic hazard and the type of construction. The results indicate that more than 80 % of all surveyed kindergartens and schools have "Low Seismic Safety" rating. On the whole, nearly nine out of ten preschools and schools fail to meet the standards for structural integrity and require immediate structural and nonstructural changes. The Ministry of Education responded by drafting a state program focused on introducing mitigation measures and improving the seismic safety of schools. The State Program "Safe Schools and Pre-School Institutions in KR" (2015-2024) has since been adopted by the Government of KR. The Program seeks to address the issue of reconstructing and retrofitting of school facilities to improve their seismic resilience and safety. Subsequently, a few World Bank (WB) projects were initiated in the country to improve the safety and functional conditions of schools in areas of highest seismic hazard in the KR.

The WB's Urban Development Project (UDP) for KR (2015-2020) [7] has supported the retrofitting of 6 schools on a pilot basis to improve both their seismic safety and energy efficiency, benefiting around 5,000 students. The schools are located in different parts of the country: Toktogul City in the Jalal-Abad Region (south-west part of the country), and Balykchy City in the Issyk-Kul Region (north-east part of the country). Another WB project, Enhancing Resilience in Kyrgyzstan (ERIK), started in 2018 as a lending operation to support the Government of the Kyrgyz Republic in strengthening capacity to respond to disasters, providing safer and quality learning environments for children, and managing the cost of disasters and climate shocks [8]. As a part of the ERIK project, field inspection and seismic assessment were performed for typical schools to establish a framework for future seismic mitigation initiatives for schools in the country [9].

Since the UDP's school pilot retrofitting project represented one of the first field applications of seismic retrofitting in the KR, capacity building was considered an important project activity. The authors of this paper served as consultants on the project and were responsible for developing *The Practical Seismic*

Design and Construction Manual for Retrofitting Schools in the Kyrgyz Republic (referred to as the Manual in the further text) [1]. The Manual is a comprehensive publication which was developed to provide technical guidance to local engineers in the KR with regards to the selection of practical and cost-effective techniques for mitigating seismic vulnerability of school buildings. The Manual was developed keeping in mind the following goals: i) to describe building typologies for reinforced concrete (RC) and masonry schools in the KR and identify their seismic deficiencies, ii) to describe seismic retrofit techniques and schemes for structural elements of masonry and RC school buildings in the KR, iii) to discuss construction procedures and implementation challenges, and iv) to present design case studies to illustrate seismic retrofit process for RC and masonry schools. The retrofit techniques were selected keeping in mind the capacity of local construction industry, financial sustainability, and availability of materials in local or easily accessible markets. Ample illustrations and two retrofit case studies have been provided to clarify the theory and field applications.

The Manual was originally developed in English, and subsequently translated into Russian and Kyrgyz languages. Two capacity building events were organized in September 2018 in Bishkek, KR to present and disseminate the Manual: a one-day stakeholder event with 25 participants, and a two-day training program with 42 participants. The participants in the stakeholder event were high-level government administrators and leaders of engineering companies, while the participants in the training program were practicing engineers from local engineering companies. Subsequently, the Manual was disseminated through a training program for engineers in other parts of the country which was conducted by UNICEF. Electronic version of the Manual is available free of charge. This paper draws from the technical content presented in the Manual and highlights the topics of interest to earthquake engineers.

2. Schools in the KR: Common Building Typologies and Seismic Vulnerability

2.1 Overview of the school building stock

A survey of more than 5,400 schools was performed as a part of systematic effort by the World Bank to develop classification of the building stock for school buildings in the KR [10, 11]. Based on the survey, masonry buildings account for 58% of the overall school building stock in the country, while RC buildings account for 21% of the overall school building stock. The remaining 21% are either timber buildings or adobe buildings. A classification of building typologies in Central Asian countries was previously developed as a part of the Earthquake Model for Central Asia (EMCA) project [12]. Code SNiP KR 22-01-98 also includes a classification of the building typologies and prescribes corresponding seismic evaluation approaches. The Manual classifies schools in the KR into 8 building typologies (types), as summarized in Table 1. Typical masonry school (Type 3) is shown in Figure 1.

