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Case Study

Structural performance of URM school buildings during the 2019 Albania earthquakes

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ABSTRACT

This paper aims to study the seismic performance of school buildings, which have been built in accordance with template unreinforced masonry [URM] school projects in Albania. For this purpose, the most widely used two template designs which were damaged during the 2019 Durrës (Albania) Earthquakes, have been selected. Analytical models of each school were prepared following the experimental data on the quality of the masonry constitutive components of the selected school buildings. Geotechnical investigations were deployed to obtain the soil characteristics of the area where the schools' foundation are located. Nonlinear static analyses have been performed to obtain the seismic capacity, the performance point and the damage level states. The performance-based method has been used to that purpose. The detailed examination of capacity curves and performance evaluation identified deficiencies and weak parts of the school building blocks. Results have shown that existing school buildings constructed pre-modern codes are far from satisfying the required performance criteria, suggesting that urgent response and necessary measure should be put into action.

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1. Introduction

The school buildings play a crucial role in every society. These buildings should be earthquake resistant in earthquake-prone countries whose closure may cause disruption of community life and hampering education immediately after the earthquakes. Recent devastating earthquakes in Albania and in other countries such as Algeria, Greece, India, Iran, Italy, Morocco and Turkey in the world have underlined insufficient seismic performance of school buildings as found in OECD (2004), Bilgin (2015), Bilgin and Hysenlliu (2020).

Understanding the earthquake history of any place is important to recognize the possibility that an earthquake can affect the region again and to consider the extent of probable damage. While the latter is a function of the vulnerability of the built environment, the former notifies us of the predominant hazard, especially in regions with a history of earthquakes.

Throughout the history, earthquakes in Albania, like in many earthquake-prone countries worldwide, have seriously affected buildings causing numerous human casualties and economic loses as found in the work of Irfanoglu (2009), Magenes and Penna (2011), Yilmaz et al. (2013), Chaulagain et al. (2014), Mwafy and Elkholy (2016), Bilgin and Huta (2018), Estêvão et al. (2018). In this context, buildings' vulnerability is a key notion to focus on to reduce the consequences of catastrophic events. Generally, URM buildings present a worse seismic response as compared to reinforced concrete (RC) buildings due to the low strength and stiffness of their components.

Consequently, modern seismic guidelines include recommendations and commentaries aimed at reducing their seismic vulnerability. However, a significant part of masonry building stock has been constructed per pre-modern codes, thus considering unrestrictive requirements.

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The dominant building types in the Albanian building stock comprise URM structures with load-bearing masonry walls and buildings with RC framing system and infill baked clay and/or concrete walls. Moreover, mixed types are also observed. The majority of current buildings have been constructed according to the KTPs–Albanian Technical Codes, which were first issued and implemented as a legal provision in 1963 and last improved and updated in 1989 and still in force. Most of the existing masonry buildings in the country, like in many other European countries were designed considering earlier seismic codes (i.e. KTP-63, 1978; KTP-N2, 1989) when seismic loads were not required, or the design was to reduce the level of seismic loads. Nevertheless, its compliance requirements were not as explicit as those established by recent modern seismic codes like Eurocode 6 and Eurocode 8 from European practice. This led to a lack of seismic considerations in building's design process. In the meantime, the EN version of Eurocodes has been used for the design of structures in Albania since several years ago. Many industries and companies operating in civil engineering industry have introduced European norms in their products. Despite of this fact, according to the Albanian legislation in the field of construction, the design of structures still must follow the KTPs–Albanian Technical Codes. Therefore, Eurocodes are National Standards that can be used voluntarily as mentioned by Bilgin and Frangu (2017).

The URM structures with the load-bearing masonry walls suffered the most by the November 26, 2019 Durrës Earthquake due to reasons including old construction age, poor quality of construction, poor workmanship, interventions made by people, the design code of the time – if ever was applied- lack of maintenance and inadequate repair after previous damaging seismic events. This type suffered not only non-structural damage but also structural damage including partial or total collapse of the load-bearing masonry walls.

The object of this study, Shkolla 9-Vjeçare Publike "Emin Duraku" school blocks in Albanian capital city Tirana also suffered considerable damage during November 26, 2019 Durrës Earthquake sequences. In the on-site studies, the general condition of the buildings, the presence of observable settlements on the ground and the crack situation in the structure were determined and damage relieves were prepared. The data has been obtained from original blueprints and in-site visits to the buildings.

This study aims to evaluate the seismic performance of the typical low-rise existing masonry school buildings, constructed per pre-modern seismic codes of Albanian Construction practice. In order to reflect the properties of low-rise existing masonry buildings, two URM school buildings with template designs were selected and modelled by using the TREMURI, Lagormasino et al. (2013). Structural features such as member dimensions, material types and loading conditions of the buildings were determined from their architectural and structural designs projects and field investigations on investigated buildings in several cities of Albania. Mechanical characteristics were determined experimentally and adopted for nonlinear analysis. Nonlinear static (pushover) analyses have been performed to obtain the seismic capacities, the performance points and the damage level states according to Eurocode 8 by using 3MURI software.

2. Seismicity of Albania

Albanian neighborhood is in a rather complicated seismotectonic region and prone to earthquakes. A high frequency of earthquakes has been experienced, resulting in loss of life and property destruction in the region (Table 1).

Fault zones in Eastern Albania are mostly characterized by the influence of normal type faults. Most of them in directions of 325°-350°. The Western Albania fault zones are defined by reverse faulting– at the range of 40-50% stretching along the coastal shore (165°), while the appearance of strike-slip faults is in range of 15% of total tectonic activity (Fig. 1). Three longitudinal and two transverse active fault zones are evidenced in the region.

Table 1. Major earthquakes in Albania (after Aliaj et al. (2010)).

Date	Affected County	M_w	Depth (km)	Casualties	
				Dead	Injured
26/11/2019	Durrës	6.4	20.0	52	3000+
21/09/2019	Durrës	5.6	10.0	-	108
09/01/1988	Tirana	5.4	24.0	-	-
16 /11/1982	Fier	5.6	21.9	1	12
15/04/1979	Montenegro, Shkoder	6.9	10.0	136	1000+
30/11/1967	Diber	6.6	20.0	12	174
18 /03/1962	Fier	6.0	-	5	77
26/05/1960	Korçe	6.4	-	7	127
01/09/1959	Fier	6.2	20.0	2	-
27/08/1942	Diber	6.0	33.0	43	110
21/11/1930	Vlore	6.0	35.0	30	100
26/11/1920	Tepelena	6.4	-	36	102
06/01/1905	Shkoder	6.6	-	200	500

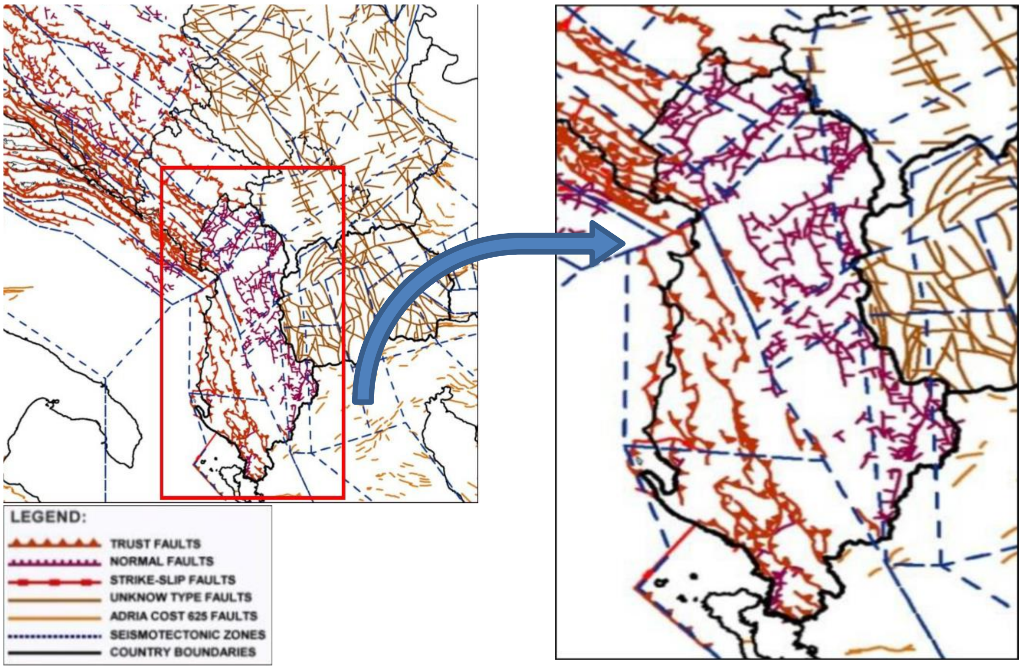

Fig. 1. From NATO SfP Project No. 983054 (BSHAP).

