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SEISMIC PERFORMANCE OF SCHOOL BUILDINGS IN RECENT EARTHQUAKES: LESSONS FOR SERBIA

Summary:

Seismic safety of schools should be one of the highest priorities for each community. Besides being important to design the school buildings such as to avoid damage or collapse in earthquakes, they should also remain safe and functional as a shelter for evacuation after an earthquake. The aim of this paper is to raise awareness of the importance to study and assess the seismic risk of existing schools, as well as to emphasize a need for adequate seismic design of new school buildings. Examples of damage in school buildings due to recent earthquakes in the region were presented since they are relevant for Serbia. Observations from the survey of school buildings in Serbia have been used for a comparison with the representative examples of damaged school buildings in Croatia and Albania, thus deriving the conclusions of what could be expected in Serbia in a case of moderate earthquake.

Key words: educational facilities, earthquakes, seismic performance, damage, seismic risk

PONAŠANJE ŠKOLSKIH OBJEKATA U SKORAŠNJIM ZEMLJOTRESIMA: LEKCIJE ZA SRBIJU

Rezime:

Bezbednost škola pri dejstvu zemljotresa treba da bude jedan od najviših prioriteta svakog društva. Osim što je važno da se školski objekti projektuju i izvedu tako da se ne oštete i ne sruše, treba omogućiti da budu funkcionalni i bezbedni kako bi služili kao mesto za evakuaciju nakon zemljotresa. Stoga je cilj ovog rada da se podigne svest o važnosti izučavanja i procene seizmičkog rizika postojećih škola, kao i da se naglasi potreba za adekvatnom pažnjom pri projektovanju novih školskih zgrada. Primeri oštećenja školskih zgrada u nedavnim zemljotresima u regionu su predstavljeni, jer su relevantni za Srbiju. Zapažanja iz pregleda školskih zgrada u Srbiji korišćena su za poređenje sa reprezentativnim slučajevima oštećenih školskih objekata u Hrvatskoj i Albaniji, na osnovu čega su izvedeni zaključci šta se može očekivati u Srbiji u slučaju zemljotresa umerene jačine.

Ključne reči:školske ustanove, zemljotresi, ponašanje pri zemljotresu, oštećenja, seizmički rizik

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1. INTRODUCTION

Seismic safety of educational facilities, especially schools and kindergartens, is of utmost importance because children are among the most vulnerable sections of each community. Several international initiatives related to school safety have been launched, such as the “Comprehensive school safety” framework, with an objective to protect school children and teachers from injuries and fatalities in schools, and to ensure educational continuity. The framework was adopted by the United Nations agencies and international non-governmental organizations [1]. It rests on three pillars: 1) Safe Learning Facilities, 2) School Disaster Management, and 3) Risk Reduction and Resilience Education. In 2014 the World Bank has launched the Global Program for Safer Schools [2], which aims to improve the safety and resilience of school infrastructure at risk from natural hazards and enhance the quality of learning environments for children.

A motivation for these initiatives is significant vulnerability of school buildings in past earthquakes. In Nepal, the April 25, 2015 Gorkha earthquake (M 7.6) and the May 12, 2015 Central Nepal earthquake (M6.8) caused collapse of more than 27,000 classrooms and damage of additional 26,000 classrooms [3]. The September 2017 Mexico earthquakes (M8.2 Tehuantepec and M7.1 Puebla) caused widespread damage to the schools in the affected areas. It was estimated that more than 19,000 schools, accounting to approximately 27.6% of the total school inventory in the affected areas, experienced damage or collapse in these earthquakes [4]. A comprehensive initiative focused on seismic assessment and retrofitting of school buildings was launched in Mexico after these earthquakes [5].

In many cases, school buildings are older buildings and were not designed according to the latest seismic design codes and are prone to damage even in moderate earthquakes. Recent earthquakes in the Balkan region, including the November 26, 2019 Albania earthquake and the December 29, 2020 Petrinja, Croatia earthquake caused significant damage of educational buildings. Serbian Association for Earthquake Engineering (SUZI-SAEE) organized visits of the teams of experts to the affected areas after these earthquakes. This paper presents findings of reconnaissance studies from Albania and Croatia which are focused on the performance of school buildings, as well as results of a survey of school buildings in Serbia and proposed classification of school building typologies.

