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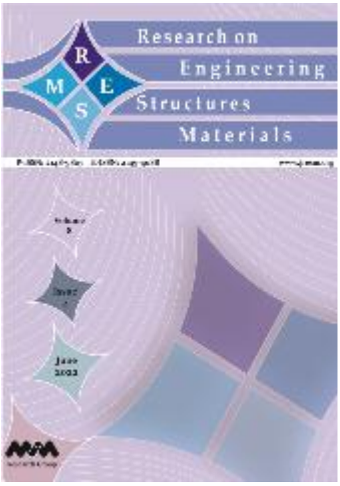

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Online Publication Date: 30 July 2022

URL: http://www.jresm.org/archive/resm2022.440ea0531.html
DOI: http://dx.doi.org/10.17515/resm2022.440ea0531

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article
Bidaj A, Bilgin H, Hysenlliu M, Premti I, Ormeni R. Performance of URM structures under earthquake shakings: Validation using a template building structure by the 2019 Albanian earthquakes. *Res. Eng. Struct. Mater.*, 2022; 8(4): 811-834.

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Research Article

Performance of URM structures under earthquake shakings: Validation using a template building structure by the 2019 Albanian earthquakes

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Article Info

Article history:

Received 31 May 2022
Revised 13 Jul 2022
Accepted 22 Jul 2022

Keywords:

Unreinforced masonry; Macro-modeling; seismic assessment; pushover analysis

Abstract

A prolonged earthquake series hit the regions of Albania on September 21 and November 26, 2019, causing loos of live and extensive damage to the civilian structures. The main aim of this study is to investigate the structural and earthquake response of a template design, commonly encountered in the region, which was seriously damaged by the 2019 Durres/Albania earthquake. A 3D mathematical model of the entire structure was prepared, implementing macro-modeling approach to simulate its response under seismic shakings. Inherent material properties of its constituents were determined experimentally and adopted for the analytical model. Initially, an eigenvalue analysis was deployed to identify the dominant vibrations modes of the structure. Then, pushover analyses were performed to assess the earthquake response of the template designed structure, and possible failure mechanisms were examined. Finally, the obtained results from the software were compared with the real-life damage experienced by the building. In the end, it was observed that the analytical model proved to accurately estimate the earthquake behavior exhibited by the structure during the seismic shaking.

1. Introduction

Recent seismic events have shown that URM buildings are prone to damage induced by earthquake shakings. The earthquake performance assessment of these structures becomes a demanding task because of various understandable reasons including the complicated geometry and structural arrangements of connections, flexibility of the diagrams, and its mechanical response [1-4]. In literature, several methods are proposed for the structural evaluation of existing URM buildings having different degrees of complexities [5]. With improvement of computational tools, analytical modeling strategies started to be used frequently for the estimation of the masonry response under different loading cases [6]. On the other hand, several uncertainties arise for the development of a structural model due to the inherent material characteristics, complex geometry arrangements, and the lack of available experimental data. Accordingly, mathematical models need to be validated to confirm their ability to realistically capture structural behavior of URM buildings. One way to accomplish this task is the comparison of calculated modal parameters estimated from the dynamic identification tests following a process of model updating until the mode shapes and frequencies match with the experimental test results. Another way can be used when the structure under consideration experienced

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DOI: http://dx.doi.org/10.17515/resm2022.440ea0531

considerable damage induced by the seismic shakings, by comparing the mathematical model with the observed damage pattern on the real building.

This study aims at evaluating the earthquake response of a commonly used template designed buildings, an URM structure located in several cities of Albania. This building typology experienced extensive damage due to November 26, 2019 Durres/Albania earthquake sequences and it was decided to demolish afterwards since the upgrading intervention was not found to be economically feasible. Firstly, the authors conducted several site visits to the earthquake-stricken area to monitor and investigate the reasons of the damages. Then, the inspections and several experimental tests performed on the selected buildings provided documentation regarding the construction details of the selected building and used for the characterization of the material properties. The importance of this study lies in the use of such detailed dedicated works by the authors, for the seismic performance of a real building. Based on the post-earthquake survey data integrated with the information about the geometry, structural configurations, and past interventions, authors are enabled to develop an accurate mathematical model of the structure, which was believed that its response was validated according to the obtained results. On the other hand, using the availability of the ground motion data allowed to check the validity of the mathematical model by comparing the real damage and the estimated damage for the seismic input which the building was subjected to.

1.1. Seismic Hazard Assessment of Albania

Albania has a long history of code-adjusted seismic design, as shown in Table 1. The first seismic regulations, accompanied by the first Map of Albania's Seismic Zone, were adopted in 1952. The 1963 revision increased the requirements of seismic design. The first code of seismic design considered the seismic charge based on static method, regardless of the dynamic properties of the structures. With the introduction of the 1963 standard, the seismic charge is defined considering its dynamic internal effect on structures. In 1978, another amendment was issued with the name of KTP 2-78 that did not bring significant improvements. In 1989, the new seismic design code, KTP-N.2-89 was released and is currently the official code in Albania. It is essential to mention that despite the existence of the seismic design code, many buildings are not in accordance with the code and many buildings have been subjected to illegal interventions in their holding systems.

Table 1. Seismic design codes of Albania and corresponding enforcement period

Seismic Design Code of Albania	Time Period
KTP 52	1952 - 1963
KTP 63	1963 - 1972
KTP 72	1972 - 1980
KTP 2-78	1978 - 1989
KTP –N2-89	1989 - Present

In the Albanian Seismic Zonation Map the hazard is categorized in three areas:

- Areas with main intensity VIII (for low soil conditions, areas with expected intensity IX are expected such as in Vlore, Lushnje, Durres, Korce, Pogradec, Shkoder),
- Areas with main intensity VII,
- Areas with main intensity VI,

The first category comprises the greatest part of Albanian territory 57.8 %. The lowest intensity of VI is mainly in the northern part of Albania 1.3 % only (Fig 1).

