buildings

Article

Reflections from the 2019 Durrës Earthquakes: An Earthquake Engineering Evaluation for Masonry Typologies

Hüseyin Bilgin [1,*], Marsed Leti [1], Rafael Shehu [2], Hayri Baytan Özmen [3], Ahmet Hilmi Deringol [4] and Rrapo Ormeni [5]

[1] Faculty of Architecture and Engineering, Department of Civil Engineering, EPOKA University, 1001 Tirana, Albania; mleti@epoka.edu.al
[2] Politecnico Di Milano, DICA Department, Piazza Leonardo Da Vinci 32, 20133 Milan, Italy
[3] Department of Civil Engineering, Usak University, 64200 Usak, Turkey; baytan.ozmen@usak.edu.tr
[4] Department of Civil Engineering, Gaziantep University, 27310 Gaziantep, Turkey; aderingol@gmail.com
[5] Seismology Department Institute of Geosciences, Energy, Water and Environment (IGEWE), Polytechnic University of Tirana, 1024 Tirana, Albania; rrapo55@yahoo.com
* Correspondence: hbilgin@epoka.edu.al

Abstract: Two earthquakes struck the NW region of Albanian territory on 21 September 2019 (M_w = 5.6) and on 26 November 2019 (M_w = 6.4). The epicenters of the seismic activity were located offshore NW Durrës, one of Albania's most populated cities, located 30 km from the capital Tirana. Various aftershocks followed subsequently. While there were no reported injuries, a number of buildings sustained significant damage near the epicenter following the initial event. Subsequently, during the second event, there was loss of life and extensive damage to civilian structures, resulting in multiple collapses. This study focuses on the earthquake damages observed in residential and public buildings in the earthquake-affected region. The earthquakes predominantly affected low-rise masonry buildings, while the newly constructed RC structures built according to the latest seismic rules were almost unaffected. The commonly encountered building typologies in the region, together with photos showing the amount of destruction are presented here. As observed by the authors during the reconnaissance visit to the stricken area, examples of various damage patterns are presented, along with a technically substantiated description of the reasons for those damages. Although modern buildings during recent earthquakes in the region show acceptable performance, the detailed surveys from the Durrës Earthquakes showed that there is still an important level of deficiency in current masonry buildings built by conventional methods and materials. This problem may reoccur in future earthquakes that may hit other rural regions of Albania, which must be focused on systematically in the near future.

Keywords: visual assessment; seismic damage; Albania; masonry structures

Citation: Bilgin, H.; Leti, M.; Shehu, R.; Ozmen, H.B.; Deringol, A.H.; Ormeni, R. Reflections from the 2019 Durrës Earthquakes: An Earthquake Engineering Evaluation for Masonry Typologies. *Buildings* **2023**, *13*, 2227. https://doi.org/10.3390/buildings13092227

Academic Editor: Ciro Del Vecchio

Received: 9 July 2023
Revised: 28 August 2023
Accepted: 30 August 2023
Published: 31 August 2023

1. Introduction

Earthquakes stand as highly destructive natural phenomena, causing substantial loss of life and posing a substantial threat to the built environment. Averaging at around 10,000 fatalities annually, earthquakes lead to economic losses reaching billions of dollars per year, often constituting a significant portion of the affected nation's gross national product [1]. To understand earthquake hazards, it is necessary to estimate the sensitivity of the built environment to earthquake risks. Over the past thirty years, the field of engineering has observed substantial advancements in the seismic assessment and retrofit design of existing structures, encompassing both the analytical approach and practical implementation methods [2–4]. Such efforts have mainly focused on developing and understanding the structural design against severe loads and the representation of earthquake risks to establish rules and practices for designing and producing new constructions. The seismic risk is equal to the product of the hazard, the value exposed and the fragility of the building stock. Our stock of old existing buildings is constantly expanding with the addition of new buildings, many of which are significant and even extremely earthquake-vulnerable. This is due, first of all, to the fundamental principles of earthquake-resistant design for new buildings, as well as the seismic characteristics of building codes that are often not followed. The reason is either ignorance, convenience, or unawareness. As a result, the seismic risk continues to rise unnecessarily.

On Saturday 21 September 2019, at 14:00 UTC (16:00 local time), a M_w 5.6 earthquake struck the Albanian capital and coast, approximately 60 km NW of the capital Tirana, with a focal depth of 10 km. Another earthquake (M_w 6.4) took place on Tuesday, 26 November 2019, at 02:54 UTC (03:54 local time), at approximately 16 km (9.9 mi) WSW of Mamurras/Durrës. Numerous aftershocks occurred including an event of M_w 5.4, which occurred on 26 November and generated extensive damage to civilian structures [5,6]. Following the earthquake, the Albanian Government promptly declared a state of emergency in the affected region. Swiftly, first responders arrived on the scene, playing a pivotal role in the humanitarian relief effort [7]. The sustained aftershocks further contributed to heightened stress and anxiety among local residents, compelling numerous individuals to evacuate their homes.