2. THE NOVEMBER 26, 2019 ALBANIA EARTHQUAKE

An M_W 6.4 earthquake occurred on Tuesday, November 26, 2019, with the epicentre at 16 km north of Durrës, and 33 km northwest of Tirana, the largest city and capital of Albania. It caused 51 fatalities, while 913 people were injured. More than 95,000 housing units in 11 affected municipalities were damaged (corresponding to 18% of all housing units in those municipalities), and the total economic loss was estimated at 985.1 million EUR [6]. Fortunately, the earthquake occurred in the early morning hours (at 3:54 local time), hence educational buildings were not occupied.

Based on a briefing by the Minister of Education of Albania, two months after the earthquake 56 primary and secondary school buildings were severely damaged and were assigned damage state (DS) 4 and 5 on the scale of 1 to 5, where DS5 denotes collapse), thus rendering them unsafe for use [1]. According to the same source, 66 school buildings experienced moderate damage and were assigned DS2 and DS3, whereas additional 151 buildings experienced light damage (DS1). Several reports documented the performance of buildings after this earthquake [6]-[12]. The following text presents observations related to damage of selected school buildings due to this earthquake.

A two-storey unreinforced masonry (URM) school in the Thumanë village (Figure 1) was severely damaged (note that in the same village two low-rise URM apartment buildings collapsed). The school was built in the 1970s and it was recently refurbished. Building damage at the exterior was not visible, however a heavy damage was observed in the interior, with diagonal cracks and failure of loadbearing URM walls and masonry piers in walls with opening. The building was determined to be unsafe and had to be demolished. Several other URM school buildings experienced damage at the slab-wall connections, indicating risk of potential out-of-plane wall collapse. Other damage patterns, such as light cracking of masonry walls and plaster, damage of parapets and other non-structural elements, were also widespread in schools in Albania.

a) b)

Figure 1 – Damage of a school building in Thumanë, Albania: a) failure of the loadbearing URM wall and b) damaged masonry piers [6]

a) b)

Figure 2 – Damage of a school building in Maminas, Albania: a) failure of the RC column and b) damaged masonry infill walls [6]

Damage of reinforced concrete (RC) school buildings was similar as damage observed in residential buildings of the same typology. These buildings experienced mostly non-structural damage to masonry infills and partition walls. For example, excessive lateral deformations occurred at the ground floor level in the school building in Maminas, causing extensive damage of exterior RC columns (Figure 2a). These columns were subjected to a high displacement demand, but the detailing was inadequate: the ties had 90 degree hooks and failed to provide required confinement. Furthermore, infill-frame interaction contributed to higher seismic demand in the columns as well as infill walls and caused failure and heavy non-structural damage in these elements (Figure 2b). Another school, Neim Babameto in Durrës, had a RC moment frame system consisting of columns and beams with a “strong beam-weak column” configuration, which was one of the causes of severe structural damage as well as infill failures.

3. THE DECEMBER 29, 2020 PETRINJA EARTHQUAKE

On December 29, 2020 a magnitude M_w 6.4 earthquake occurred in the Sisak-Moslavina county of Croatia, with the epicentre located 3 km west-southwest of the city Petrinja. The earthquake caused 7 deaths while other 26 people were injured [13]. The physical damage was estimated at approximately 4.8 billion EUR [14]. The earthquake occurred in the early afternoon, but the schools were not in session due to the COVID-19 restrictions.