a) b)

Fig. 1 – Typical masonry school building in the KR (Type 3): a) a conceptual isometric view, and b) exterior view of a typical school [1]

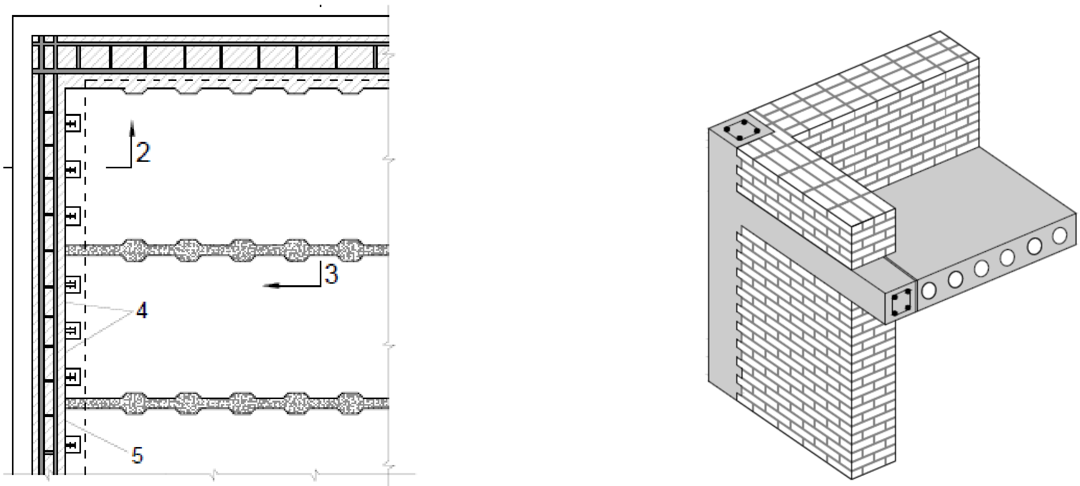
Table 1 – School building typologies in the KR

Material	**Type**	**Description**	**SNiP KR 22-01-98 Classification**	**Estimated fraction of the overall school building stock [10]**
Masonry	Type 1	Unreinforced masonry with wooden floors (no seismic design)	Subtype 1.4	58 %
	Type 2	Unreinforced masonry with precast concrete floors (no seismic design)	Subtype 1.5, Subtype 1.6	
	Type 3	Confined masonry – masonry walls with horizontal seismic belts and vertical confining elements and precast concrete floors	Subtype 1.1, Subtype 1.2	
Reinforced Concrete (RC)	Type 4	Monolithic RC moment frame with brick infill walls	Subtype 2.3	21%
	Type 5	Precast concrete frame with walls in one direction (Seria 111, IIS-04)	Subtype 2.5	
Timber	Type 6	Buildings with load-bearing braced timber frame	Subtype 9.7	21%
	Type 7	Buildings with wooden frame and mud infills	Subtype 9.6	
Other	Type 8	Non-engineered adobe buildings	Subtype 9.5	