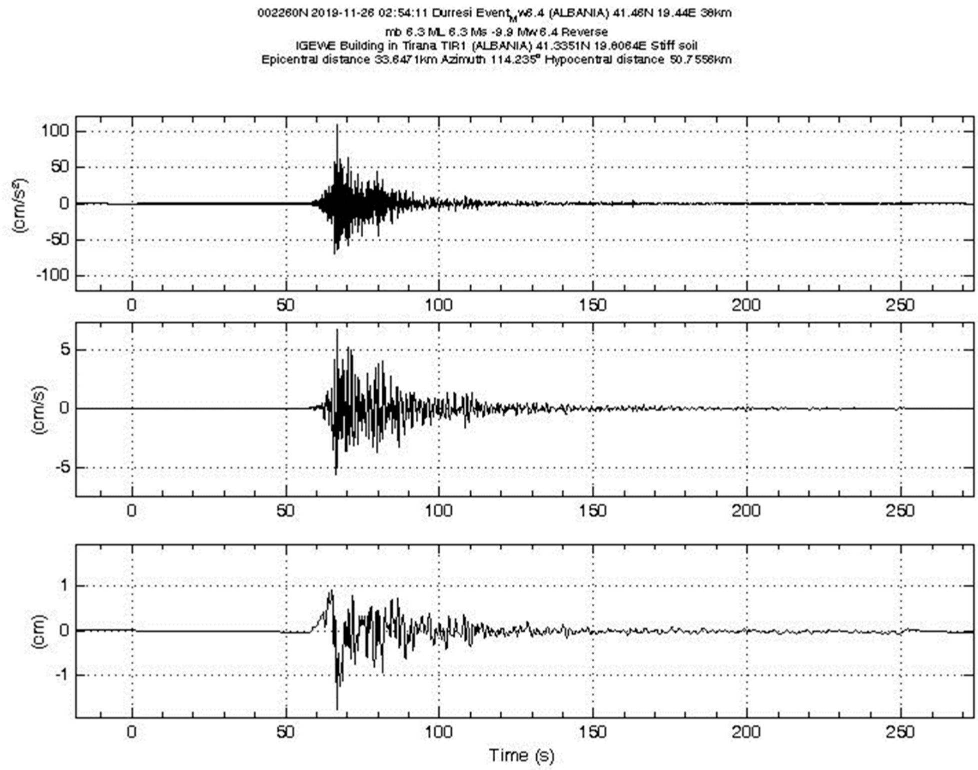
Destructive effects witnessed in masonry structures during recent global seismic events have been extensively documented in various research studies, see [8–10]. Given the significant toll of casualties and impaired structures, distinct investigations have been conducted on masonry buildings for several earthquake occurrences [6,11–15]. Notably, the 2019 earthquake in Albania revealed varying degrees of masonry building damage [16–19].

This study aims to offer a comprehensive understanding of the seismic performance displayed by various masonry structures, including schools and historical buildings, across the nation. These structures were impacted by the series of earthquakes that occurred on 26 November 2019. The primary impact of the earthquakes was observed on low-rise residential masonry structures, whereas the more contemporary RC buildings constructed according to recent seismic regulations remained largely unaffected. Specifically, this paper delves into the seismic activity within the Durrës basin and its surrounding area, the recorded strong ground motions, their correlation with the existing seismic codes in Albania, the initial assessment of structural damages in buildings, and the findings derived from a post-earthquake damage survey conducted in the region shortly after the occurrence of the twin earthquakes. The presented case studies in this paper emphasize the fundamental factors contributing to damage and shed light on the susceptibility of prevailing masonry structures constructed using traditional techniques and materials in the region.