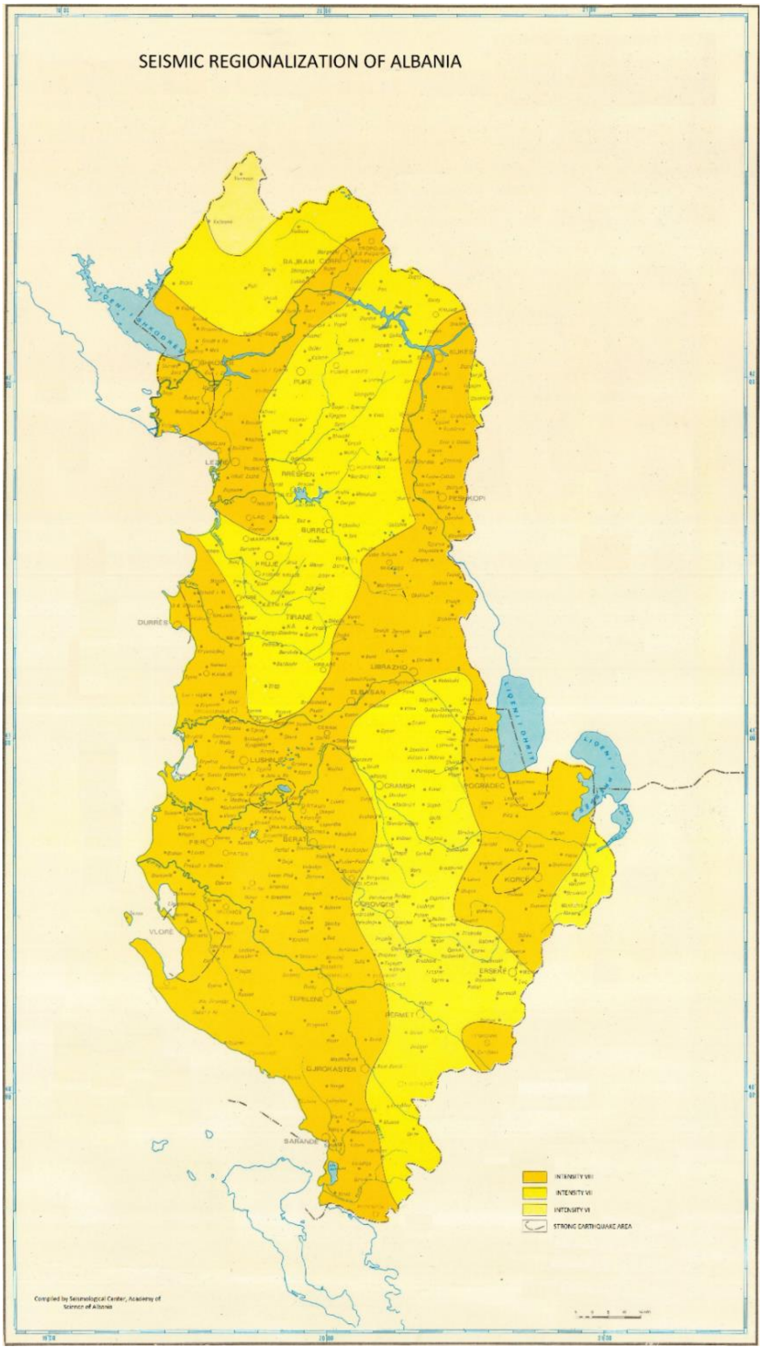


Fig. 1 Albanian Seismic Zonation Map [7]

The November 26, 2019 earthquake Mw6.4 was generated with the activation of reverse faulting of Frakull-Rodon Cape fault zone in western Albania [13]. Due to many complex tectonic fault lines (Fig 2), Albania is currently lying on an active movement with a potential of producing Mw = 6.5 ground shakings [8]. A complete list of previous important earthquakes is given in Table 2.

Table 2. Earthquakes in Albania After [7]

No.	Year	Place	Magnitude/Intensity
1	1905	Shkodra	M_s = 6.6
2	1911	Pogradec	M_s = 6.7
3	1919	Leskovik	M_s = 6.1
4	1920	Tepelene	M_s = 6.4
5	1920	Elbasan	M_s = 5.6
6	1921	Peshkopia	I_o= VIII-IX
7	1926	Durres	M_s = 5.8
8	1930	Llogara	M_s = 5.8
9	1935	Librazhdt	M_s = 5.7
10	1942	Peshkopi	M_s = 6.0
11	1948	Shkoder	M_s = 5.5
12	1959	Lushnje	M_s = 6.2
13	1960	Korce	M_s = 6.4
14	1962	Fier	M_s = 6.0
15	1967	Diber	M_s = 6.6
16	1969	Tepelene,Fier	I_o= VII
17	1979	Mali i Zi	M_s = 6.9
18	1982	Fier, Berat	M_s = 5.7
19	2019	Durres	M_s = 6.4

In the first probabilistic spectral hazard maps for Albania ten seismic source zones were used to define the seismicity, and 5% damped spectral acceleration values at 0.2, 0.5, 1.0, and 2 seconds for a 10 % chance of non-exceedence in 50 years [9].

Table 3. Peak ground and spectral accelerations for cities of Albania [7]

City	Lat- N	Lon-W	S_a (0.2)	S_a (0.5)	S_a (1.0)	S_a (2.0)	PGA
Tirana	41.33	19.83	77	58	28	9.6	32
Durres	41.34	19.44	86	66	31	10.3	35
Elbasan	41.12	20.09	90	66	30	10.1	38
Shkodra	42.07	19.52	75	57	28	9.3	30
Vlora	40.47	19.48	88	69	33	11.0	36
Fier	40.73	19.57	86	68	32	10.8	35
Korca	40.62	20.79	99	75	34	11.0	41
Kukes	42.08	20.43	81	58	26	8.6	34
Burrel	41.63	20.02	48	40	20	7.6	18

A new probabilistic seismic hazard assessment of Albania observed that the updated seismic hazard map (Fig 4) yields higher design accelerations that the values introduced in the current regulation [10]. For the 475-year return period, ground motion across Albania represented by PGA is in the range 0.20 – 0.24 g almost over all the territory, up to 0.30 – 0. 38 g in NW and SW part of the country [10]. But the reality is that for 33 years it's officially approved the 1989 code. Recently, these probabilistic seismic hazard maps produced by different authors has gained much consensus among the community of seismologists. But from the limited seismological, geological, and geophysical data, the problems with PSHA, and the increasing exposures, it is necessary to adopt the advanced approaches for seismic hazard assessment, such as a scenario-based neo-deterministic (NDSHA) that utilize seismological, geological, and geophysical data directly and implement them as unified SHA tool at international scale [11]. There are also serious efforts to adopt Eurocode 8 [EN 1998-1, 2005, "Eurocode 8] as Albania's official code of seismic design. Currently significant part our country population is concentrated in two cities, about 34% of the Albanian Population lives in Tirana-Durres area. These cities with hundreds of thousands of buildings and millions of people at stake should receive at a very minimum the same consideration as critical facilities [12]. The last generation of standards (codes) for earthquake resistant design and construction - the common European standard EN1998-1 (Eurocode 8) - has been endorsed in Albania after the earthquake of November 26, 2019. As a conclusion a new seismic hazard maps needs to calculate. The assessment of seismic hazard by the NDSHA method or combined to PSHA, is closer to reality [11].

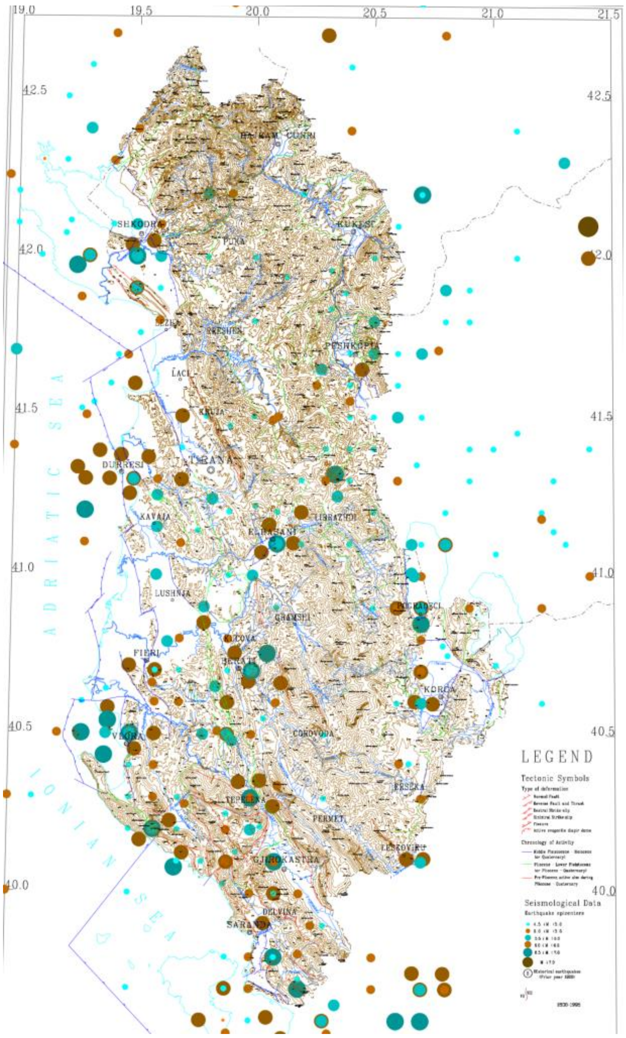


Fig 2 Albanian Seismotectonic map [7]