Out of 53 schools in the Sisak-Moslavina County, 5 required complete reconstruction, 9 schools were significantly damaged, while 13 schools experienced non-structural damage and needed minor repairs. As a result, more than 5,000 students had to be relocated to other schools. Performance of buildings in this earthquake is presented elsewhere [13], [15]-[17], whereas this section presents observations related to the damage of selected school buildings.


a)


b)

Figure 3 – Damage of URM schools in Petrinja, Croatia: a) exterior damage of the First school building and b) inclined shear cracks in the walls of the Petrinja High School

Structural system of the First Primary School in Petrinja, which was built at the beginning of 20th century, consisted of URM walls and jack arch floor slabs (known as *Pruski svod* in Serbian). The building had a timber roof with clay tile roofing, which partially collapsed (Figure 3a). The building also experienced significant non-structural damage, especially in the interior partition walls between the classrooms which were severely damaged due to inadequate slab-wall connection. Another school in Petrinja, Petrinja High School, was a massive URM building constructed in 1860, and experienced extensive damage in the form of inclined shear cracks in the loadbearing walls (Figure 3b). It could be observed that cracking in exterior walls above the windows was less pronounced, but the reported interior damage was so severe that the building was classified as unsafe for entry.

Majority of RC school buildings in Petrinja experienced minor structural damage, however non-structural damage was severe. Elementary school Dragutin Tadijanović, built in 1974, is a masonry-infilled RC moment frame structure with an irregular plan shape. The building did not experience structural damage, but several infill walls experienced long cracks along the infill-frame interface (Figure 4a). Another educational building, Faculty of Education, was built in 1962 as an RC frame building with masonry infills. The infill walls were severely damaged due to in-plane seismic effects, with diagonal cracks in the walls (Figure 4b) and along the infill-frame connection. Out-of-plane displacements were observed in several infill walls. Furthermore, a ceiling collapsed in one of the classrooms.

a)

b)

Figure 4 – Damage of RC schools in Petrinja, Croatia: a) cracks at the infill-frame interface, school Dragutin Tadijanović and b) damage of infill walls and plaster spalling, the Faculty of Education

a)

b)

Figure 5 – Damage in the former elementary school in Donja Bačuga: a) shear failure of an interior column and b) a "short column" failure of an exterior column

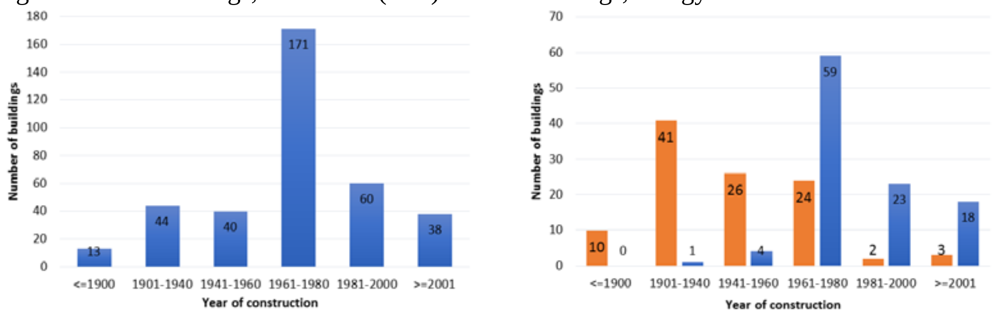
Former elementary school in Donja Bačuga is currently the Centre for Plum and Chestnut, an educational institution for agriculture, has an RC moment frame system with masonry infill walls, and experienced severe structural damage in the earthquake. Interior columns had 55x30cm cross-sectional dimensions (longer dimension was aligned in transverse direction) and experienced shear failure, as shown in Figure 5a. The building survey showed that ties were provided at 20 cm spacing in interior columns and at 30 cm for exterior columns. Excessively large tie spacing and interaction between partial-height infill and the frame in exterior columns caused a "short column" effect (Figure 5b). Almost all infill walls in the building experienced severe cracking in the walls and horizontal cracks at the infill-to-top beam interface.