2.2 Masonry building typologies

These are low-rise buildings, usually one- to three-storey high. Brick masonry walls were constructed using either solid or multi-perforated clay bricks. Cement-based mortar was used in most cases, with the exception of older schools in rural areas where mud mortar was used. Exterior walls are about 51 cm thick, while interior walls are about 38 cm thick. Unreinforced masonry buildings with timber floors (Type 1) were constructed mostly in the 1950s or earlier [13]. These buildings have wooden floor structures, which act as flexible diaphragms. Details of floor-to-wall connections show that wooden floor beams are supported by the walls without any anchorage. Lintels above the windows and doors are in the form of timber planks or steel bars embedded in mortar. Walls in Type 2 masonry buildings are similar to Type 1 buildings, but floor systems consist of precast hollow-core planks, with typical 220 mm thickness, 5.86 m length, and 1.2 m width. The planks are aligned parallel to one another and the gaps between them are filled by cast-in-place concrete (Fig. 2a). The floors are overlayed by 20 mm thick cast-in-place unreinforced concrete topping. Type 3 masonry buildings have horizontal and vertical RC confining elements (inclusions) - similar to confined masonry construction (Fig. 2b). These RC elements were first introduced in the former Soviet Union in 1957 (based on the code CH-8-57). Vertical RC confining elements are placed at wall intersections and at the openings. Horizontal RC bond beams (seismic belts) were constructed at the building perimeter at all floor levels to provide confinement and diaphragm action for seismic load effects. This typology is similar to housing construction typologies in the KR described in [14]. Roof structures in majority of masonry schools have pitched timber rafters and purlins with light-weight roofing consisting of asbestos sheeting. The foundations are continuous RC strip footings.

Seismic vulnerability of unreinforced masonry school buildings is caused by a lack of ductility, which is characteristic for unreinforced masonry construction and results in brittle seismic response. An additional factor contributing to seismic vulnerability is a significant building mass due to thick masonry walls – this contributes to development of high seismic intertial forces which are proportional to the mass of a structure. Timber floors and roofs in these buildings act as flexible diaphragms, which is unfavourable from the perspective of building integrity, and might cause out-of-plane damage or collape of the walls if the floor-to-wall connections are inadequate. Masonry buildings with RC confining elements are less vulnerable to seismic effects than unreinforced masonry buildings. Precast hollow-core RC slab floor system (common in masonry and also RC school buildings) also poses a risk due to inadequate concrete topping. The topic needs to be sufficiently thick (on the order of 75 mm) and reinforced with steel mesh to ensure the integrity and in-plane stiffness of floor diaphragms. Some of the masonry school buildings experienced damage in past earthquakes in the KR, e.g. the 1992 Suusamyr earthquake and the 2008 Karasuu earthquake [1].



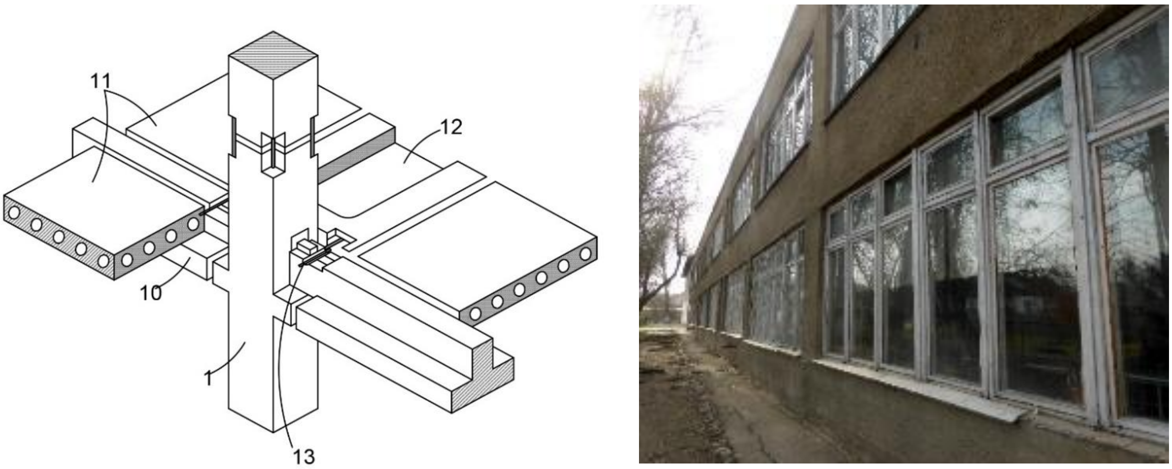
a)

b)

Fig. 2 – Features of masonry school buildings: a) precast RC floor slab showing hollow-core planks, and b) RC confining elements embedded in masonry walls [1]