The 2019 earthquake affected area is dominated by NW-SE striking reverse active faults. The seismicity of Albania is characterized by an intensive seismic micro activity ($1.0 < M \leq 3.0$), many small earthquakes ($3.0 < M \leq 5.0$), rare medium-sized earthquakes ($5.0 < M \leq 7.0$) and very seldom by strong earthquakes ($M > 7.0$).

2.1. The November 26, 2019 earthquake and its consequences on Albanian buildings

On November 26, 2019, an earthquake hit the central western part of Albania. It was assessed as M_w 6.4 (Fig. 2). Its epicenter was located offshore NW Durrës, about 7 km north of the city and 30 km west from the capital city of Tirana. Its focal depth was about 10 km [USGS, 2019].

Based on the focal plane solutions provided by several seismological institutes and observations, the main shock was generated by the activation of a NW-SE striking reverse fault. The main shock was felt in the neighboring Kosovo, Montenegro, Italy, Northern Macedonia and Greece, especially in Corfu Island. This was the second major earthquake to strike the region in the space of three months.

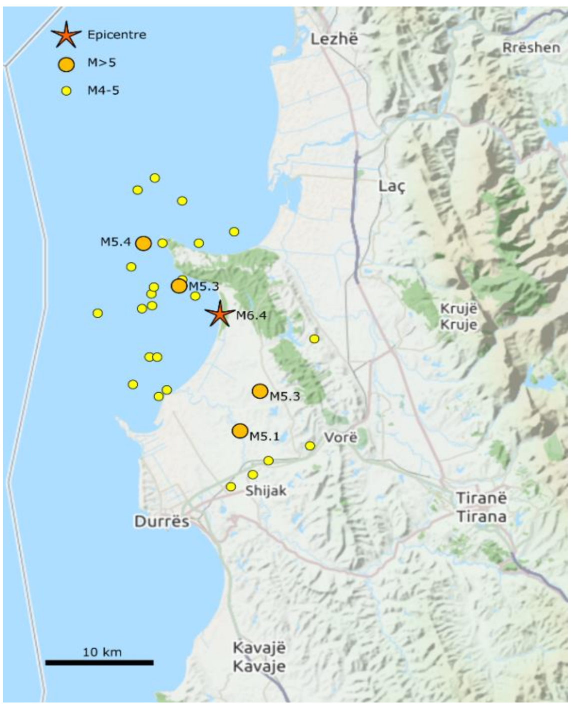

Fig. 2. Location of epicenter and aftershocks in the first twenty days of the 26 November Earthquake.

As regards the impact on the current building stock, the main shock and the following aftershocks induced damage to buildings of Durrës, Tirana and several settlements of the broader area. The most earthquake-affected regions are found in the city of Durrës and the town of Thumanë at the central-western Albania. Damage was also observed in Laç town, Fushë-Krujë town, Kamëz as well as capital city, Tirana.

Building damage was concentrated along two ellipses, whose major axis is oriented generally NW-SE (Fig. 3). This direction coincides with the strike of the seismogenic fault as it is derived from the fault plane solutions provided by several seismological institutes and observatories (INGV, 2019; USGS, 2019).

Spectral response of the earthquake is given for 0.3s and 1.0s in Fig. 4.

Fig. 3. Earthquake-affected area during the November 26, 2019 Durrës Earthquake.

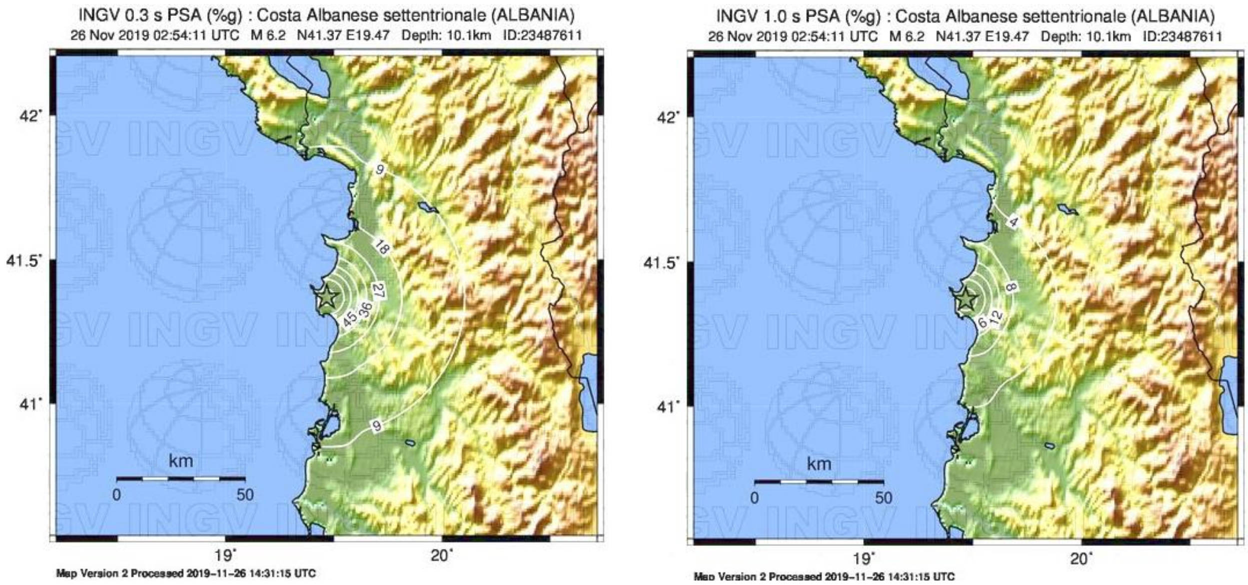

Fig. 4. Spectral response maps are given for 0.3s and 1.0 s for November 26 Earthquake. (http://shakemap.rm.ingv.it/shake/23487611/products.html).

2.2. Seismic hazard maps of Albania

Based on the seismic zonation map of Albania from the Earthquake Resistant Design Regulations, issued by the Seismic Center, Academy of Science of Albania, Department of Design, Ministry of Construction (1989), it is concluded that the resulted intensities from the earthquake under consideration, are within the limits specified in the Seismic Zonation Map (Fig. 5).

It is significant to note that the seismic zonation map in the seismic design code of Albania comprises zones based on observed seismic intensities and not on design accelerations.

On the other hand, based on the probabilistic approach, the seismic hazard maps for horizontal PGA, with the return period of 475 years, is shown for hard rock conditions (Fig. 6).

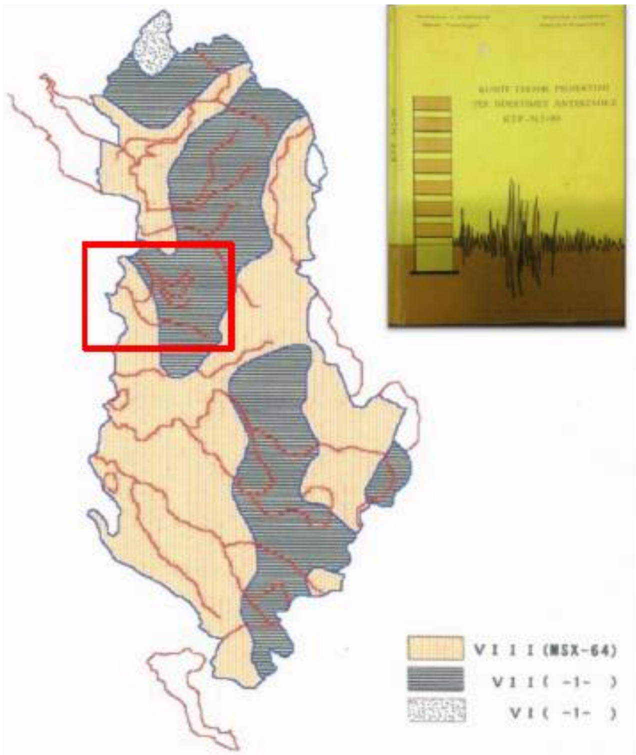

Fig. 5. Seismic zonation map of Albania.

3. Current Status of the School Buildings and the Load Bearing Systems of the Main Blocks and Its Adequacy according to the Earthquake Resistant Rules

The 9-vjeçare "Emin Duraku" school building blocks were built and located in the capital city of Tirana (Fig. 7).

Since the buildings under investigation are old ones, limited number of architectural drawings or details of the initial conditions of the buildings were reached. Only the original design plan of block B could be reached, and details of block A could not be found. Therefore, a detailed inspection of the existing structures was extracted. In these plans, the location and dimensions of the walls, windows and doors were determined. Based on the measurements obtained, structural floor plans of the existing structures were prepared, and structural models were developed accordingly for seismic analysis.

Building blocks were designed as two stories. But later, an additional story was added to both of them and became 3-stories due to the demand by time. So, buildings original designs were changed by these interventions. From the site survey and inspections, the floor plans of the blocks were generated and used for detailed seismic analysis.