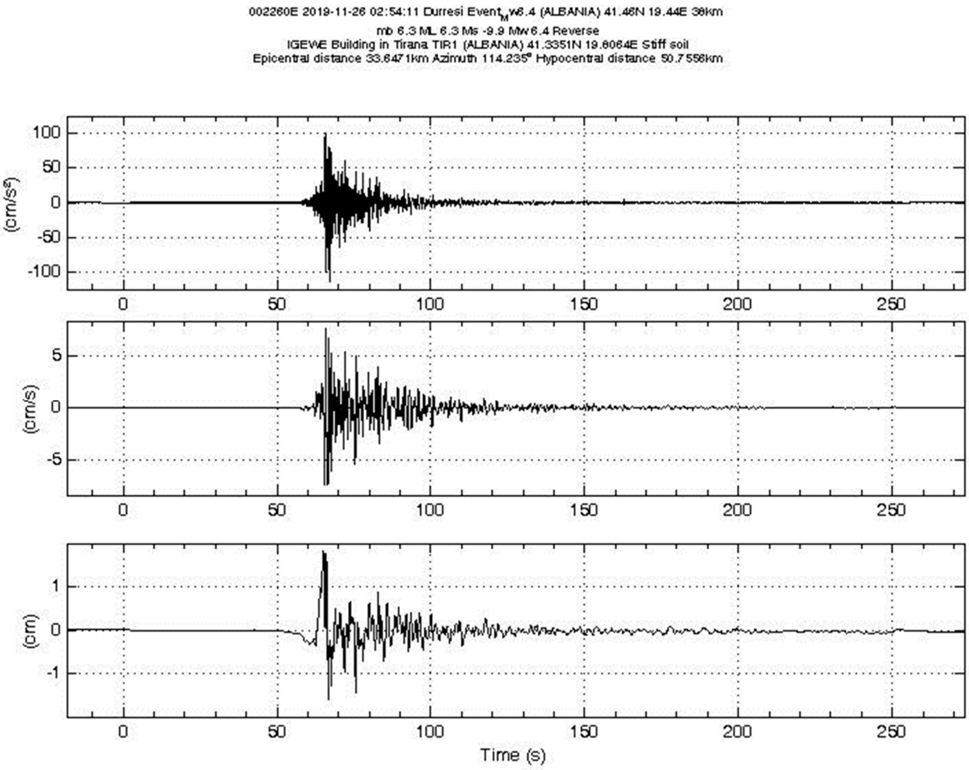
2. Seismicity of Albania and Characteristics of 2019 Earthquakes

Positioned at the convergence boundary of the African and Eurasian plates, the Mediterranean Sea presents an intricate tectonic configuration characterized by the interactions of various microplates and larger regional structures. The seismic activity in Albania can be directly attributed to the convergence of the Adria and Moesia plates across the Southern Dinarides [17]. Specifically, in the context of the November earthquake, the manifestation of reverse faulting in Albania, particularly along the eastern Adriatic coast, corresponds to the closure of the sea and the compression exerted across the mountain ranges that extend from Croatia to Greece. Given the intricate tectonic nature of the region, a significant number of geological faults in Albania remain active and have the potential to generate earthquakes with magnitudes exceeding 6.5 [18]. Historical records, as documented in the European-Mediterranean Earthquake Catalogue, reveal a considerable number of moderate-to-strong earthquakes ($M_w > 4.5$) within Albanian territory. For a comprehensive compilation of past impactful earthquakes, refer to the list provided by Bilgin and Hysenlliu, 2020 [19].

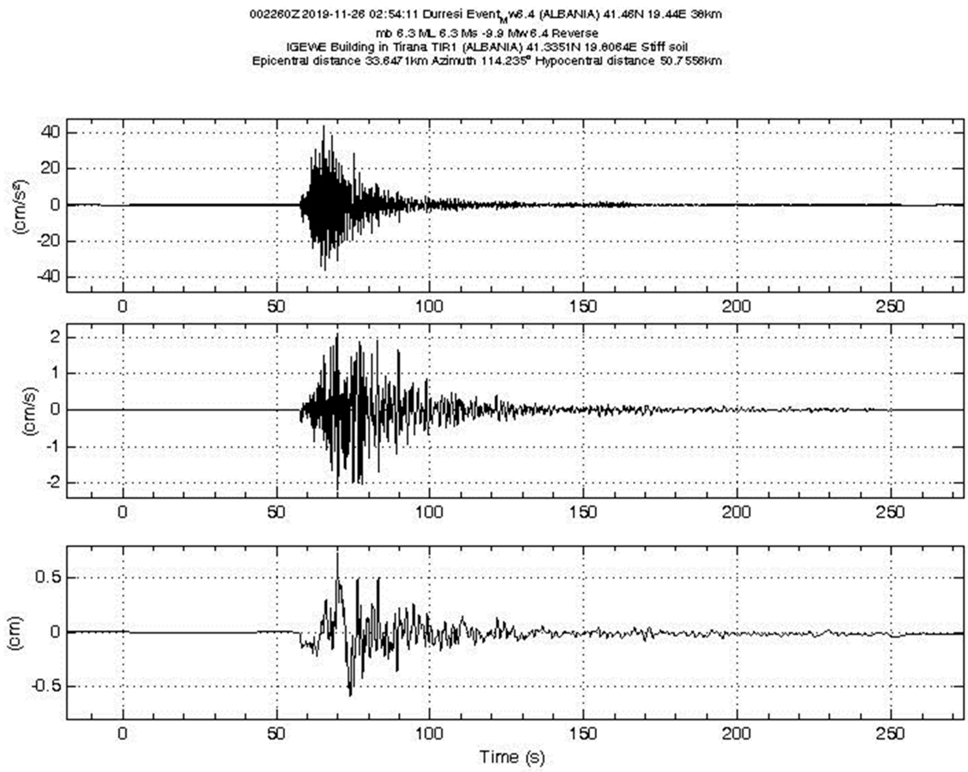
The seismic occurrence on 26 November 2019, was identified and captured by seven seismic monitoring stations affiliated with the Albanian Seismological Network. These stations were positioned at varying distances from the epicenter, ranging from 15 to 130 km [18]. Figure 1a–c illustrates the ground motions captured by Tirana station. The epicentral distances between the Tirana and Durrës accelerometric stations and the earthquake's epicenter are approximately 34 km for Tirana and 16 km for Durrës.



