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Seismic performance assessment of a typified school building damaged during the 2019 Albanian earthquakes

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Abstract. This study presents the seismic performance evaluation of a typified masonry school building, Shkolla 9-Vjeçare "26 Nëntori", which was damaged by the recent earthquakes which hit Albanian territory on November 26, 2019. This building was constructed in 1985 by following the template school projects in Albanian construction practice. The current situation of the building was evaluated by considering the provisions of modern codes i.e. Eurocode 6, Eurocode 8 and Turkish building Code. Analytical model of the school building was developed using the experimental test results conducted on the brick units and mortar. Nonlinear static pushover analyses were executed to estimate the seismic capacity, the performance point, and the damage limit state levels. The performance based assessment rules were used for this objective. Deficiencies and weak points were identified by the detailed examination of the pushover curves. Results showed that selected school designed per pre-modern code is far from satisfying the desired criteria, suggesting that urgent response and necessary measures should be put into action.

1. Introduction

The school buildings should be seismic 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 the world have highlighted deficient seismic performance of school buildings [1, 2].

Throughout the history, earthquakes in Albanian territory, like in various earthquake-prone regions of our world, have damaged built environment causing several fatalities and economic loses [3-8]. In this context, structures' vulnerability is a crucial notion to concentrate on to decrease the consequences of devastating events. Usually, unreinforced masonry [URM] structures represent a poorer earthquake response compared to reinforced concrete (RC) structures because of low strength and stiffness of their elements. Therefore, new seismic guidelines comprise suggestions and commentaries aimed at reducing their earthquake vulnerability. However, a significant portion of the current masonry construction has been designed and constructed per older code requirements.

The main building typology in the Albanian building stock consist of URM buildings, RC framed systems and prefabricated concrete wall systems. The majority of current masonry buildings are built following the guidance of the Albanian technical codes and regulations. These codes were initially

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published and put into force as a legal document in 1963 and latest amendment was done in 1989 and still in law. Most of the existing URM buildings in the country, like in several European countries were constructed considering previous seismic guidelines when earthquake forces were not mandatory, or the design was to reduce the degree of seismic loads. Nonetheless, its conformity conditions were not as clear as those suggested by recent modern seismic codes like Eurocode 6 and Eurocode 8 from European practice. This caused the lack of seismic issues in building design procedures. Several construction companies have recently introduced European norms in their projects. However, design of structures must follow the Albanian technical codes and guidelines according to Albanian legislation in the field of construction [9-10]. Today, Eurocode norms in construction sector are national standards that are used voluntarily [11].

The URM buildings suffered the most by the November 26, 2019 Durrës Earthquake due to several reasons including the poor construction quality, old construction age, interventions, poor workmanship, the design code of the time, lack of maintenance and insufficient repair after former damaging earthquakes. The object of this study, Shkolla 9-Vjeçare Publike "26 Nentori" school 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 building, the presence of observable settlements on the ground and the crack situation in the structure were determined and damage relieves were prepared. The necessary information has been taken from the blueprints and on-site visits to the building.

This aim of this paper is to assess the earthquake performance of a typified low-rise URM school building, constructed following the guidance of pre-modern seismic codes of Albanian Construction practice. To reveal the properties of low-rise current masonry buildings, a damaged URM school building during November 26, 2019 Earthquake was chosen and modelled by using the TREMURI [12]. Structural characteristics such as component sizes, material kinds and loading conditions of the building were obtained from their architectural and structural projects and site inspections on studied building in several Albanian cities. Mechanical features were revealed from experimental tests and used for inelastic analysis. 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 [12].

2. Seismicity of the region

Albanian neighborhood is in a quite complicated seismo-tectonic area and susceptible to earthquakes. Faulting regions in East Albania are typically characterized by the impact of normal faulting. Into the Albanian orogeny are evidenced two transverse and three longitudinal active fault zones (Figure 1).



Figure 1. Active faults in Albania (From NATO SfP Project No. 983054 (BSHAP)).

The 2019 Durres earthquake affected zones are induced by Northwest-Southeast striking reverse faults. Blue lines represent the faults triggered for the period of middle Pleistocene-Holocene, the green lines triggered during Pliocene-Lower Pleistocene and the red lines to faults initiated during Pre-Pliocene age. Based on the tectonic structure of the earthquake-affected area and the fault plane solutions of the November 26, 2019 Durrës earthquake, it can be revealed that there is a correlation between fault plane explanations and the geological data on the field.

Albanian seismicity can be described by severe seismic micro activity $(1.0 < M \le 3.0)$, several minor earthquakes $(3.0 < M \le 5.0)$, few mid-sized earthquakes $(5.0 < M \le 7.0)$ and very rarely by powerful earthquakes (M > 7.0).

2.1. Seismic hazard maps of Albania

Based on the Albanian seismic map's zonation, it can be stated that the induced intensities from this earthquake under consideration, are in the boundaries stipulated by the Seismic Zonation Map (Figure 2).



Figure 2. Seismic zonation map of Albania.