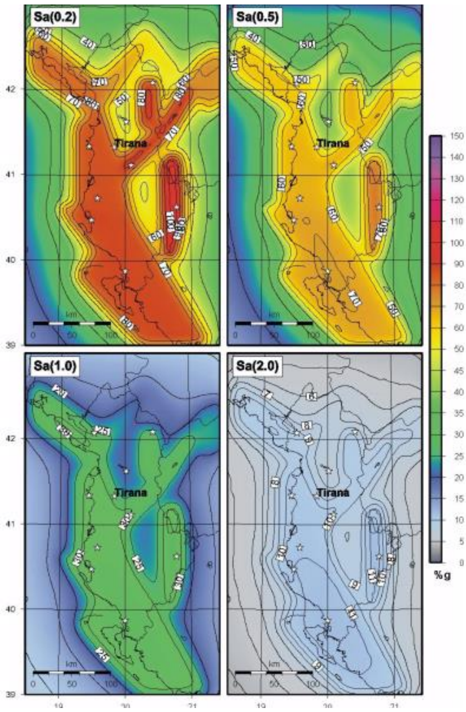


Fig. 3 Seismic hazard on rock for different ground acceleration [7]

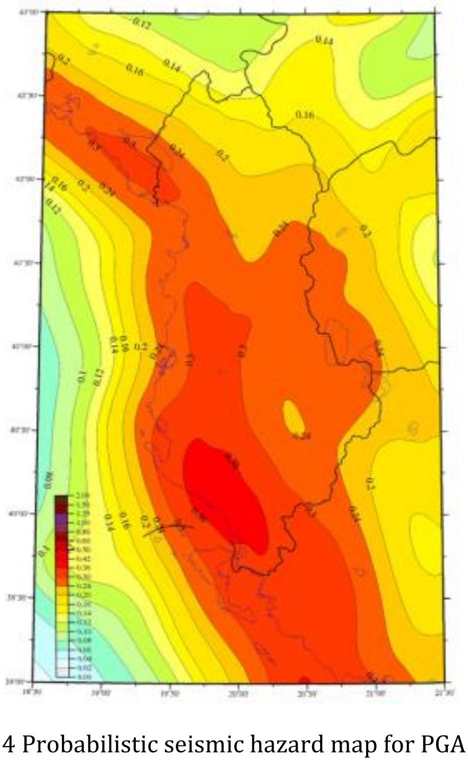


Fig. 4 Probabilistic seismic hazard map for PGA [10]

1.2 The November 26, 2019 Earthquake

The M_w = 6.4 magnitude earthquake that occurred on 26 November 2019 at 03:56 local time struck western Albania with a focal depth about 38 km and caused severe damage to many public and residential buildings in Durres, Tirana, Lezha, Shkodër and Berat districts [13]. There are several factors that determined just how destructive this earthquake was: location, magnitude, depth, distance from epicenter, local geological conditions, secondary effects and architecture. The depth of Durres earthquake of 26 November 2019 determined as 38 km is less damaging than an earthquake with 8 km because their energy dissipates before it reaches the surface. The depth generated by earthquakes represents an interest for seismotectonic studies especially in seismic hazard assessement [14]. It was recorded by Albanian Seismological Network, at seven stations [15]. Figures 5a-b show the North-South and East-West components of ground motions measured by the accelerometer station in Tirana, Albania's largest city. This accelerometer station is located at a distance of 34 km from the epicenter. It is located on ground Type C sites according to EC 8 with average shear wave velocities in the upper 30 m V_{s30} = 312 m/s [16].

Based on the earthquake time histories, the horizontal PGA recorded in Tirana was around 0.10 g, while in Durres it was around 0.20 g. However, the accelerometer station in Durrës was only able to record the earthquake for the first 15 seconds, due to a power outage caused by the earthquake (Fig 6). To make a clear interpretation of the earthquake impacts, Figures 6 shows the response spectra from recorded ground motions versus elastic response spectrum functions derived as per KTP-N.2-89 (Albanian seismic design code) for soils II and III, represents the ground types at the locations of the stations in Tirana and Durres cities.

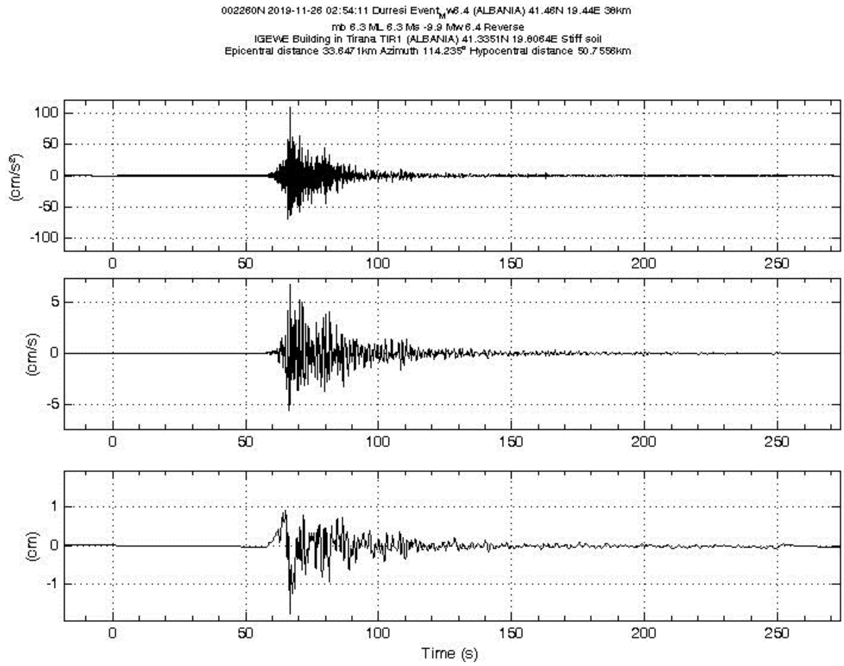
Figure 6 clearly shows that spectral ordinates recorded in Tirana station reaches up to two times more than the spectrum of the seismic code provisions at spectral periods 0.2 to 0.7 s. Buildings having a period in that range are expected to be experienced damages. On the other hand, the recorded spectrum values in Durres were below the code enforcements except around 1 sec. However, this representation might not be realistic due to the missing data after 15 seconds.

2. Description of the Studied Building

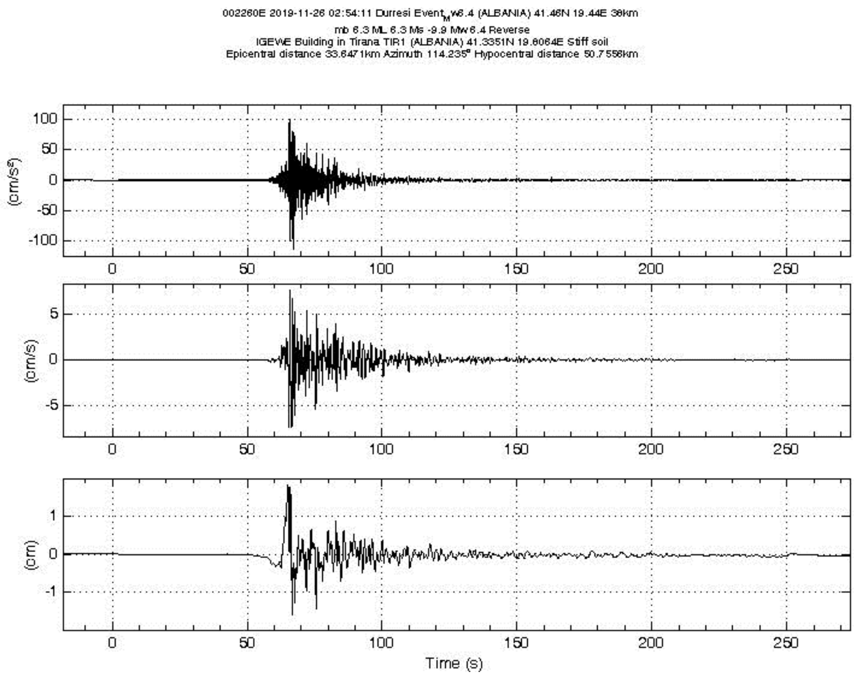
Built in 1970s, this building (Fig 7) is located in Tirana near "Rruga e Kavajes" and was constructed using red clay bricks as one of the most used template design unreinforced masonry (URM) building in Albania [17]. The building had five levels above the ground with the given planimetry (Fig 7-8). It has a regular story height of 2.80 m and an attic floor about 1 m, resulting in a total height above the ground of 15.00 m in corresponding of the main façade. There is no irregularity along the height of the building.