2.3 Reinforced concrete building typologies

RC school buildings constitute more than 20% of the overall stock in Kyrgyz Republic. Before the 1990s (during the Soviet Union), precast concrete technology was commonly used for construction of residential and public buildings, including schools. Precast RC frame construction with exterior precast RC panels (Type 5 in Table 1) is known as Seria IIS-04 (Госстрое СССР, 1964), and it was one of the standard precast (prefabricated) construction systems in the former Soviet Union (refer to [15] for more details). This technology was used both for the construction of residential buildings (9- to 12-storey high), and also public buildings such as schools (1- to 4-storey high). All structural elements, including foundations, columns, beams, slabs, staircases, and wall panels, were manufactured in specialized plants. The building assemblage started at the foundation level with precast RC footings. Subsequently, RC columns were erected in vertical position and joined by welding above the floor level. Subsequently, beams are lifted in the final position (note that columns have corbels on two sides to receive RC beams). Beams are joined to the columns by welding, and finally cast-in-place concrete is placed to fill the voids. Beam-column connections are usually considered as rigid for seismic design purposes. Floor system consists of precast hollow-core planks. Connections between the floor planks and the RC beams, and the connections between the planks in longitudinal direction are achieved through welded plates (welding was performed at the construction site). Design engineers in the KR usually consider these floors as rigid diaphragms for seismic design purposes. The façade in these buildings consists of precast concrete panels which are connected to the columns by welding. Details of the panel-to-column connections are shown in Fig. 3a. A façade view of the school with exterior precast panels is shown in Fig. 3b.



a) b)

Fig. 3 – Typical precast RC school building in the KR (Type 5): a) precast RC beams, columns, and the connections, and b) exterior view of the building showing precast RC panels [1]

Precast RC frame buildings (Seria IIS-04) are vulnerable to seismic effects due to the welded beam and column joints. Welded connections are rigid and brittle and have a limited ability to dissipate earthquake energy. There is no evidence of ductile detailing of RC beams and columns, which can be expected since most buildings of this type were constructed in the 1960s and 1970s. Failure of exterior RC wall panels is also possible once the capacity of welded connections has been reached. Buildings of this typology experienced severe damage and collapse in a few earthquakes in the former Soviet Union, including the 1988 Spitak, Armenia earthquake (M 7.5, MSK intensity IX-X); 1984 Gazli, Russia earthquake (M 7.2, MSK intensity IX); and the 1994 Shikotansk, Russia earthquake (M 8.1, MSK intensity more than 10) [15, 16]. Precast hollow-core RC slabs may also pose a risk from earthquake-induced collapse in flexible RC frame structures, as observed in the 2010/2011 New Zealand (NZ) earthquakes [17]. It is believed that poor seismic performance of hollow-core slabs in the NZ earthquakes was due to elongation of beams in ductile RC frames. Precast RC frame structures in the KR are found to be flexible due to relatively large spans and absence of shear walls to control lateral drift, hence there is a concern of poor seismic performance of floor systems in these buildings.

Construction of cast-in-place RC school buildings started in the 1990s and is currently most common RC construction practice in the country (Type 4, Table 1). The main gravity and lateral load-resisting system is RC frame consisting of columns and beams. RC floor slabs are beam and slab systems where beams span between the columns and are cast monolithically with the slabs. Beam-to-column joints are rigid and enable transfer of bending moments between these elements. Exterior walls, and some interior walls, are of unreinforced masonry construction and are referred to as masonry infills. Cast-in-place RC frame buildings have been designed according to the modern KR seismic codes, and there is no evidence regarding the seismic performance of these buildings.

The review has shown that both masonry and RC school building typologies are vulnerable to earthquake effects. The UDP school retrofitting project was focused on masonry buildings as the prevalent school typology in the country. Experience related to the retrofit of RC schools in the KR is limited to repair of earthquake-induced damage and restoring of building to pre-earthquake condition. A discussion regarding the seismic retrofitting of RC school buildings has been omitted from this paper, but the Manual contains a case study of a typical RC school building (Seria IIS-04), and illustrates seismic evaluation and design of an appropriate retrofit scheme [1].