2.2. The November 26, 2019 Earthquake and its consequences on Albanian Buildings

A strong earthquake hit the central western part of Albania on November 26, 2019. It was measured as Mw 6.4. Its epicenter was situated off-shore NW Durres, around 7-km North of the city and 30 km from the capital Tirana. Its focal depth was about 10 km [USGS, 2019]. According to the focal plane explanations given by numerous seismological organizations and studies, the main shock was produced by the launch of a NW-SE striking reverse fault. The aftershock sequence until 30 November included 100s of aftershocks, 22 with magnitude larger than M=4.0 and 4 with magnitude larger than M=5.0 (aftershocks by USGS until December 1, 2019).

Regarding the impact on the building stock, the main shock and the following aftershocks induced moderate to severe destruction to buildings in Durrës, Tirana and numerous dwellings of the wider neighborhood. The most earthquake-affected regions are found in the city of Durrës and the town of Thumanë at the central-western Albania. More specifically, Durrës city is located along the coastal part of the central-western Albania in a distance of 30 km West from the Tirana, while Thumanë in a distance of about 25 km NW from the capital city of Tirana. Damage was also observed in Laç town, Fushë-Krujë town, Kamëz as well as capital city, Tirana. Building damage was concentrated along NW-SE (Figure 3.). This direction overlaps along with the strike of the seismogenic faults as it is obtained from the fault plane solutions provided by several seismological institutes and observatories [INGV, 2019 and USGS, 2019].



Figure 3. Earthquake-affected area during the November 26, 2019 Durres Earthquake.

3. Current status of the school building and the load bearing system and its adequacy according to seismic guidelines

The Shkolla 9-Vjeçare "26 Nëntori" school and sport hall were built and located in the city of Tirana. General views of the hospital buildings are given in Figure 4.



Figure 4. Front view of the main building under investigation.

The primary dimensions of the load bearing system of the school building were determined with insitu site investigations and compared with the blueprints of the school designs obtained from national archive. Analyses were carried out according to the prepared load bearing system dimensions. Since the buildings under investigation are old ones, limited number of architectural drawings or details of the initial conditions of the building were reached. 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 in computer environment. This building was designed as three stories and did not experience a serious structural

intervention since its design. From the site survey and inspections, the floor plans of the blocks were generated and used for detailed seismic analysis (Figure 5).



To determine the type of wall material used in the masonry structures and the way the walls are built in the corner area, the covering material was removed and examined. Mortar and solid silicate bricks are used for wall construction.



Figure 6. Damage on pier element on the corner and typical shear crack on the load-bearing wall.

During the inspection inside the buildings, a considerable damage was observed on the main building walls. We observed a 450 inclined shear crack on a number of walls on the ground floor (Figure 6.). These structural cracks were formed on the 45 cm thick wall, which was subsequently

removed in the upper floors to make additional space, occurred during the Durres earthquake of 26 November 2019.

4. Pushover analyses and damage assessment

The nonlinear static pushover analysis consists of the use of gravity loads and a pre-defined horizontal load pattern. Gravity loading is in place throughout lateral push. Lateral loads are monotonically applied in a step-by-step fashion. The lateral loads are proportional to the product of mass and the first mode-shape amplitude at every story levels. In pushover analysis, the behavior of buildings is measured using a pushover (capacity) curve that symbolizes the relationship between the base shear force and roof displacement. This approach in not only very practical but also gives easy visual graphic of the condition of the building.

4.1. Determination of the material characteristics of the school building

For the analytical modelling of the school building, there are two major issues to be thought: accurate description of the computer model and nonlinear characteristics of materials. URM is a compound building material which comprises of masonry units and mortar as bonding element. Brick and stone are the traditional elements of masonry components, in this case are brick parts. Subjected to the vertical and horizontal loads, load bearing of masonry is considered as the assemblage of the masonry components and mortar is affected by several factors including water absorption, durability, compressive, shear and flexural strengths, and thermal expansion of both materials.

Building block is comprised of two main parts, namely load-bearing blocks, and rigid diaphragms. The blocks are rigid with cavities and the diagrams are typically constructed by continuous RC slabs. For the construction of the school building, calcium silicate solid bricks and cement mortar was used.

For the mathematical modelling and the seismic analyses of the school building, material properties obtained from site investigations and experimental test were used. To accurately characterize the strength and structural integrity of the building, inherent characteristics of the material were obtained from the laboratory tests with destructive methods. Samples were taken from the building for material testing. Then, tests were executed on samples to define the compressive strength of the solid bricks and the obtained results are used for seismic analyses.

Building block is comprised of two main parts, namely load-bearing blocks, and rigid diaphragms. The representation of masonry wall blocks in current buildings is a rather complicated procedure. In this paper, mechanical properties were taken by guidelines of the building regulations, blueprints of the original design and the experimental tests on samples from the building. In the case when experimental data is not reached, numerous equations are recommended by various codes and guidelines to evaluate the compressive strength of the masonry walls. In this paper, Eurocode 6 [15] criteria are followed:

	-
Building Type	URM
Compressive strength f_k (MPa)	4.0
Mortar strength f_m (MPa)	5.00
Fracture energy (Tensile) G_t (N/mm)	0.1
Shear strength f_t (N/mm ²) as per EC 6	0.29
E (MPa) as per EC 6	4000
G (MPa) as per EC 6	1400
Poisson ratio v	0.2

Table 1. Masonry wall data used as Input for analytical modelling.