The structure of the studied template design consists of load-bearing walls that were continuous along the height of the building. The prevalent type of masonry is brick masonry, whereas the rare presence of stone masonry is observed in some pillars around staircase. The thickness of the load bearing walls is 38 cm from bottom to top of the building, as shown in Fig 8. Foundations are made of the stone masonry till the planking level of the basement. The floor slabs are lightweight precast slabs with a thickness of 15 cm each. The staircase is made of reinforced concrete and is supported by masonry load-bearing walls on three sides.

This building was lightly damaged by the September 21, 2019 seismic events that struck the regions of Albina. Cracks were mostly on non-load bearing elements and there was no strengthening intervention performed after the event.



November 26, 2019 Earthquake N-S component



November 26, 2019 Earthquake E-W component

Fig. 5 Ground motions recorded in Tirana during the November 26, 2019 earthquake (www.geo.edu.al/newwe b/?fq=bota&gj=gj2&kid=20)

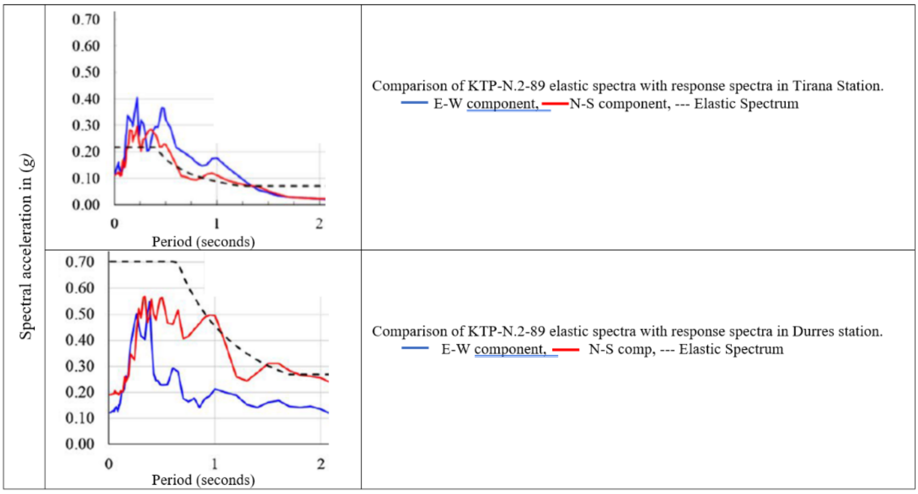


Fig. 6 KTP-N.2-89 response spectra of response spectra

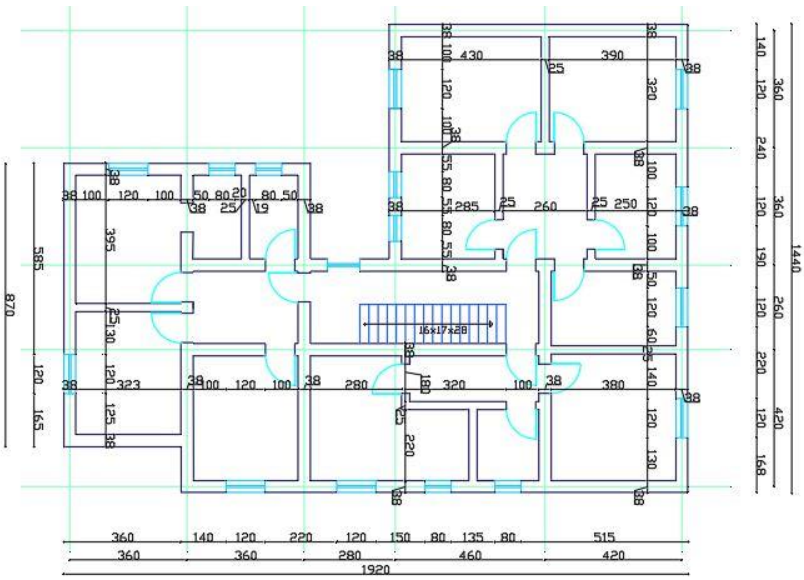


Fig 7. Plan view of the studied building

3. 2019 Earthquakes and Induced Damage

The 2019 Albania seismic sequence started on September 21, 2019, with moderate shakings (Mw 5.6) generated from a shallow focal depth by causing a widespread damage to the built environment at the outskirts of Durres city [14]. This first event had relatively slight effects without causing any casualties. Most of the damage was concentrated on non-structural elements of the RC and URM buildings structures [18-19]. Second severe shaking with Mw 6.4 struck the wider regions of Albania on November 26, 2019 (Fig 9). Its focal depth was about 20 km [20] causing an extensive damage with 51 fatalities and about 3000 injured [16]. The tremor was felt strongly in Tirana where the significant duration of the earthquake strong motion was estimated as 24 seconds. The most important damage was observed on masonry structures built mostly before 1990s.

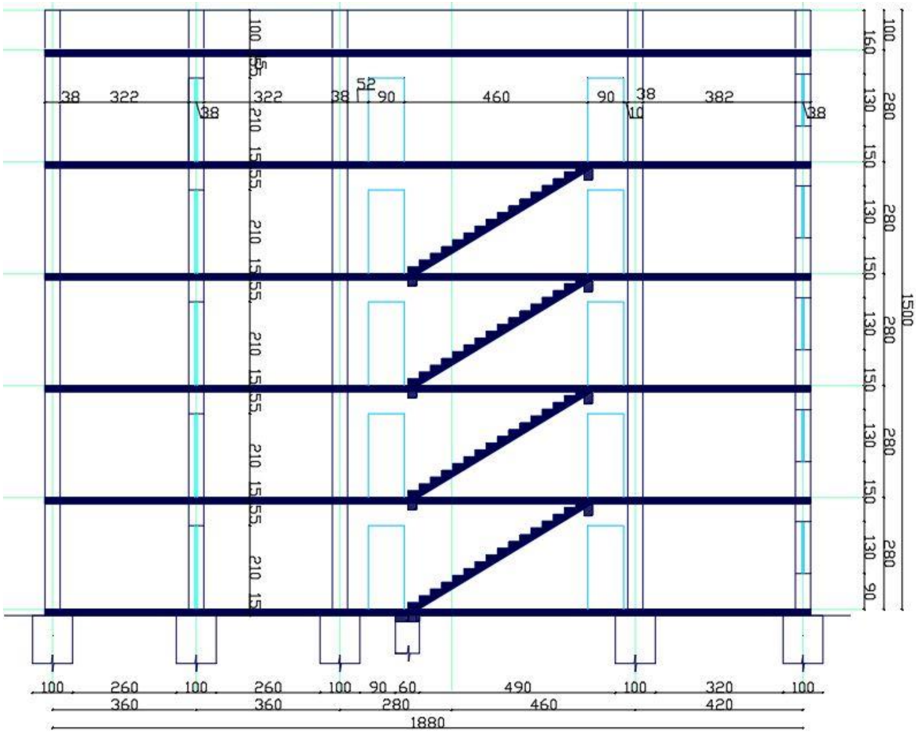


Fig. 8 Elevation view of the studied building

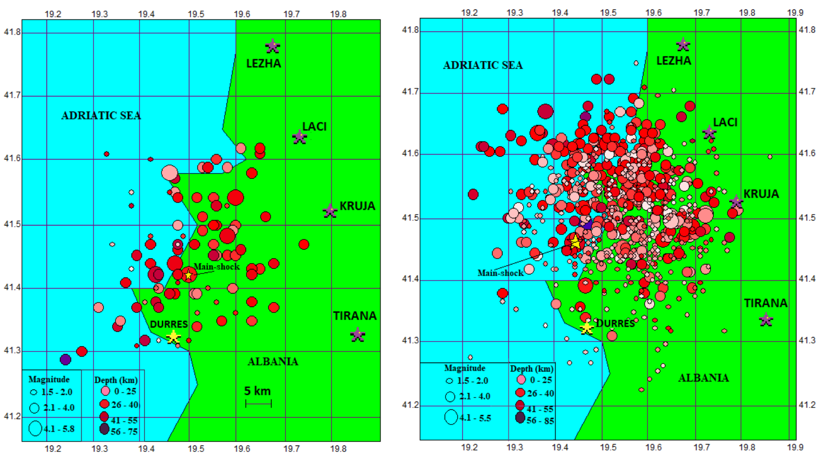


Fig. 9 Epicenters of main- and aftershock shakings of September 21, 2019 (right) and November 26, 2019 (left) Durres/Albania earthquakes [21]

The closeness of the main fault to the cities of Tirana and Durrës caused severe damage or partial collapse of many buildings, resulting in loss of life and extensive damage to both newly designed and old buildings. Damage patterns commonly encountered in masonry building typologies are shown in Figure 10-12.