3. Seismic Retrofitting of Masonry School Buildings: Case Study

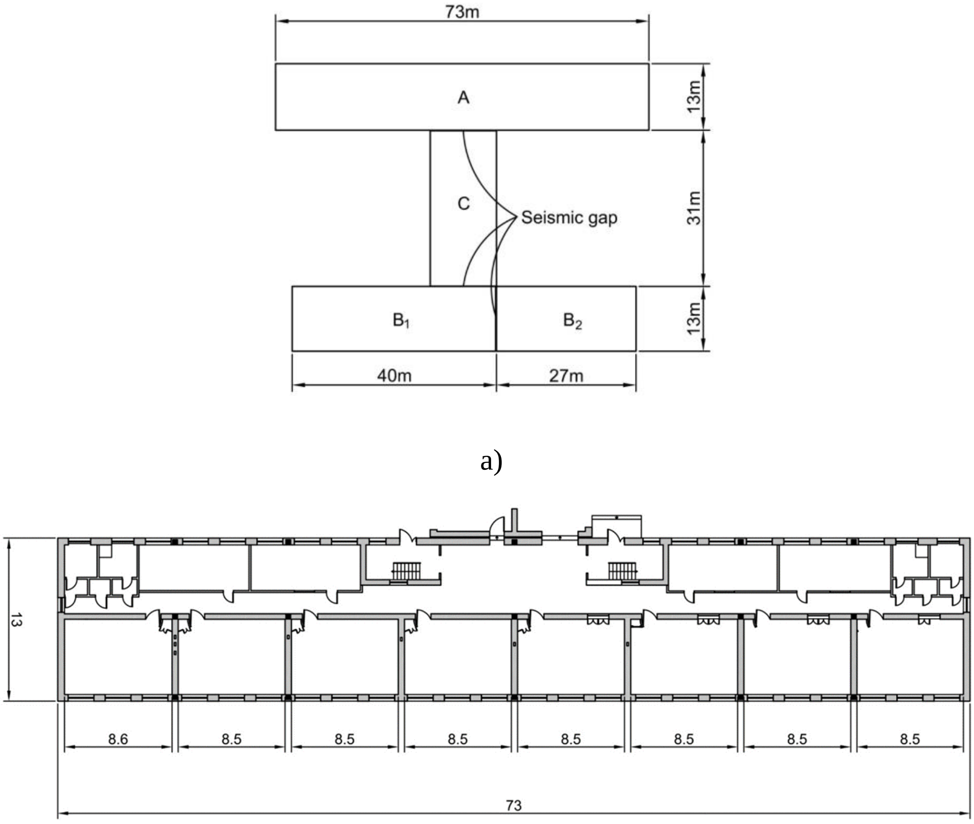
3.1 Building description

The school building presented in the case study has H-shaped plan, and it consists of 4 rectangular-shaped building blocks (2- or 3-storey buildings) separated by seismic gaps. The largest block, A, is 73 m long and 13 m wide and is 3-storey high. This is a Type 3 masonry building typology and the main lateral load-resisting system comprises of loadbearing masonry walls made of solid clay bricks bonded by cement-based mortar. Exterior walls are 51 cm thick and interior walls are 38 cm thick. According to the original drawings there are two types of RC inclusions within the masonry walls (Level 1 and Level 2). Level 1 inclusions are RC column-like elements inside the masonry walls, which are connected with RC beams at the floor level in order to achieve RC frames in transverse direction of the building. Level 2 inclusions consist of secondary RC vertical ties placed around the openings and wall intersections. Seismic bands and lintel beams are provided at each floor level. Four 6 mm diameter horizontal bars embedded in mortar joints are placed at 300 mm vertical spacing in 51 cm thick masonry walls, and two 6 mm bars at 300 mm spacing are placed in 38 cm thick walls. Floor system consists of precast hollow-core slabs, as explained earlier in the paper. The roof system consists of pitched roof with corrugated galvanized iron roofing and timber rafters supported by exterior walls, and vertical timber posts supported by precast floor slabs. Seismic evaluation and retrofit approach for this building were described in detail [1]. Block A shown in FIGURE X will be discussed in this section.