Following the Eurocode 6 guidelines [CEN, 2005] together with the appropriate material properties gained from laboratory tests are calculated the necessary input data for mathematical modeling of the building [Table.1]

4.2. Mathematical modeling

Modelling masonry buildings is not an easy job due to the inelastic response of masonry and lack of experimental data concerning the inherent characteristics of masonry structural components. In-situ investigations were performed to obtain the necessary information about the geometry and structural aspects of the model. From the national archives of Albania, the original designs were obtained and checked comparing to the actual status of the current buildings. To define the physical and mechanical characteristics of the materials, laboratory tests were performed on samples taken from the building. Masonry behavior under different loadings may be very complex. To model the behavior of masonry, numerous theories and analytical models are suggested in literature [Lourenço, 2010]. Each of these techniques necessitates the implementation of unique constitutive simulations. Due to the complexity of the case study building, some assumptions on the material characteristics and the need of having high performance computers to process the analyses, macro-modelling approach was considered in this study. Nonlinear static analyses (pushover) have been performed by 3Muri software package that is a multi-purpose FE program committed for the linear and nonlinear analyses of masonry buildings. "26 Nentori" School building block is analytically modelled, and seismic load bearing capacities are estimated by using pushover analysis in TREMURI software (Figure. 7).



Figure 7. 3D view of the school building mathematical models (3MURI software).

During the modelling, the load bearing components are considered the masonry walls, while the floors are considered as rigid elements, which distribute the lateral loading effects between the connected walls.

Damage limit states are mathematical characterization of performance levels by a suitable damage value characterizing the seismic performance with proper damage levels. Generally, displacements and deformation quantities are used to characterize the structural response while defining the damage limit states. In this study, they were defined according to Eurocode 8 [17]. Capacity assessment of the

school building is done according to Eurocode 8. Limited Damage (LD), Significant Damage (SD) and Near Collapse (NC) limit states are considered for the performance assessment.

4.3. Seismic analyses of the school building

The building is pushed by 24 different loading cases and the pushover curves are plotted for the most critical loading pattern (Figure 8 and 10).



Figure 8. Pushover curve for x- direction.

Damage levels are identified for each damage states specified in Eurocode under pushover loading in x- direction (Figure 9.) and pushover loading in y- direction (Figure 11).



a) Limited Damage (LD) state.



b) Significiant Damage (SD) state.



- c) No collapse (NC) damage state.
- d) Legend (description of the damage type).

Figure 9. Damage limit state levels according to EC 8 under pushover x- direction.



Figure 10. Pushover curve for y- direction.



a) Limited Damage (LD) state.



b) Significiant Damage (SD) state.



c) No collapse (NC) damage state.
 d) Legend (description of the damage type)
 Figure 11. Damage limit state levels according to EC 8 under pushover y- direction.

Table 2-3 defines the peak ground acceleration (PGA) limits that can be sustained by building for the damage limit states according to EC 8.

Limit state	PGA [m/s2]	α	
NC	1,759	2,513	
SD	1,401	2,803	
DL	0,686	2,286	

Table 2. PGA limit states in x- direction $(1 \text{ m/s}^2 = 0.101972 \text{ g})$.

Tabl	le 3.	PGA	limit state	es in y-	direction	(1 m/s²	f = 0.1	01972	g).
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Limit state	PGA [m/s2]	α	
NC	1,272	1,817	
SD	1,020	2,041	
DL	0,494	1,646	

Due to the low material quality and consequently the insufficient amount of stiffness, school building's seismic capacities in both directions are relatively small compared to the similar buildings for this type. Pushover analyses results and the damage patterns observed during the damage inspection confirms the induced damage during the November 26, 2019 earthquake for the school building.

5. Conclusions

The school structure used as 26 Nentori school block was examined on site after November 26, 2019 Earthquakes. The masonry structures, which were built as pre-2000 schools, were originally designed as 3- floors. The current situation of the buildings was evaluated by considering the provisions of earthquake resistant design rules and Eurocode regulation for masonry structures under seismic loads. The seismic capacity of the school building was assessed with TREMURI software, which uses a structural model based on macro-modelling method for the load bearing walls.

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 180 kPa. 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. Pushover analyses were conducted, and the damaged regions with the corresponding reasons are marked on the 3-D analytical model. Seismic capacity of the school on both transverse directions are determined according to EC-8.

During the Durres earthquake of 6.4 magnitude on November 2019, slight-moderate damage was observed. However, this earthquake is smaller than design earthquake and it is classified as a medium intensity earthquake. 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. Considering the actual status of these school buildings, urgent need needs to be put into action.

Conflict of interest

No conflict of interest was declared by the authors.

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