(a) (b)

Fig 10. Heavy shear cracks on load bearing walls of the two multi-story masonry buildings

As shown in Figure 10, the load bearing walls were affected by serious cracks at both the raised-up ground and first floors. Most of the damaged buildings presented shear cracks which are diagonal developed along the entire thickness of the walls in both spandrels and piers (Fig 11a-12). Flexural cracks were also observed in several buildings. Moreover, out-of-plane mechanisms were very common both in URM and RC buildings resulting in partial or total collapse of masonry walls (Fig 11b). One of the commonly encountered highlights after the November 26, 2019 earthquake was the out-of-plane collapse of masonry walls (Fig 11b). In some cases, masonry walls collapsed without any vertical load other than their own weight. The most important reason for the out-of-plane collapse of URM walls was the lack of sufficient fastening of the wall with the diaphragm.

(a) (b)

Fig. 11 (a) Extensive shear crack on load bearing wall and seperation of two orthagonal masonry walls, (b) Heavily damaged partiton wall in an URM building

Diagonal shear cracks were observed in several URM walls of residential buildings. Many masonry constructions had diagonal cracks in the infill panels and in the URM piers between the door/window openings (Figure 12). On-site examination of the mortar used on the part of the destroyed URM building has been carried out and the mortar can be easily crushed with naked fingers, indicating that the mortar has relatively low strength [22].

Figure 12 shows a typical diagonal "stair step" cracking of a solid brick wall; this is a sign that the wall has not been able to withstand shear stress from in-plane forces.

(a)

(b)

Fig. 12 (a) Heavily damaged load bearing wall (built by silicate bricks) and seperation of wall and slab edges, (b) Heavily damaged load bearing wall in an URM building built by red clay bricks

4. Material and Mathematical Model

A 3D finite element model (FEM) of the template design was prepared in 3Muri [23]. A macro-modeling approach was adopted to simulated response of masonry. Based on the blueprints and site surveys done on the template design building, numerical model of the building was developed for structural analyses.

There are various analysis procedures to assess the nonlinear response of structures in which the geometric and material nonlinearity are taken into consideration (Fig 13). Analytical modeling of URM structures has always been a demanding task due to the presence of connections as the main source of material weakness, nonlinearity and discontinuity. A suitable model must consider both the response of the mortar and brick units and the interaction between them.

Two types of structural response need be considered in a suitable model: (1) response of masonry units; and (2) the response of the combined material. In recent years, great research has been done on theoretical methods supported by experimental tests.

Analytical techniques can be reviewed at the following three levels of refinement for wall models [24]:

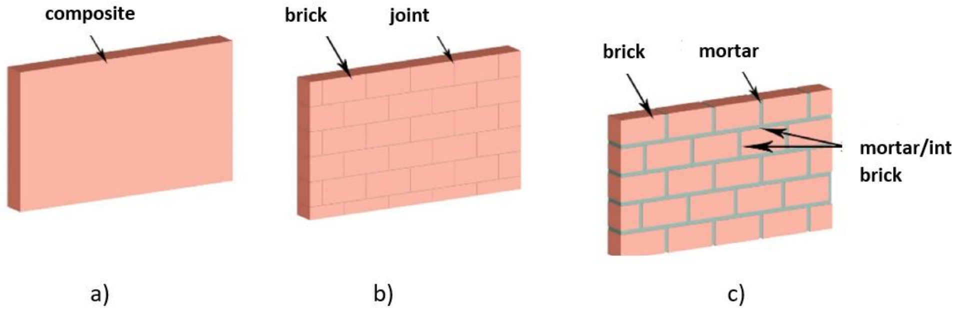


Fig. 13 Modelling techniques of masonry (a) Macro modelling, (b) simplified micro modelling, (c) micro modelling [20].

- Macro-modeling: In this approach, bricks, mortar and the brick–mortar interface are spread in a uniform band. Masonry is considered as a homogeneous, isotropic or anisotropic field. The influence of mortar joints as the main cause of weakness and nonlinearity cannot be taken into consideration using this approach. Although this method may be ideal for the analysis of large-scale masonry structures, it is not appropriate for the detailed analysis of small masonry panels, because of the difficulty of capturing all its expected failure modes.
- Simplified micro-modeling: In this approach, the structural components are considered as imaginary extended sections by uninterrupted members of the identical size as those of the original bricks merged with the actual joint thickness. The mortar joint is also modeled as a zero-thickness interface. This technique leads to a reduction in computational cost and gives a model applicable to a broader range of structures.
- Micro-modeling: In this method, bricks and mortar in the joints are described by continuum elements whereas the unit–mortar edge is characterized by discontinuum elements. While this approach yields more accurate results, the degree of refinement and the consequent analysis is computationally demanding, limiting its use to small-scale structures.

In this study, a simplified geometry of the building was adopted by following the macro-modeling technique since it is mostly used for analyzing large-scale structures and the effect of global factors. Such approach was followed by several researchers [25-26]. 3Muri [23] is utilized to execute the numerical analysis. The nonlinear macro-element method, suggested by Gambarotta and Lagomarsino (1996), allows with a partial number of DOF to describe the two main in-plane failure modes, shear-sliding, and bending-rocking mechanisms on the basis of mechanical characterizations. Deformations are assumed to be lumped on piers and spandrels, and they are connected with rigid nodes.

The macro-element applied for nonlinear static analyses is outlined with the kinematic model shown in Fig. 14. The 3D model of the studied masonry building, where it is apparent that masonry walls are modelled through a mesh of masonry piers and spandrels, is depicted in Fig 15.

In this software, piers are vertical load bearing elements that supports gravity loads and spandrels are straight components positioned between two vertically aligned openings. This a multi-purpose FE program dedicated for the linear and non-linear analysis of masonry buildings (Table 4).