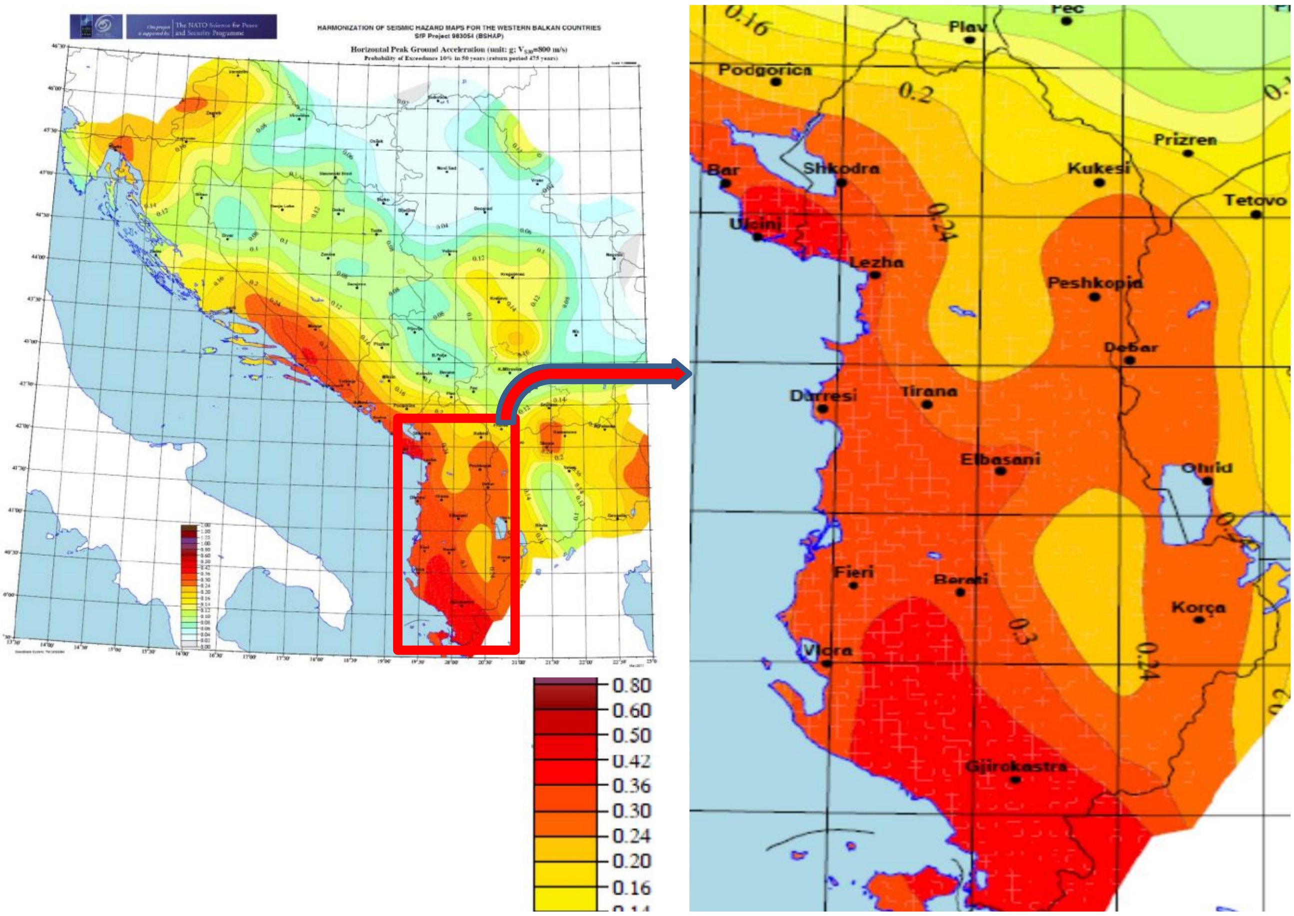

Fig. 6. Probabilistic seismic hazard map for horizontal PGA, with the return period of 475 years, for hard rock conditions ($V_{s30} \geq 800$ m/sec) (from NATO SfP Project No. 983054).

(a)

(b)

Fig. 7. a) Front view of A Block; b) Front view of B Block and its intersection with A Block.

The expansion joint in the junction area of the old masonry structure (Block A) with the later added Block B structure is insufficient (Fig. 8).

The actual floor plans of the Blocks are given in Fig. 9.

In order to determine the type of wall material used in the masonry structures and the way the walls were built in the corner area, the cover layer was removed (Fig. 10). Lime mortar and solid clay bricks were used for wall construction in Block A and silicate bricks were used in Block B.

During the inspection inside the buildings, a considerable damage was observed on Block B. We observed a 45^0 inclined shear crack on a number of walls on the ground floor (Fig. 11). This structural crack was formed on the 45 cm thick wall, which was subsequently removed in the upper floors to make additional space, during the Durrës earthquake of 26 November 2019.

Fig. 8. Expansion joint between two buildings (11.55 mm < 30.00 mm).

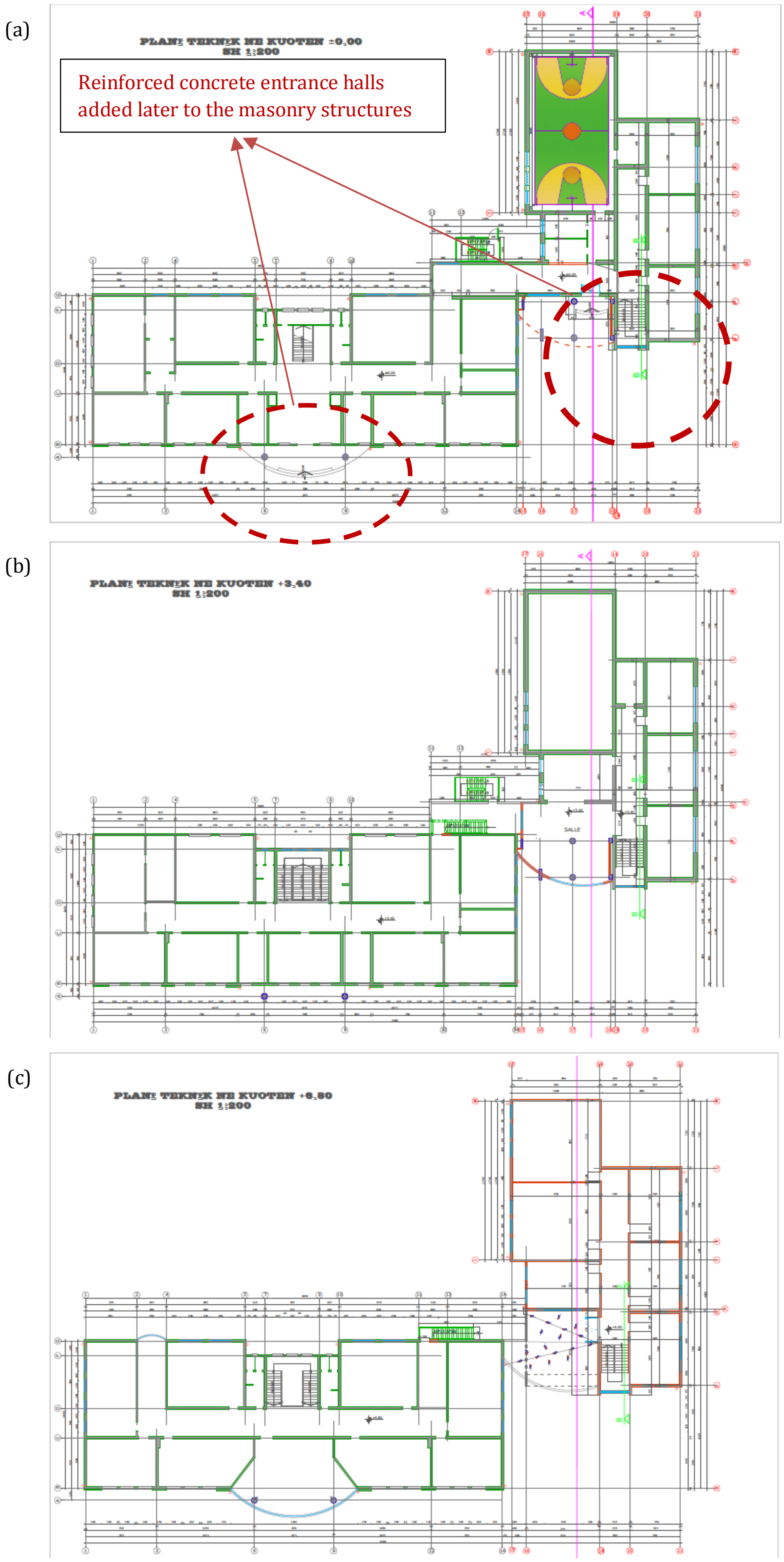

Fig. 9. a) Structural layout of Block A and B (ground floor), Reinforced concrete entrance halls added later to the masonry structures (shown by dashed red circles); b) Structural layout of Block A and B (1st floor); c) Structural layout of Block A and B (2nd floor).

a) Block A- Clay bricks b) Block B- Silicate masonry

Fig. 10. Type of bricks used for the school building blocks.