3.2 Seismic assessment

The school was retrofitted as a part of the pilot project, based on the design prepared by the consultants [18]. First, seismic assessment was performed using a linear elastic seismic analysis procedure (Spectral Method) according to СНиП КР 20-02:2009. A Finite Element Model was developed where the walls were modelled as 2-D plate elements and the floors were modelled as rigid diaphragms. As expected, modal analysis showed that the building is rather rigid, since the fundamental periods of 0.16 and 0.2 sec were determined for the longitudinal and transverse directions, respectively.

Seismic analysis has shown a rather large seismic demand: the design (V/Q) ratio was 0.36, where V is design base shear and Q is seismic weight. Seismic evaluation showed that the building did not meet the requirements of the seismic code effective at the time of project implementation (СНиП КР 20-02:2009). The analysis showed that several walls, mostly the ones located at the ground floor level, were deficient with regard to both in-plane shear and flexural capacity. Vulnerability Index, *I*, is a ratio of the stresses induced by seismic loading and allowable stresses for masonry according to the local codes, and in some cases the analysis showed the *I* values as low as 0.25. The analysis results pointed out to a more significant deficiency in the longitudinal direction; this is due to large openings in the exterior walls and a limited amount of interior longitudinal walls. Seismic resistance in the transverse direction appeared to be deficient due to small number of transverse walls, which were placed at large spacing due to the architectural requirements, e.g. classroom dimensions. The analysis showed that the out-of-plane seismic safety of the walls was adequate.



a)

b)

Fig. 4 – Masonry school case study: a) school plan showing building blocks separated by seismic gaps, and b) architectural plan for block A [1]

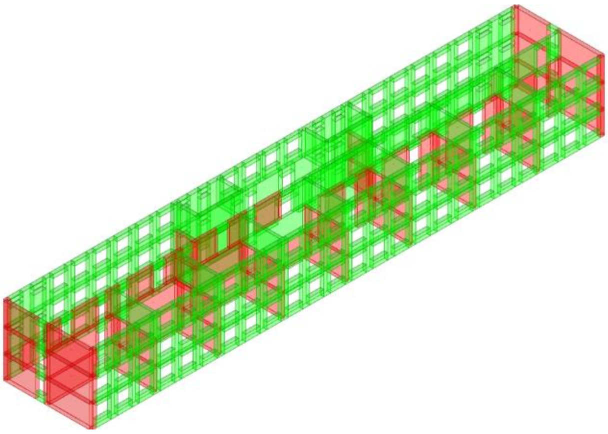
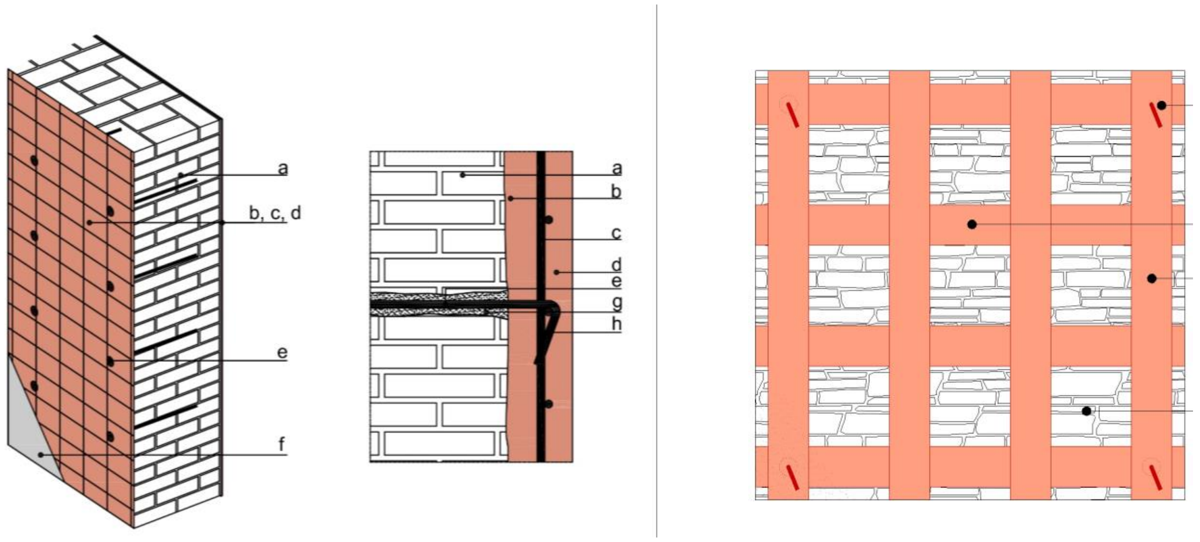