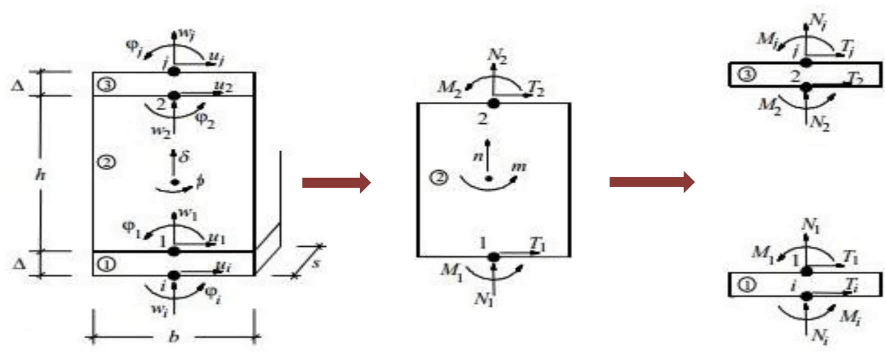


Fig. 14 Macro-element kinematic models in 3Muri

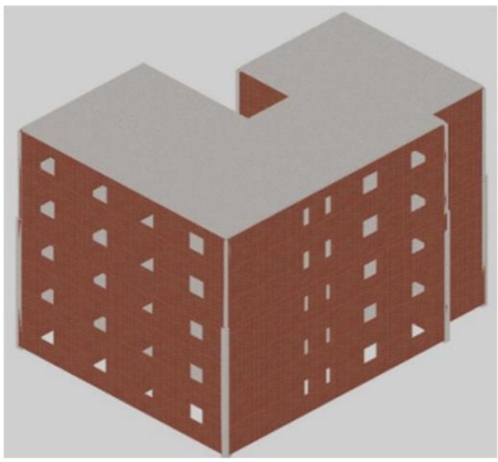


Fig. 15 Three-dimensional model of the building

Table 4. Brief outline of the strength criteria adopted by TREMURI

	Type of mechanism	Ultimate Strength
Spandrel elements	Shear strength	$V_u = f_{v0}ht$
	Rocking/Crushing	$M_u = \left[1 - \frac{H_p}{0.85dtf_{hu}}\right]\frac{dH_p}{2}$
Pier elements	Cracking (diagonal)	$V_{u,s} = lt\check{c} + \acute{\mu}N$
		$V_{u,dc\_1} = lt\frac{1.5\tau_0}{b}\left(1 + \frac{N}{1.5\tau_0 lt}\right)^{1/2}$
	Rocking/Crushing	$M_u = \frac{Nl}{0.425f_m}\left(1 - \frac{N}{lt}\right)$
	Bed joint sliding	$V_{u,bjs} = l'\check{c}t + \mu N$

where;

- *h:* height of the spandrel (transversal section),
- H_p: minimum value between the tensile strength of elements coupled to the spandrel
- criterion with: $\acute{\mu}$ and $\check{c}$ equivalent cohesion and friction parameters,

- τ_0 : masonry shear strength and
- b: reduction factor as a function of slenderness,
- *l'*: length of section,
- *t:* thickness
- f_m : masonry compressive strength,
- Mohr-Coulomb criterion with:
- *l'*: length of compressed section,
- μ : friction coefficient of mortar joint,
- c: cohesion of mortar joint.

Masonry is a conventional composite building material which consists of masonry units and bonding material. Depending on the composition, it is grouped as unreinforced masonry [URM], confined masonry and reinforced masonry. URM consists of masonry blocks connected with mortar. The dominant type in the Albanian building stock is of unreinforced masonry like in many other European countries [27].

To define the strength and structural integrity of the building, fundamental mechanical characteristics of the masonry material are evaluated based on the experimental tests for the studied building. It comprises of compressive tests on brick units and mortar samples, as well as shear tests on small masonry triplets [28-29]. For the determination of the mortar compressive strengths, mortar samples were extracted from the areas where the connection between brick units and mortar has failed. Based on to the several experimental test results, bricks, mortar and masonry wall unit features to be used in mathematical modelling are summarized in Table 5:

Brick tests results: f_{brick}=7.48 MPa, f_{bt} =1.71 MPa

Mortar test results: f_{mortar} =4.80 MPa, f_{mt} =1.10 MPa.

The earthquake performance level of structures can be determined using linear and nonlinear analysis techniques. The response of the structure under seismic loads can be obtained more realistically with nonlinear analysis. This method can be broken in two ways as the nonlinear static (pushover) analysis and nonlinear time-history analysis. In this study, pushover analyses are deployed to estimate the seismic capacity of the structure.

In literature, various methods have been developed for the seismic performance of masonry buildings [30-33]. The earthquake capacity assessment of the studied URM building in this paper is performed through the recommendations provided by Eurocode 8 [34]. Three limit states, namely Limited Damage (LD), Significant Damage (SD), and Near Collapse (NC) are defined as stated in this code.

The modal analysis was performed, and the obtained results were presented for twelve modes of vibrations. The results of the linear modal analyses were synthesized in Table 6 in terms of periods and modal mass participating ratios.

Then, nonlinear static analyses were carried out to assess the seismic performance. The building was pushed by two lateral load patterns (Fig 16) in both orthogonal directions; namely: first mode shape distribution based on the fundamental mode shape of the structure, and a uniform load distribution to all stories. These analyses were done for three more combination: without eccentricity of gravity load and with eccentricity of two different levels. 24 analyses were deployed for all load combinations, along x- and y- global axis of the mathematical model, corresponding to the transverse and longitudinal directions of the building (Fig. 17-18).

Table 5. Material (masonry wall) properties considered in mathematical model

Material Property	Masonry wall properties
Specific weight (kN/m^3)	19.6
Modulus of Elasticity (N/mm^2)	2420
Compressive fracture energy (N/mm^2)	3.87
Shear Modulus (N/mm^2)	605
Poisson's ratio (-)	0.20
Compressive strength (N/mm^2)	2.42
Shear strength (N/mm^2)	0.36
Initial Shear strength (N/mm^2)	0.20
Tensile strength (N/mm^2)	0.12
Shear drift	0.004
Bending drift	0.008
Flexural strength with a plane of failure parallel to the bed joint (N/mm^2)	0.26
Flexural strength with a plane of failure perpendicular to the bed joint (N/mm^2)	0.19

Table 6. Modal analysis parameters

Mode	T [s]	M_x [%]	M_y [%]	M_z [%]
1	0,24719	0,03	76,97	0,00
2	0,21997	77,01	0,10	0,02
3	0,18609	1,93	0,95	0,06
4	0,09254	0,02	14,67	0,00
5	0,08298	13,94	0,04	0,85
6	0,07251	0,03	0,40	6,44
7	0,06949	0,56	0,02	19,71
8	0,06151	0,02	0,00	1,50
9	0,05878	0,02	0,00	35,10
10	0,05489	0,00	0,14	0,55
11	0,05313	0,02	3,25	1,24
12	0,05168	0,07	0,11	3,90

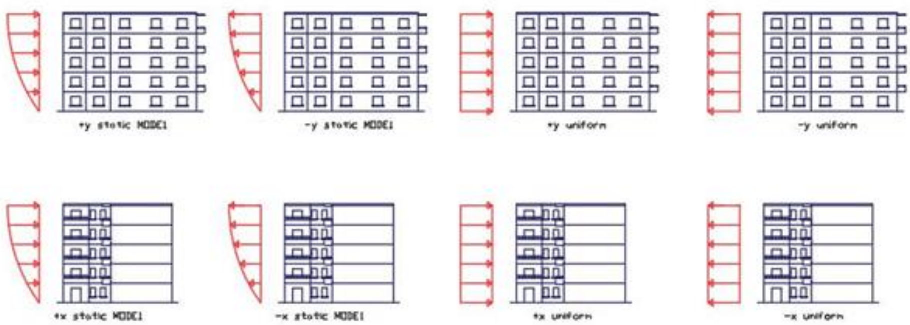


Fig. 16 Load patterns and different cases of pushover analysis

Control points located at the top of the building were adopted as control nodes during the analyses.

The worst cases were chosen as representing the pushover curves for both x- and y-direction of buildings and bi-linearized (Fig. 19). The seismic performance of the building was evaluated considering capacity curves and failure mechanisms.