Fig. 11. Shear cracks on load bearing walls in the ground floor of the Block B.

In the structure, a reinforced concrete slab system was applied to the beams above the wall. It was realized that due to the thick coating applied as a covering material on the reinforced concrete slabs, the total weight of the structure was increased. In this way, due to overlapping floor coverings, the floor thickness in the structure has approached to ~25 cm. As a natural consequence of this, there is much higher load transfer from the slabs to the supporting walls than it should be.

According to modern earthquake codes in force (i.e. TSDC, 2018), "In masonry-masonry buildings, the height of each floor shall not be more than 3.0 m". It is observed that this condition was exceeded in this building.

In Block B, wall thicknesses range from 45 cm to 25 cm. Thicknesses vary between layers, even on the same floor. On the ground floor, the walls were applied in two different thicknesses: 45 cm and 25-30 cm. The outer walls on the ground and first floor are usually 45 cm. The wall thicknesses vary from 30 cm to 25 cm on the top floor. In Block A, the wall thicknesses vary between 38 cm and 25 cm and there is a more regular distribution in the level of the floor than Block B.

In the masonry structures, all the vertical and horizontal loads acting on the structure are carried by the load bearing walls and transferred to the foundation. For this reason, in the earthquake-resistant structure design regulations, it is stated that "The load bearing walls of masonry buildings shall be arranged as regularly as possible and symmetrical or close to symmetry with respect to the main axes".

So, in order to create different spaces in a masonry structure, the location and thickness of the walls should not be changed. Different walls should not be applied between the floors. However, as can be seen from the floor plans given in Fig. 12, different wall axes were applied between the ground floor, first floor and second floors in some parts of the structure. In this way, vertical discontinuities are created between the floors and all the loads coming from the upper floor wall are loaded onto the floor covering.

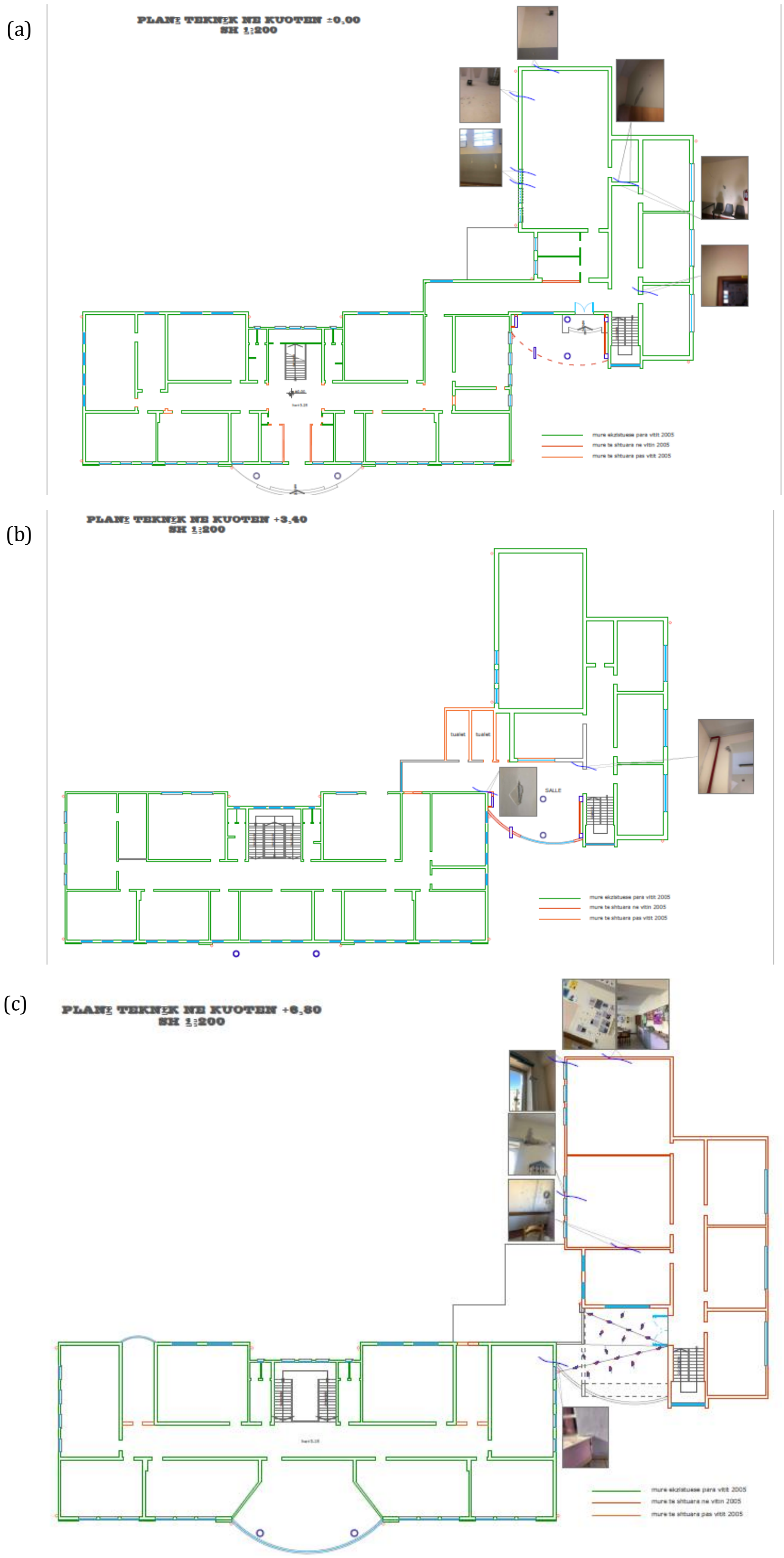

Fig. 12. a) Slight-moderate damaged locations on the ground floor; b) Slight-moderate damaged location on the 1st floor; c) Moderate-severe damaged locations on the 2nd floor of the Block B (This floor was added lately and made the building more vulnerable during 26 November earthquake.

In modern earthquake regulations (i.e., EC 8; TSDC 2018), it should be noted that in the masonry structures, the plan length of the wall part to be left between the window or door space closest to the building corner should not be less than 1.5 m in the 1st and 2nd degree earthquake zones and 1.0 m in the 3rd and 4th degree earthquake zones. As can be seen in Fig 6, this requirement in Block B is not satisfied in many locations. For example, at the corners this value is measured as 0.5 meter << 1.5 meters. An important detail to note in Fig. 9 is that the window locations and wall axes are variable between the floors. However, in masonry structures, the axes of the walls must be the same between the floors. In addition, the positions of the windows between the floors should not be shifted.

On the last floor, it was observed that the beams were located on the spandrels in the middle of the windows (Fig. 13). During the earthquake, this caused serious damage in the inner and outer part of the connecting areas. They should have been cast on the pier elements to safely convey the slab and roof loads to the foundation.

Apart from the corners of the building, the length of the filled wall pieces between the window and door spaces in the plan was determined. According to the modern seismic codes in practice, it is suggested that the length of the masonry wall between the two openings cannot be less than 1.0 m in the 1st and 2nd degree earthquake zones and 0.8 m in the 3rd and 4th degree earthquake zones. It was determined that this value decreased up to 60 cm in Block B which does comply the requirements. This application was made on the top floors, especially on the exterior.

(a)

(b)

Fig. 13. a) A beam casted on spandrel over a window in the last floor of Block B and caused serious damage; b) Diagonal shear cracks on outer façade of the last story. This damage patterns also continue in the inner part.

The evaluation of the building blocks is based on conceptual earthquake-resistant design rules in modern earthquake regulations. These rules are summarized and listed in Table 2. As a result of the on-site inspections and measurements, the compliance of the buildings with the earthquake resistant design regulations is evaluated in the same table.

Table 2. Suggested earthquake resistant design rules for masonry buildings and the adequacy of the school blocks (Following EC-8 and TSDC, 2018).