4. SURVEY OF SCHOOL BUILDINGS IN SERBIA: PRELIMINARY RESULTS

The territory of the Republic of Serbia is located in a seismically active area characterized by moderate seismicity. More than 10 earthquakes with magnitude of 5.0 or higher occurred in the 20th century. The strongest earthquake in the 21st century hit Kraljevo in November 2010 (M 5.4), causing 2 fatalities and significant damage and material losses. At least 12 school buildings in Kraljevo experienced damage and had to be repaired after the earthquake [18], which indicated vulnerability of school buildings in Serbia due to even moderate earthquakes.

This section presents preliminary results of a detailed study on 212 elementary and secondary schools in Serbia which are located in seismic zone VIII according to the national seismic hazard map. This study was part of the Serbia National Disaster Risk Management Program: Scaling Up Resilient Infrastructure Project, funded by World Bank, implemented by Public Investment Management Office Government of Republic of Serbia. It included a field survey and the assessment of building condition, and the results were presented in the form of detailed reports. A database containing relevant information for each school was created, and selected results are presented here.

Although the scope of the project included 212 schools, additional buildings were constructed in some schools due to a need to increase school capacity (number of students) over time. As a result, the database includes information on 366 buildings, including the original school buildings, additional (new) school buildings, and gymnasiums.

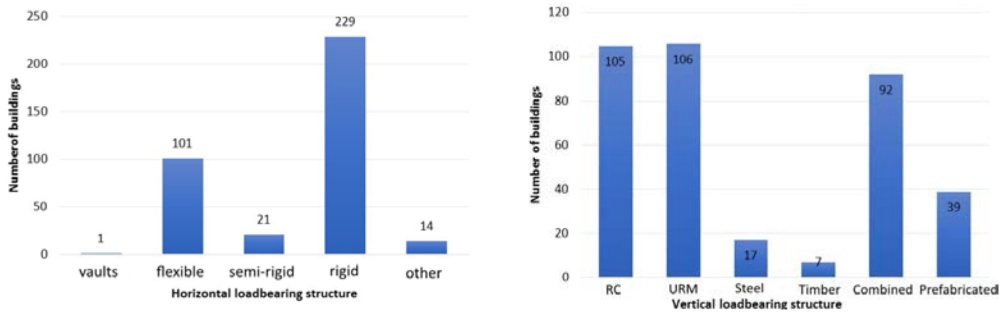


a) b)

Figure 6 – Year of construction: a) all surveyed school buildings and b) RC (blue) and URM (orange) buildings

One of the most relevant indicators of level of seismic safety is the year of construction, which is shown in Figure 6a. It can be seen that approximately 50% of all school buildings were built in the period 1961-1980, when the 1964 Yugoslav seismic design code was in place.

One of the most important criteria is the type of structure, i.e., material of loadbearing (vertical) system, which is the same as the material of Lateral Load Resisting System (LLRS). Vertical system was classified into RC, URM, confined masonry, wood, steel, prefabricated, and combined (e.g. URM and RC, masonry and wood). Horizontal structure has been classified into vaults, flexible floors (e.g. wooden floors), semi-rigid floors (e.g. steel beams), rigid floors (RC slabs), and others. Figure 7 illustrates types of vertical and horizontal structures for the surveyed buildings. It can be observed that most schools (211 out of 366 buildings) have either masonry or RC vertical loadbearing structure. In terms of the horizontal structure, majority of schools (approximately 60%) have rigid floors. Figure 6b shows that most URM school buildings were constructed in the first half of 20th century, whereas majority of RC school buildings were constructed in the second half of the 20th century, mostly from 1961 to 1980.



a) b)

Figure 7 – Loadbearing structure: a) horizontal and b) vertical

a) b)

Figure 8 – URM schools in Serbia: a) Primary School Milisav Nikolić in Malo Crniće and b) High School in Valjevo

If we take a look at the building type and year of construction of schools damaged in earthquakes in Albania and Petrinja (Croatia), it can be seen that exactly the most dominant structural types and year of construction of schools in Serbia match to them. Most of the schools are RC frame buildings and URM. Significant number of surveyed URM school buildings in Serbia is the same as the two-storey URM school in Thumanë (Figure 1) that was severely damaged. Most URM school buildings are built at the beginning of the 20th century

(Figure 6b), as it was the case with the highly damaged First Primary School in Petrinja (Figure 3a). One example is Primary School Milisav Nikolić in Malo Crniće (Figure 8a), built at the same time and in the same structural type (URM walls and jack arch floor slabs, known as *Pruski svod* in Serbian). Petrinja earthquake also showed what could be expected with the massive URM building of High School in Valjevo (Figure 8b) and similar, since it was built at the same time and with an identical structural type as Petrinja High School (Figure 3b).