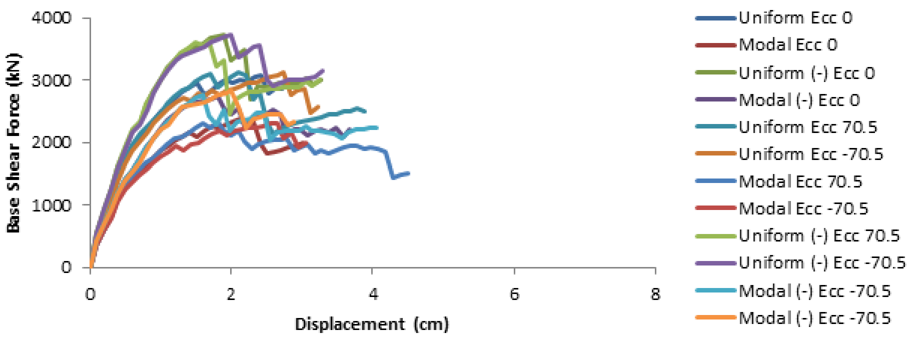


Fig. 17 Pushover analysis in x-direction

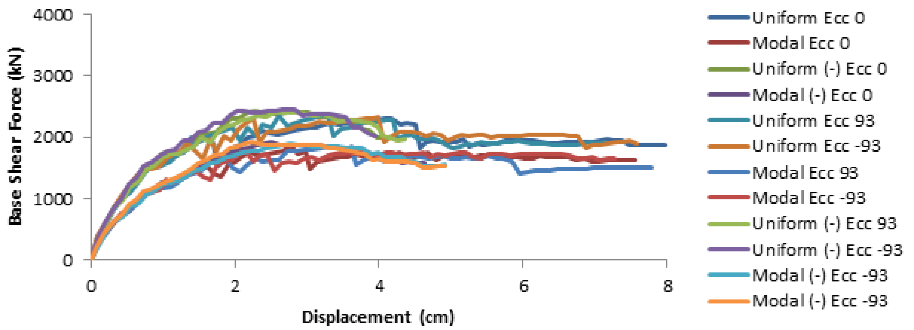


Fig. 18 Pushover analysis in y-direction

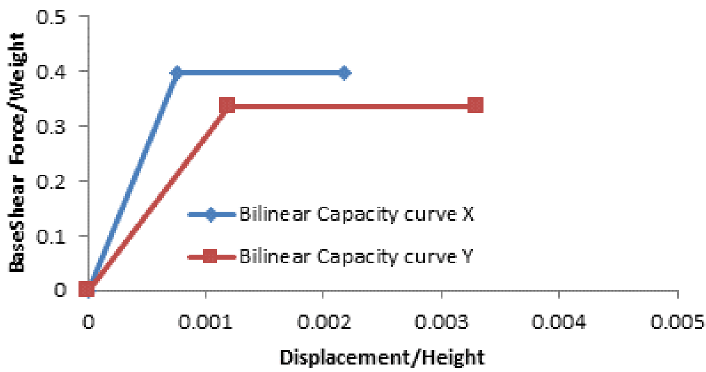


Fig. 19 Normalized bilinear capacity curves

In Figure 19, the maximum displacement attained were marked for both *x*- and *y*-directions. The building has a remarkable higher load bearing capacity in x- direction whereas the y- direction exhibits a more ductile response (Table 7).

Table 7. Response parameters for the studied URM building

Direction	Initial stiffness	Yield shear Force/Weight	Yield Disp./Height	Max Disp./Height	Ductility
x-	2386	0.413	0.00079	0.00181	2.30
y-	1334	0.333	0.00105	0.00303	2.89

5. Discussion of Analyses Results

The capacity curves estimated from the nonlinear static analyses in both orthogonal directions are presented in Figs 17-18. The load bearing capacity and the stiffness in x-direction is higher compared to y- direction of the building. These results could be expected since the intensity of the load bearing walls are dominant in this direction. Based on the capacity curves, a max load factor (base shear/seismic weight) of about 41% is observed in x- direction, while a max load bearing load bearing capacity of 0.33 is obtained in other orthogonal direction (Table 7).

With the objective to compare the damage observed induced by 2019 Albania earthquakes and estimated from numerical model, the damage evaluation was performed for the values of applied load comparable to the peak ground acceleration values recorded during the seismic events of September and November 2019. The seismic event of September 21 (Mw 5.6) was not considered since it did not cause a structural damage to the structure. It is essential to highlight that no damage accumulation because of the series of seismic events (Table 8) could be accounted for in the assumed mathematical approach.

Table 8 Recorded PGA values from the strongest shakings of 2019 Albania earthquakes

Date	Moment magnitude	Tirana station (g)	Durrës station (g)
September 21	5.1	0.03	0.10
September 21	5.6	0.18	0.12
November 26	5.4	0.02	0.04
November 26	6.4	0.12	≥0.20*

*: It is important to highlight that the Durrës station only recorded the event for the first 15 seconds due to an electricity cut triggered by the earthquake, thus the 0.20 g could be considered a lower bound value of the actual peak ground acceleration felt at the site.

In Figure 20, the damage state of the building from the last step of the pushover analysis is depicted. Bending damage and tension failure are dominant while a couple of walls and spandrels are damaged in shear.

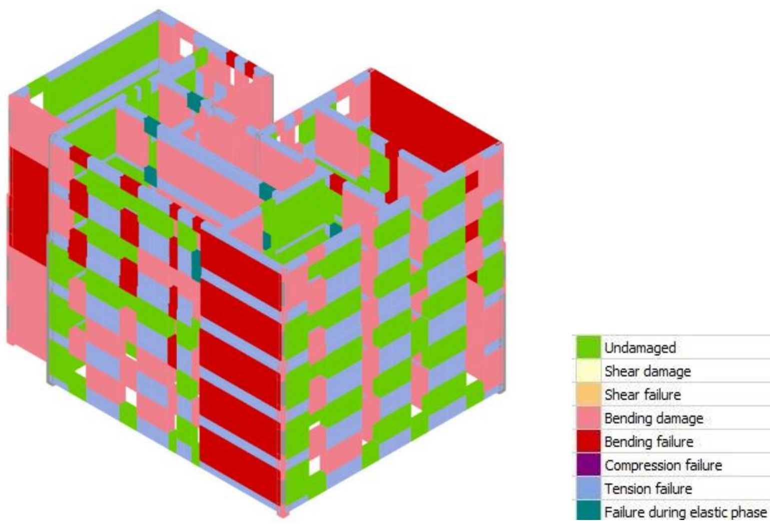


Fig. 20 Damage at maximum deformation capacity in 3D

Detailed damage distribution along the height of the walls of the studied building is shown in Figure 21. Building reached failure when perimeter walls reach their load bearing capacity in both orthogonal directions. Failure is reached when all the right part of the perimeter wall fails in bending and also in the wall in the back part on upper levels.

In pushover analyses, it is assumed that appropriate connections are achieved between the connected elements and floors to accomplish the building's global in-plane response. However, the 3Muri software does not take into account the out-of-plane loos of stability of the walls.