	Provision	Limit	Current status of the buildings	Adequacy
1	Number of floors for masonry buildings can be maximum 2 in 1st Degree Earthquake Zones	2	Both Block A and B are 3 floors. Their original design projects (projected as 2-stories) were intervened by adding one additional floor.	Inadequate
2	In masonry buildings, the height of each floor shall not be more than 3 m above the floor.	3 m	For both blocks, story heights are more than 3 meters.	Inadequate
3	The load bearing walls of the masonry buildings shall be arranged as regularly as possible in the plan and symmetrical or symmetrical to the main axes.	As much as possible	Although orientation of the walls and the axes are symmetric or close to symmetry in Blok A, the plan orientation of the walls and the continuation has some discontinues over the height of the building on Block B.	Inadequate for Block B. A could be considered as adequate.
4	All bearing walls shall be constructed on top of each other in the plan.		The underneath of some load bearing walls remained empty. There are discontinuities in the floor height, especially in Block B.	Inadequate. Block A is regular.
5	Natural stone, filled bricks, filled concrete briquettes or similar blocks will be used as masonry materials in the construction of bearing walls.		Clay bricks and silicate brick were used as load bearing material.	Adequate
6	Natural stone load bearing walls will be used only in foundations and ground floors of masonry buildings.		The building is not made of stone with walls.	Adequate
7	In the 1st degree earthquake zones, natural stone load bearing walls shall be at least 50 cm in the foundation and ground floor.	50 cm	70 cm > 50 cm	Adequate
8	The unrestrained length of any load bearing wall between the axis of the load bearing wall perpendicular to the plan shall not exceed 5.5 m in the 1st degree earthquake zone and 7.0 m in other earthquake zones.	5.5 m	On the upper floors, this length can reach up to 5.5 meters and more.	Inadequate
9	In the case of masonry structures, additional measures should be takenif the following condition is not met in one direction. L_d / A> 0:25 * I; I: Building Importance Coefficient (1.5 for Schools)	0.25*1.5= =0.375	This value is very low especially in the last floors	Inadequate
10	The length of the solid wall part to be left between the window or door space closest to the building corner shall not be less than 1.5 m in the 1st and 2nd seismic zones and 1.0 m in the 3rd and 4th seismic zones.	1.0-1.5 m	The length of this filled wall section decreases up to 60 cm in places, especially on the upper floors of Block B.	Inadequate
11	Apart from the corners of the building, the length of the solid wall pieces between the window and door spaces shall not be less than 1.0 m in the first and second seismic zones and 0.8 m in the third and fourth seismic zones.	1.0 m	The distance between the two openings decreases up to 31 cm.	Inadequate
12	Apart from the corners of the building, the length of the full wall piece to be left between the window or door space closest to the intersection of the walls intersecting each other and the intersection of the walls shall not be less than 0.50 m in all earthquake zones.	0.50 m	This value is lower than 50 cm especially in upper floors.	Inadequate
13	The length of each door and window opening in the plan shall not be more than 3.0 m.	3.0 m	There are openings reaching up to 4.0 meters in Block B.	Inadequate
14	Eurocode-8 Part-3 (EC8-3) establishes that URM buildings can only be constructed in areas of low seismicity (a_g<0.08g) (where a_g is the EC8 design acceleration)		Nearly all the municipalities located around Tirana have higher values of a_g, greater than 0.15g.	Inadequate

4. Seismic Capacity Evaluation of the School Buildings Blocks

The pushover analysis consists of the application of gravity loads and a representative lateral load pattern. Gravity loads were in place during lateral loading. In all cases, lateral forces were applied monotonically in a step-by-step nonlinear static analysis. The applied lateral forces were proportional to the product of mass and the first mode shape amplitude at each story level under consideration.

In pushover analysis, the behavior of structure is characterized by a capacity curve that represents the relationship between the base shear force and the displacement of the roof. This useful demonstration is very practical and can easily be visualized by practicing engineers. Roof displacement is commonly used for capacity curve.

4.1. Determination of the material and soil characteristics of the school buildings

For the modelling of the selected buildings two types of issues should be considered: correct representation of the mathematical model and inelastic characteristics of materials. URM is a composite construction material which consists of masonry units and mortar. Brick and stone are the usual elements of masonry units. Mortar is used to make the connection between these units. Under vertical and horizontal loads, load bearing of masonry considered as the assemblage of the masonry units and mortar is influenced by the compressive, shear and flexural strengths, durability, water absorption and thermal expansion.

These two structures are composed of two main components, namely load bearing walls and roof diaphragms. The walls are stiff with openings and the diagrams are usually constructed by RC slabs. For the construction of the Blok A, solid clay bricks with 250 mm x 120 mm x 60 mm dimensions connected with cement mortar are used to build the masonry walls. In order to achieve a better distribution of the loads, perimeter RC beams are used to create a better connection between slabs and load bearing walls. Block B was constructed by the calcium silicate solid bricks and cement mortar and Block A was constructed by solid clay bricks.

The load bearing walls are made with masonry walls that can be classified in facade with a thickness of 380 mm and inner masonry walls 250 mm thick. The thickness of outer load bearing walls has 380 mm for Block A and these values are 450 mm for Block B. Calcium silicate solid and solid clay bricks with 250 mm x 120 mm x 65 mm dimensions connected with cement mortar were used to build the masonry walls of the school blocks.

For the mathematical modelling and the seismic analyses of the school buildings, as built material properties determined from site investigations and experimental test were taken into consideration. In order to truly represent the strength and structural integrity of the buildings, mechanical characteristics were obtained from the experimental tests with destructive methods (Fig. 14). The samples were tested to determine the compressive strength of the solid bricks units and the obtained results are used for seismic analyses.

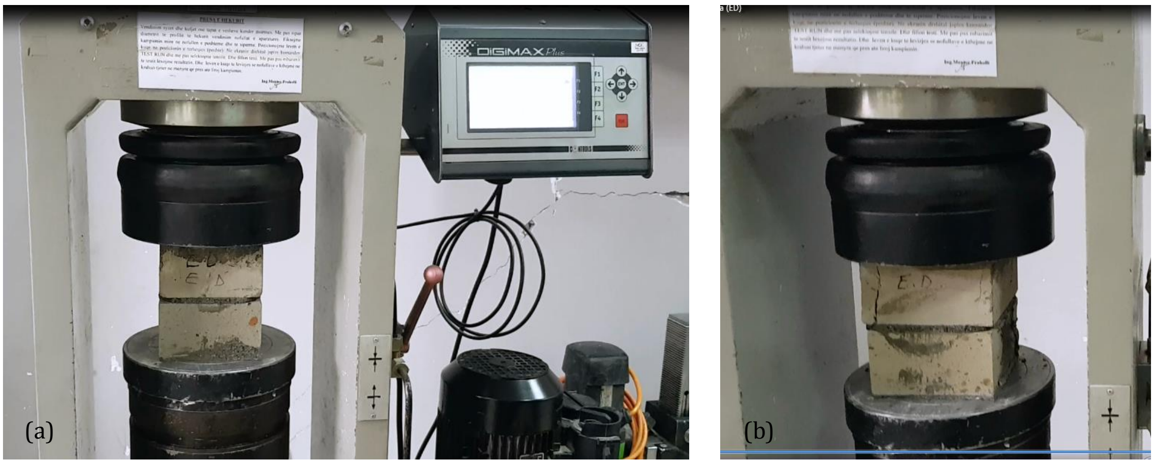

Fig. 14. a) Sample during testing; b) Sample after testing.

The characterization of masonry walls in existing buildings is complex. In this study, mechanical characteristics have been obtained by using the building codes, blueprints and the similar buildings constructed during the similar periods. In the case when experimental data is not sufficient, several equations are proposed by different codes and guidelines to calculate the compressive strength of the masonry walls. In this study, Eurocode 6 (2005) guideless are followed as given in Eq. (1);

$$f_k = K * f_b^{0.70} * f_m^{0.30} \text{ (MPa)} \quad (1)$$

Following the Eurocode 6 guidelines CEN (2005) together with the relevant material characteristics obtained from experimental tests are used to calculate the required input data for mathematical modeling of the buildings (Table 3).

Seismic loads are usually characterized by response spectrum functions which are derived from the time history records of past earthquakes in specific locations. To perform a reliable performance evaluation, seismic demands of the studied buildings were determined based on detailed seismic hazard assessment. A detailed soil investigation was carried out in order to have a comprehensive understanding of the actual structural conditions for the area where both buildings are located. The boreholes were drilled, and the samples were analyzed. According to the geotechnical investigations, the type of soil that forms the foundation of the area is classified as “Dense gravel or medium dense sand and gravel” according to the laboratory test results that has an allowable load bearing capacity of 220 kPa (2.2 kg/cm^2).

According to the European norms (EC 8), the soil class of the unit is considered in the seismic analysis as Type C. In this study, the demand calculations for the seismic assessment of the considered buildings were performed considering the actual soil conditions with a moderate seismicity according to Eurocode 8. Elastic seismic demand spectra shape was given in comparison between Eurocode 8 and KTP-N2-89 (Fig. 15).

Table 3. Masonry wall data used as Input for analytical modeling.