Fig. 5 – A numerical model of the building showing critical vulnerable walls (in red color) which were identified as a result of the seismic assessment [1, 18]

3.3 Seismic retrofitting project

Seismic retrofitting project comprised of retrofitting the existing masonry walls and the foundations. It was not required to retrofit the roof structure, but some deteriorated elements were replaced. Two alternative wall retrofit techniques were considered in the project: i) RC jacketing and ii) Carbon Fiber Reinforced Polymer (CFRP) strips applied in horizontal and vertical directions (Fig. 6). Since the CFRP retrofit technology has not been implemented in KR yet on a retrofit project, it was expected to be more challenging and expensive to implement than RC jacketing. The RC jacketing technique was considered as a more feasible solution due to the availability of construction materials and lower construction costs than the CFRP retrofit. Another advantage of RC jacketing is that the required level of construction skills is not very high, but on the negative side the level of disturbance to the occupants during the construction is significantly higher than for the CFRP retrofit.

The adopted seismic retrofit scheme for the walls comprises of double-sided RC jackets (Fig. 6a). Initially, the wall surface was prepared by removing existing plaster. RC jackets were 80 mm thick and were constructed using shotcrete technology, that is, by spraying fresh concrete through a hose in two 40 mm thick layers (Fig. 7b). Steel reinforcing mesh was installed in the middle of the jacket, and attached to the existing wall by means of through-wall steel anchors (Fig. 7a). The anchors were installed in predrilled holes and bonded to the existing masonry walls by means of cement-based grout. The size and spacing of anchors was determined by design: 12 mm diameter steel bars were used and 4 anchors were installed per square metre of the wall surface. RC jacketing was provided continuously from the foundation to the roof level. For cost optimization purposes, the extent of reinforcement for RC jacketing varied along the building height. Steel reinforcement was in the form of mesh (8 to 12 mm bar diameter) at 200 mm spacing. Largest bar size was used for wall reinforcement at the ground floor level where seismic demand is largest, and the amount decreased at upper floors. Fig. 8 shows ground floor plan with walls which need to be retrofitted (highlighted in colour).



a) existing masonry; b) first layer of concrete; c) steel wire mesh;
d) second layer of concrete; e) steel anchors; g) hole in the masonry wall filled with epoxy resin or cementitious grout;
h) steel anchor with a 90-degree hook.

a) b)

Fig. 6 – Seismic retrofitting techniques for masonry walls: a) RC jacketing and b) CFRP strips [1, 18]

The existing foundations were retrofitted by constructing new RC elements on each side of the existing foundation. Horizontal steel dowels were provided to connect the new and the existing foundations. Wall reinforcement was extended down to the foundation and anchored into the new RC elements.