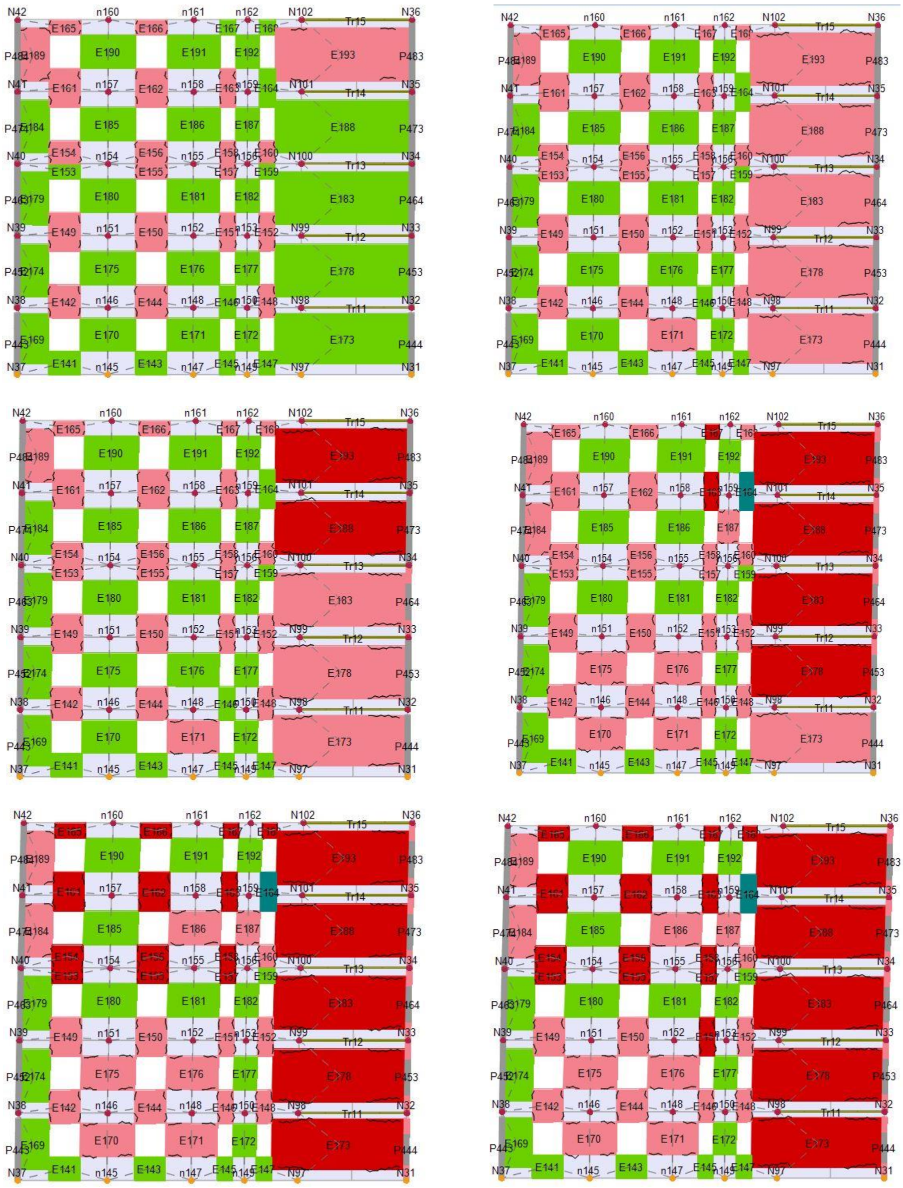


Fig. 21 Distribution of damage and the failure mechanism of perimeter walls from pushover analysis

For the November 26 earthquake sequences, a global in-plan damage mechanism was observed for the template design building. The findings of the numerical analysis (Fig 20-

21) were compared to the real-life damage (Figs 23-25). The damage observed for the studied building comprise of bending, tensile and shear cracks occurring in both internal and external walls, in agreement with the damage observed on-site. From the comparison of the failure mechanism estimated by the pushover analyses and the modal behavior of the structure, it is observed a good consistency. First three modes of vibration did not include a local mechanism and ensure a global response. On the other hand, estimation of the out-of-plane response induced in a number of walls by the November 26, 2019 earthquake sequences was difficult in the numerical model since the presence of bond beams helps to prevent such behavior. It is believed that such failures occurred due to the fragmentation of materials, that was not considered in the mathematical model.

Fig. 22 The examined building

Fig. 23 Typical damage patterns observed at several locations of the studied template design

As mentioned before, the first event did not cause a visible damage whereas the November 26 produce slight-moderate damage on load and non-load bearing walls. Figure 12 and 13 exhibits a correlation between the mathematical model and real damage occurred in a number of walls induced by November 26, 2019 earthquakes.

Template building, which was damaged during the 26 November 2019 earthquake, has a 5-story unreinforced masonry building constructed by using solid clay bricks (Fig 12.). The construction of the buildings was completed in 1981. Generally, they have regular plans in elevation supported by load bearing unreinforced masonry walls. The load bearing walls were formed by solid clay bricks and the partition walls with hollow bricks. This building underwent changes including some plaster renewals and paintings after the September 12, 2019 earthquake. For that reason, from the outer parts, damages are not clearly observed with visual inspection.

As seen from the photos, the material quality especially the mortar is very weak and could not prevent the segregation of the bricks in several parts. Damage was concentrated on the 1st, 2nd and 3rd floors. Level of the damage on load bearing walls was severe whereas the partition walls were heavily damaged. Typical damage patterns like bending and shear cracks, spalling of mortar, separation of the load bearing wall segments especially over or under the openings are observed all over the first three floors and are shown in the Figs 23-25.

Fig. 24 Diagonal cracks extending over the height of the wall (left), spandrel damage patterns below the openings

Fig. 25 Heavy cracks (more than 3 cm separation) on load bearing walls and extensive damage on non- load bearing wall (left), serious damage observed on outer facade of the building in lower stories (right)

On the upper floors, it was observed that the doors are not closed properly due to the possible drift concentrations on load bearing elements. According to the inspections and damage surveys done on the buildings, the buildings have serious deficiencies which do not meet the conditions stipulated in Eurocode 8. Especially, on the first 3 floors, severe damage patterns were observed on load bearing walls and very heavy damage was observed on partition walls. Material quality is extremely weak and caused degradation by time.

Using the capacity curves and the following the criteria in Eurocode 8-3, damage limit states of was assessed, and seismic capacity of the template design was predicted. Three limits states levels, i.e, “Damage Limitation (DL)”, “Significant Damage (SD)” and “Near Collapse (NC)” are identified for performance assessment (Table 9).

Table 9. Seismic spectral acceleration capacities for the corresponding performance levels

Estimated Earthquake level [17]	ag DL	ag SD	ag NC
2.0-2.2 m/s2	1.18 m/s^2 Passed	2.02 m/s^2 Passed	2.614 m/s^2 Not reached

Based on the detailed inspection on the studies area [17], the level of the PGA acceleration was found to be in the order of 2.0-2.2 m/s^2. The performance of the studied building is slightly exceeding *Significant Damage* and corresponding to *Near Collapse* level. The inspected damage and performance are in accordance with the results of analysis results from the numerical model.

6. Conclusions

This study presented the seismic evaluation of a commonly used template designed URM masonry building for residential purposes in Tirana, Albania. Template designs were developed during the communist era to save architectures fees and ensures quality control all of the country till 1990s. Selected template design is an interesting one to evaluate the ability of numerical methods to accurately estimate the behavior of existing masonry buildings under horizontal loads.

This URM building was damaged slight-moderate level by the seismic shakings that struck the central Albania during November 2019. The accumulated damage experienced by the template design building because of the serious seismic shakings was investigated in terms of damage patterns and story drifts. Based on the detailed site visits, it was observed that the buildings showed a global failure mechanism associated with the in-plane behavior of load bearing walls. Slight-moderate damage was induced by the November 26, 2019 earthquake sequences, which produced several cracks throughout the structure and triggered out of plane mechanism in some of the non-load bearing walls. The most important in-plane damage occurred on load-bearing walls of the located in y- direction of the building, in line with the PGA values and drift ratios in this orientation compared to the x- direction.

To represent the earthquake behavior of the building, a 3D finite element model was prepared, following a macro-modeling approach. Inherent material characteristics were determined through the experimental tests recommended in in the international guidelines. Then, nonlinear static analyses were deployed in both orthogonal axes of the building. Based on the results of the pushover analyses, weak orientation of the building was identified in y- axis as the vulnerable direction. Relatively lower stiffness and load-bearing capacity were observed in y- direction. The damage was evaluated for values of lateral load considering the PGA values recorded during the November 26, 2019 seismic shakings.

To sum up, observed damage and the estimated failure mechanism in the mathematical model are consistent with each other. As for the out-of-plane mechanism triggered by the November shakings, it is assumed that its occurrence in the mathematical model was prevented by the presence of bond beams modeled to remain in elastic mode. Moreover, such a response may have occurred from the possible disintegration of the masonry materials, that was not taken into consideration in the numerical model. On the other hand, it should be kept in mind that pushover analysis is an approximate method and findings from such a method may not perfectly simulate the structural performance of the buildings under a particular ground motion. Especially, buildings having irregular floor plans may lead to misleading results due to the influence of torsional mode effects even though this problem might be partially resolved with the use of rigid diaphragms.

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