Building Type	Compressive strength f_k (N/mm^2)	Mortar strength f_m (N/mm^2)	Tensile fracture energy G_t (N/mm)	Shear strength f_t (N/mm^2) as per EC 6	E (N/mm^2) as per EC 6	G (N/mm^2) as per EC 6	Poisson ratio v
Block A	5.50	5.00	0.1	0.50	5500	1675	0.2
Block B	5.50	5.00	0.1	0.50	5500	1675	0.2

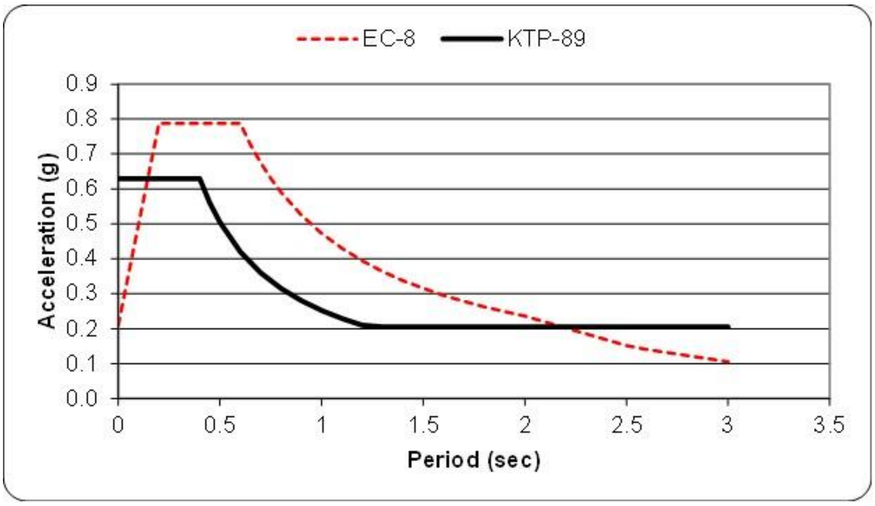

Fig. 15. Shape of the Elastic Acceleration Response Spectrum in EC-8 and KTP-N2-89 (Albanian Seismic Code).

4.2. Mathematical modeling

Modelling masonry structures is not an easy task due to the nonlinear response of masonry and lack of experimental data regarding the inherent characteristics of masonry structural elements. Masonry is a heterogeneous material composed of masonry bricks and mortar whose mechanical characteristics depend upon the inherent properties of its constituents. Its behaviour under different loadings may be very complex. In order to model the response of masonry, numerous assumptions and analytical models are proposed in Lourenço (2010). Each of these techniques requires the adoption of different constitutive models. Due to the complexity of the two case study buildings, several assumptions on the material properties and the necessity of having high performance computers to process the nonlinear analyses, macro-modelling technique was considered in this study. Nonlinear static analyses have been conducted by TREMURI software that is a multi-purpose finite element program dedicated for the linear and nonlinear analysis of masonry structures.

School building blocks are analysed considering 4 different cases. According to the 1st design, both blocks were constructed as two stories and later on depending on space demand for education, one additional story was added to both of the blocks. Currently, each building has 3 stories and Block B experienced moderate-severe damages during the November 26 Earthquake and Block A did not have a serious observed damage. To make a comparative performance assessment, actual status of each building (3-story) and the original designs (2-story) are modelled separately and seismic load bearing capacities are estimated. A 3-D model of each building typology is created in TREMURI to carry out pushover analyses (Fig.16).

During the modelling, the walls are the load bearing elements, while the floors are considered as stiffening elements, on which the lateral effects are distributed between the connected walls.

Damage limit states are quantitative definition of performance levels by a convenient damage indicator capable of representing the seismic performance with appropriate damage thresholds. They should be defined in terms of quantitative measure of structural behavior such as displacements and deformation quantities. In this study, damage limit states were defined as suggested in Eurocode 8.

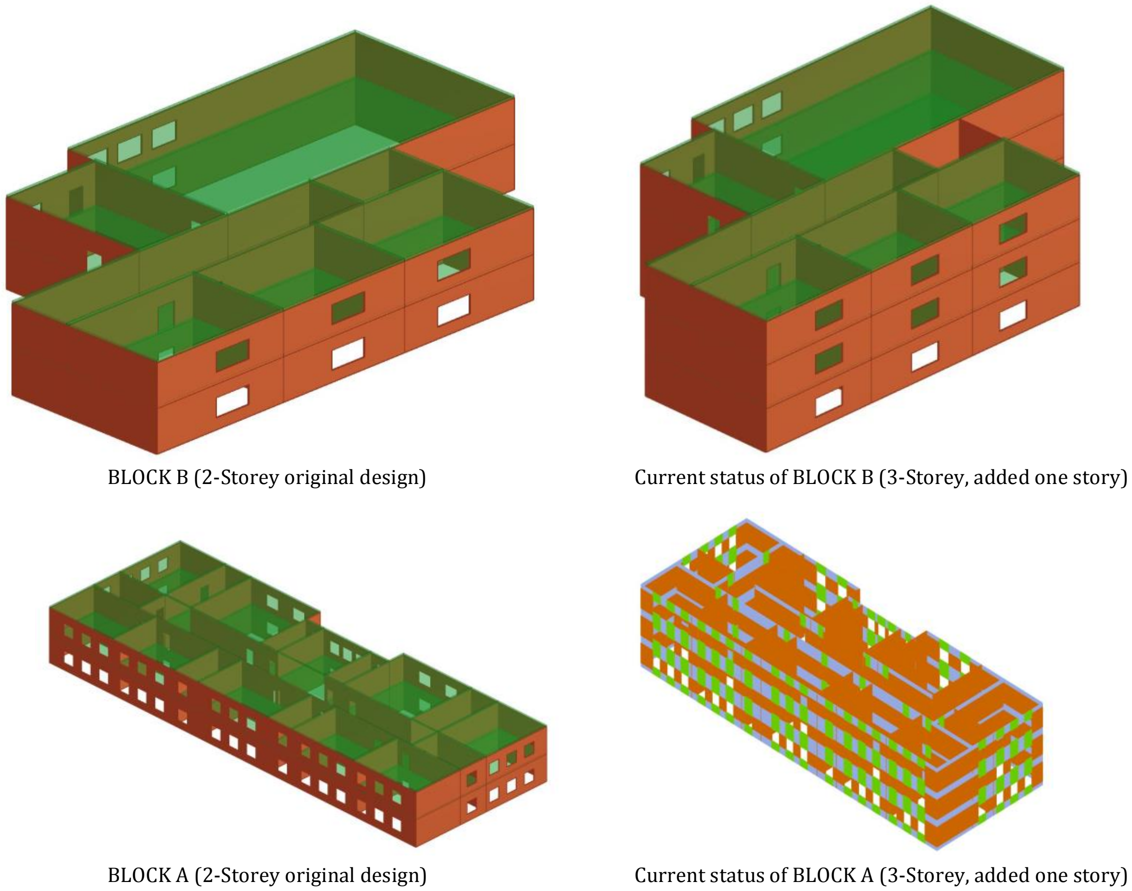

Fig. 16. 3D view of the school building mathematical models (3MURI software).

Capacity evaluation of the investigated buildings is performed using Eurocode 8. Three damage limit states levels, i.e., "Limited Damage" (LD), the limit state "Significant Damage" (SD) and the limit state "Near Collapse" (NC) are considered. Eurocode 8 approximates the base shear force-drift relationship of masonry piers by a bilinear curve.

4.3. Seismic analyses of Block B

4.3.1. 2-story model

The building is pushed by 24 different loading cases and the pushover curves are plotted for the most critical loading pattern (Fig. 17).

4.3.2. 3-story model (current status)

The building is pushed by 24 different loading cases and the pushover curves are plotted for the most critical loading patterns (Fig. 18).

Table 4 defines the PGA limits that can be sustained by building for the damage limit states according to EC 8 for Block B.

From the comparison of *2*- and *3*- story building performances of Block B, it can be revealed that the 3-story building has nearly 25-30% less load bearing capacity than the 2- story design. Pushover analyses results and the damage patterns observed during the damage inspection confirms the induced damage patterns during the November 26, 2019 earthquake.

4.4. Seismic analyses of Block A

4.4.1. 2-story model

The building is pushed by 24 different loading cases and the pushover curves are plotted for the most critical loading pattern (Fig. 19).

4.4.2. 3-story model

The building is pushed by 24 different loading cases and the pushover curves are plotted for the most critical loading pattern (Fig. 20).

Table 5 defines the peak ground acceleration (PGA) limits that can be sustained by building for the damage limit states according to EC 8 for Block A.

Similar to the Block B vulnerability, addition of one story caused a reduction to the seismic resistance of Block A. This reduction in seismic resistance (around 30%) can easily be observed from the comparisons PGA values.