a) b)

Fig. 7 – Features of RC jacketing technique: a) wall reinforcement and anchors, and b) shotcrete application (photos: S. Brzev and U. Begaliev) [1]

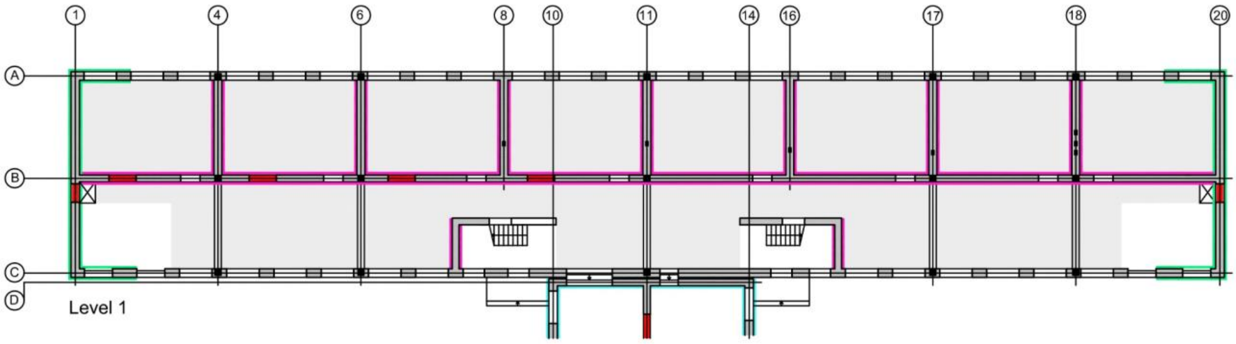


Fig. 8 – Ground floor plan showing the walls earmarked for RC jacketing [1, 18]

4. Seismic Retrofitting Field Application: Challenges

Challenges associated with the seismic retrofitting of school buildings in the KR were due to several factors, some of which were pointed out by local earthquake engineering experts [2]. The main challenges encountered during the pilot school retrofitting project are discussed next.

Lack of local experience related to construction materials and technologies which are specific for seismic retrofitting posed a major challenge. Local design engineers, contractors, and construction crews, did not have previous exposure to seismic retrofitting projects. There is a significant ongoing construction activity in the country, however seismic retrofitting technologies require additional skills which are not required for the construction of new buildings. Some technologies, like steel anchors and shotcrete, were used for the first time for a building application in the KR. In the past, shotcrete technology was primarily used for the tunnel construction in the KR. There was no experience associated with using steel anchors for seismic retrofitting of buildings. Due to the high cost of proprietary chemical anchor systems which are currently available in the KR, it was required to custom-design anchor installation procedure, material specifications (e.g. grout mix), and anchor testing process. In many other countries anchor installation is a common construction activity, and numerous chemical anchor technologies are commercially available.

One of the challenges and the reasons for limited application of seismic retrofitting in the KR is related to the absence of a local code for seismic retrofitting of buildings, although code related to seismic evaluation is available – SNiP KR 22-01-2018 [4]. Engineers have access to a few local technical resources on the subject which were developed in the KR, e.g. [19], which dates back to 1996 and outlines seismic retrofitting techniques for buildings, and there are a few other relevant technical resources dating back to the Soviet Union.

5. Conclusions and Recommendations

The paper describes a pilot project focused on seismic retrofitting of 6 school buildings in the KR. The project was successfully implemented. Future retrofit field applications in the KR will benefit from the experience gained from this project. Education and training of stakeholders in the construction process is of critical importance for the successful implementation of any seismic retrofit project. Current education curriculum related to civil engineers and construction managers, as well as construction trades, is focused on the design and construction of new buildings and other structures, and there is a very limited coverage of topics related to the existing buildings and infrastructure. For that reason, capacity building activities, including development of training materials and dissemination of these materials through training activities, need to be developed for different stakeholders in the retrofit process, ranging from construction crews to design engineers.

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