The results of the survey showed that the most common structural type of schools in Serbia is RC frame (Figure 6b and 7b). Frames are always filled with masonry infill walls. Furthermore, the biggest number of the RC framed schools is built between 1960 and 1970. In exactly the same period as damaged school buildings in Petrinja, (Figure 4 and 5). Since at that period Serbia and Croatia were part of the same country (Yugoslavia), it is for sure that the same materials and construction practice were used in building these schools both in Serbia and Petrinja. Therefore, the performance of the damaged schools in Petrinja can serve as an example what can be expected in Serbia. Some representative examples of the schools from Serbia matching the damaged ones from Petrinja are Primary School Sveti Sava in Mladenovac (Figure 9a), Primary School Slavko Rodić in Sečanj (Figure 9b) and others.

a) b)

Figure 9 – Infilled RC frame schools in Serbia: a) Primary School Sveti Sava in Mladenovac and b) Primary School Slavko Rodić in Sečanj

5. PROPOSED CLASSIFICATION OF EDUCATIONAL BUILDINGS IN SERBIA

A classification of school building typologies in Serbia has been proposed by the authors, based on the survey of school buildings in Serbia presented in this paper, and also similarity between school building typologies in Serbia and neighbouring countries which experienced recent earthquakes, especially Croatia [19]. The authors have also reviewed more comprehensive classifications/taxonomies, such as the GEM taxonomy [20], as well as recently developed global taxonomy for school buildings (GLoSI) with 12 attributes [21]. The proposed classification was developed by considering the most important attributes which are believed to influence the seismic performance of schools, such as i) LLRS, e.g. moment frame, wall, dual frame-wall system; ii) material of LLRS (e.g. masonry, RC), and iii) type of floor/roof diaphragm (flexible or rigid). The survey of school buildings in Serbia showed that majority of buildings were constructed using masonry and RC, hence the proposed classification is focused on these materials, while steel and wood can be classified as "Other" systems. The classification is intended to be simple and easy for application in field surveys. It is important to note that other relevant attributes, such as building height and year of construction, also need to be considered in the classification.

Table 1 – Classification of school buildings in Serbia

Material of construction	Typology ID	Description
Masonry	M1	Earthen buildings (rammed earth or adobe)
	M2	Unreinforced masonry buildings with flexible floors
	M3	Unreinforced masonry buildings with rigid floors
	M4	Confined masonry buildings
Reinforced concrete	RC1	RC frames (cast in-situ) with masonry infills
	RC2	RC structural walls (cast in-situ) or dual RC frame-wall system
	RC3	Prefabricated (precast) RC buildings
Other	O	Steel or wood structures

6. SUMMARY

The aim of this paper was to raise awareness of the seismic vulnerability of school buildings in Serbia, through examples of damage caused by recent earthquakes in the region. Damage of school buildings due to recent earthquakes in Albania and Croatia can be attributed to design flaws and interventions (building extensions, removal of structural walls etc.) which did not consider seismic safety. The damage of infills and partitions may cause a need for repair/reconstruction, thereby reducing building functionality, interrupting the business etc.

Observations from the survey of school buildings in Serbia showed that majority of school buildings are similar to the ones damaged during the earthquakes in Croatia and Albania. The most dominant structural types, construction practices, and year of construction are very similar for schools in Serbia and Croatia, hence earthquake damage patterns in Croatian schools are very useful to predict damage in school in Serbia due to future earthquakes.

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