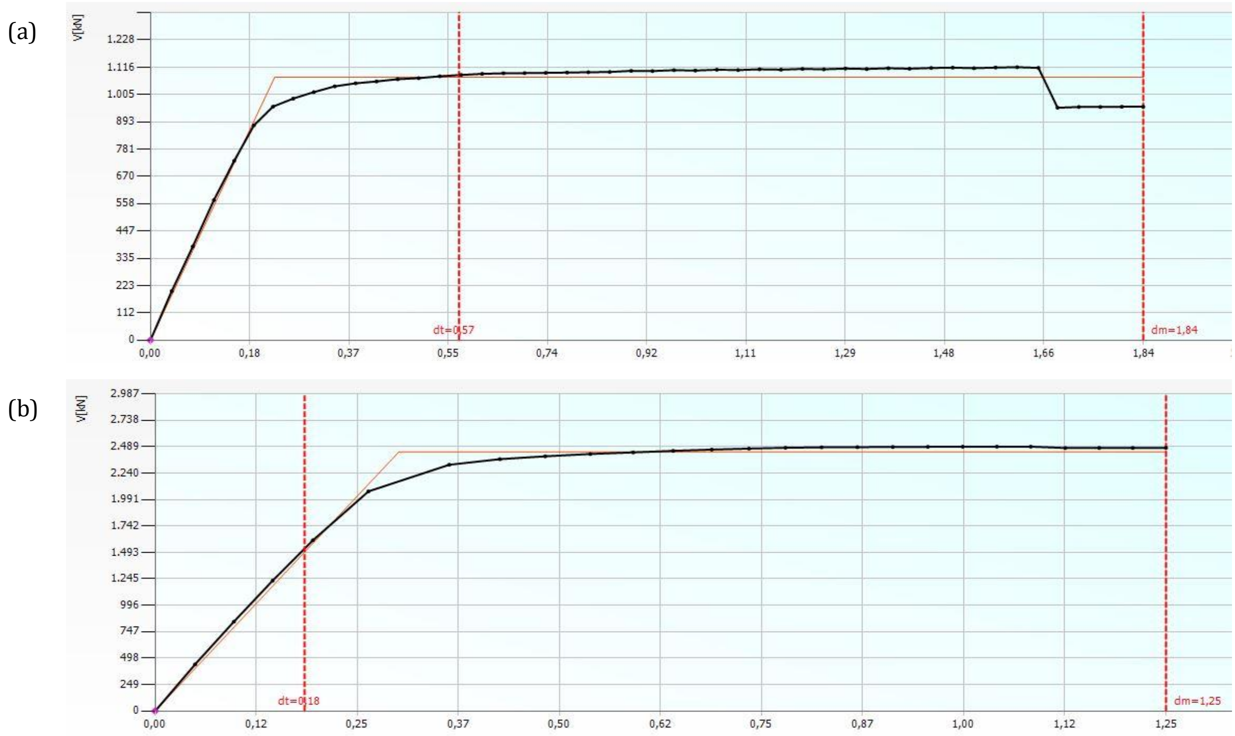

Fig. 17. Pushover curves of B Block_2-Story: a) *x*- direction; b) *y*- direction.

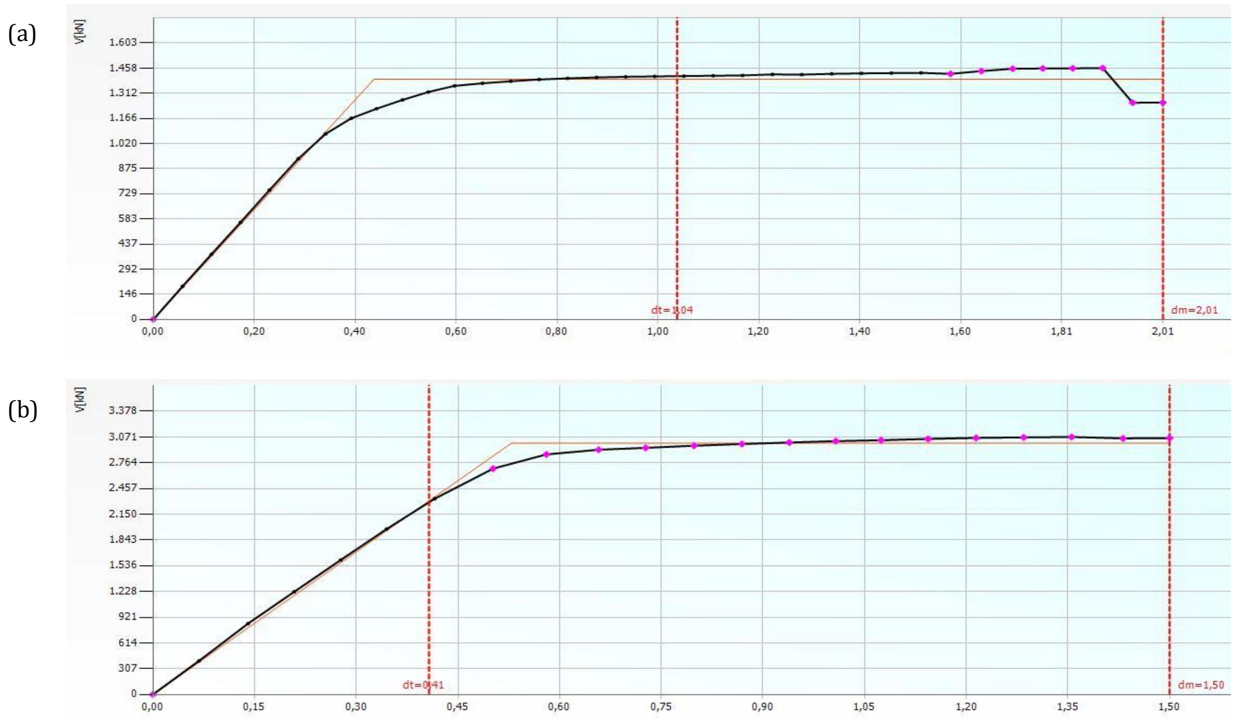

Fig. 18. Pushover curves of B Block_3-Story: a) *x*- direction; b) *y*- direction.

Table 4. PGA limit states for Block B.

Limit State	PGA (m/s²)			
	2-story		3-story	
	x-	*y*-	*x*-	*y*-
NC	2.947	3.880	2.139	2.823
SD	2.349	3.330	1.703	2.385
DL	0.856	2.110	0.777	1.688

(a)

(b)

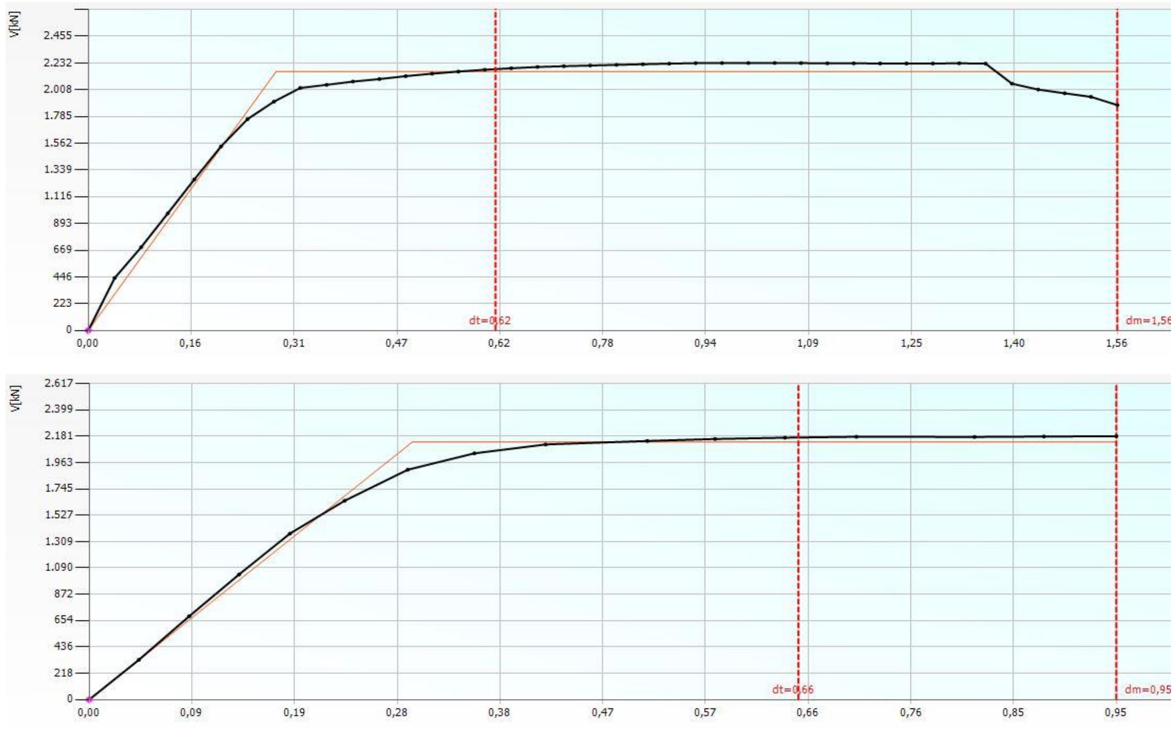

Fig. 19. Pushover curves of A Block_2-Story: a) *x*- direction; b) *y*- direction.

(a)

(b)

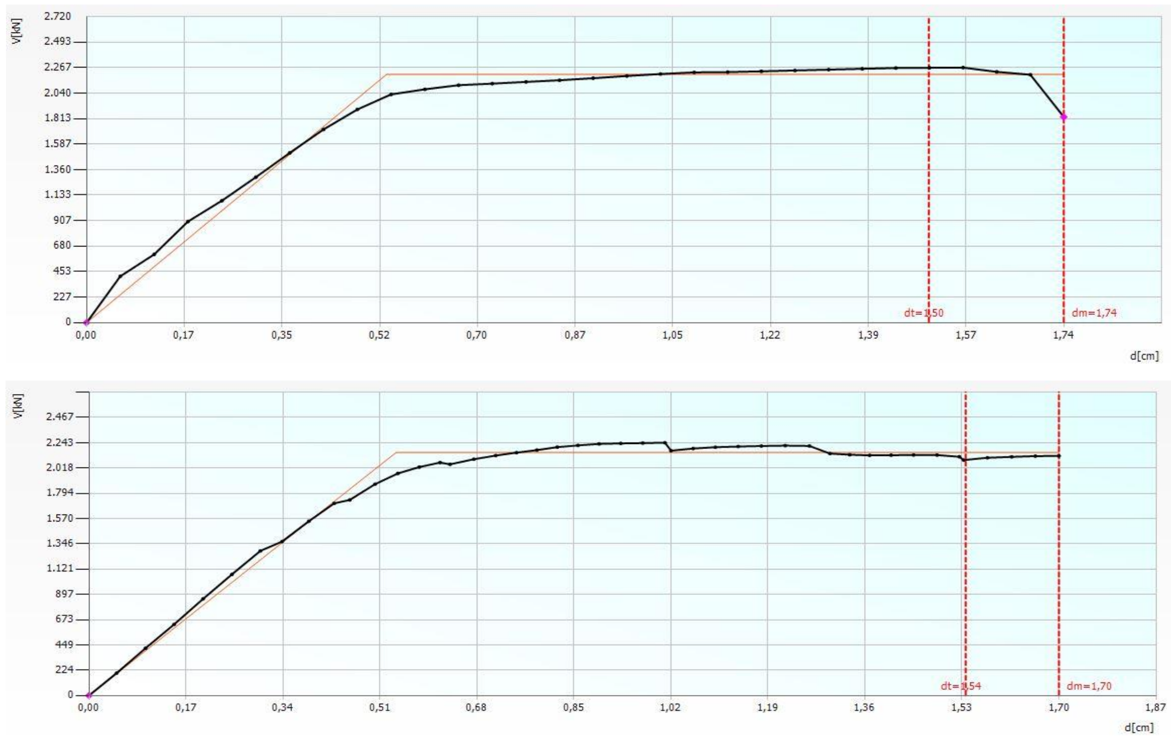

Fig. 20. Pushover curves of A Block_3-Story: a) *x*- direction; b) *y*- direction.

Table 5. PGA limit states for Block A.

Limit State	PGA (m/s^2)			
	2-story		3-story	
	x-	*y*-	*x*-	*y*-
NC	2.713	1.866	1.767	1.629
SD	2.211	1.570	1.447	1.356
DL	1.072	1.055	0.849	0.927

5. Conclusions

The structures used as Emin Durbaku School blocks were examined on site. The masonry structures, which were built as pre-2000 schools, were originally designed as 2- floors and were subsequently increased to 3- floors. The current situation of the buildings was evaluated by considering the provisions of earthquake resistant design rules and Eurocode regulations (Eurocode 6 and 8) for masonry structures under seismic loads. The seismic capacities of the buildings were estimated by using a structural model which uses macro modelling approach for the load bearing masonry walls using TREMURI.

The type of soil that forms the foundation of the area is classified as "Dense gravel or medium dense sand and gravel" according to the laboratory test results that has an allowable load bearing capacity of 220 kPa (2.2 kg/cm^2). According to the EC 8, the soil class is considered in the seismic analysis as Type C. The study area is in one of the earthquake-prone zones of the country according to the Albanian probabilistic seismic hazard map.

The provisions of earthquake-resistant building design regulations on masonry structures and the suitability of the building are summarized in Table 2. Particularly in Block B, serious damage and non-conformities were found. Block A is generally more regular but due to the increase in the floor according to the seismic analysis results, the earthquake resistance capacity decreases up to 30%. The same applies to Block B. Both buildings suffered slight-moderate structural and non-structural damages due to the lack of sufficient stiffness during the November 26, 2019 Albania earthquake.

In conclusion, school buildings are buildings that need to be preserved in terms of their location, history and construction. School buildings to be used immediately after the earthquake should not be damaged. The buildings examined may be damaged due to the observed irregularities and inadequacies in a possible new earthquake. During the Durres earthquake of 6.4 magnitude on November 2019, serious damage was observed especially in Block B. However, this earthquake is smaller than design earthquake and it is classified as a medium intensity earthquake. Considering the actual status of these school buildings, urgent need needs to be put into action.

Data Availability

- Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.
- All data, models, and code generated or used during the study appear in the submitted article.

REFERENCES

Aliaj S, Kociu S, Muco B and Sulstarova E (2010). Seismicity, Seismotectonics and Seismic Hazard Assessment in Albania. The Academy of Sciences of Albania. ISBN: 978-99956-10-26. Albania.

Bilgin H (2015). Seismic performance evaluation of an existing school building in Turkey. *Challenge Journal of Structural Mechanics*. 1(4), 161-167.

Bilgin H, Frangu I (2017). Predicting the seismic performance of typical R/C healthcare facilities: emphasis on hospitals. *International Journal of Advanced Structural Engineering,* 9(3), 277-292.

Bilgin H, Huta E (2018). Earthquake performance assessment of low and mid-rise buildings: Emphasis on URM buildings in Albania. *Earthquakes and Structures*, 14(6), 599-614.

Bilgin H, Hysenlliu M (2020). Comparison of near and far-fault ground motion effects on low and mid-rise masonry buildings. *Journal of Building Engineering*, 30, 101248.

Chaulagain H, Rodrigues H, Spacone E, Varum H (2014). Design procedures of reinforced concrete framed buildings in Nepal and its impact on seismic safety. *Advances in Structural Engineering*, 17(10), 1419-1442.

Decanni L, D'Amore E, Goretti A, Langenbach R, Mollaioli F, Rasulo A (2004). Performance of masonry buildings during the 2002 Molise, Italy earthquake. *Earthquake Spectra*, S1, 191-220.

Estêvão J, Ferreira M, Morales-Esteban A, Martı´nez-A´ lvarez F, Fazendeiro Sa´ L, Requena-Garcı´a-Cruz MV (2018). Earthquake resilient schools in Algarve (Portugal) and Huelva (Spain). *16th European Conference on Earthquake Engineering,* Thessaloniki, Greece, 1–11.

Eurocode 6 (2005). Design of Masonry Structures - Part 1-1: General Rules for Buildings-Rules for Reinforced and Unreinforced Masonry. European Committee for Standardization, Brussels.

Eurocode-8 (2005) Design of structures for earthquake resistance. Part 3: Assessment and retrofitting of buildings. European Committee for Standardization, Brussels.

Irfanoglu A (2009). Performance of template school buildings during earthquakes in Turkey and Peru. *Journal of Performance of Construction Facilities*, 23, 5–14.

Katsuichiro G, Kiyota T, Pokhrel RM, Chiaro G, Katagiri T, Sharma K, Wilkinson S (2015). The 2015 Gorkha Nepal Earthquake: insights from earthquake damage survey. *Frontiers in Built Environment*, 1(8), 1-15.

KTP-9-78 (1978). Albanian Masonry Design Code. Tirana, Albania.

KTP-N2-89 (1989). Albanian Seismic Design Code. Tirana, Albania.

Lagomarsino S, Penna A, Galasco A, Cattari S (2013). TREMURI program: an equivalent frame model for the nonlinear seismic analysis of masonry buildings. *Engineering Structures,* 56, 1787-1799.

Lourenco P, Mendes N, Marques R (2009). Earthquake design and assessment of masonry structures: review and applications. *In book: Trends in Civil and Structural Engineering Computing, Chapter: 4.* Publisher: Saxe-Coburg Publications Editors: B.H.V. Topping, L.F. Costa Neves, R.C. Barros.

Magenes G, Penna A (2011). Seismic design and assessment of masonry buildings in Europe: recent research and code development issues. *9th Australasian Masonry Conference*, 583–603.

Mendes N, Lourenço PB (2010). Seismic assessment of masonry "Gaiolerio" buildings in Lisbon. *Journal of Earthquake Engineering*, 14(1), 80-101.

Mwafy A, Elkholy S (2016). Performance assessment and prioritization of mitigation approaches for pre-seismic code structures. *Advances in Structural Engineering*, 20(6), 917-939.

Nato Sfp – 983054 (2007-2010). Harmonization of Seismic Hazard Maps for The Western Balkan Countries (Bshap).

OECD Report (2004). Keeping schools safe in earthquakes. *Proceedings of the ad hoc experts' group meeting on earthquake safety in schools*, Organisation for Economic Co-operation and Development, Paris, 9-11 February.

TSDC (2018). Turkish Seismic Design Code. Ankara, Turkey.

Yılmaz S, Tama YS, Bilgin H (2013). Seismic performance evaluation of unreinforced masonry school buildings in Turkey. *Journal of Vibration and Control,* 19(16), 2421-2433.