(**a**)



(**b**)



(**c**)

Figure 1. Ground motions recorded in Tirana (TIR1 Station, https://www.geo.edu.4iranaana_record/, 10 June 20223). (**a**) 26 November 2019 Earthquake N-S

component. (**b**) 26 November 2019 Earthquake E-W component. (**c**) 26 November 2019 Earthquake Vertical component.

The horizontal Peak Ground Acceleration (PGA) recorded in Tirana was approximately 0.12 g, whereas, in Durrës (which was in closer proximity to the epicenter), this measurement elevated to approximately 0.20 g. Nonetheless, a significant point to consider is that the accelerometric station in Durrës had its recording capacity limited to the initial 15 s of the event, as a power outage triggered by the earthquake affected its operation. To assess the earthquake's impact, Figure 2 presents the response spectra derived from the recorded ground motions, compared to the elastic response spectra defined according to the Albanian code [20]. These soil types align with the geological conditions at the specific sites of the accelerometric stations in Durrës.

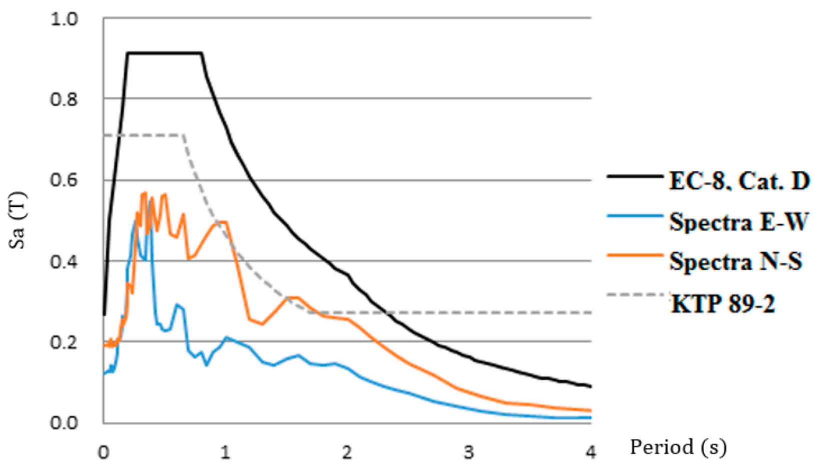


Figure 2. Elastic spectra according to EC-8, KTP-89. N2 at Durrës station.

In the city of Tirana, the spectral accelerations obtained from the recorded data (as shown in Figure 2) are consistently 1.5 to 2.0 times higher than the code-provided values for spectral periods ranging from 0.2 to 0.8 s. This is particularly significant because most buildings in the affected areas are expected to have their fundamental periods within this range. Conversely, in the case of Durrës, the elastic design spectrum (illustrated in Figure 2) demonstrates elevated values in contrast to the response spectra derived from the recorded ground movements in both horizontal orientations. Nevertheless, an exception arises within the natural period range of 1 to 2 s, where the spectrum of the recorded ground motion for the North-South component closely corresponds to the elastic response spectrum outlined in the code. It is important to note that this comparison may not accurately represent the true conditions due to the limited data for the Durrës station, as previously mentioned.

3. Seismicity Codes of Albania

Albania has a rich historical background in implementing seismic design regulations. The initial set of seismic regulations, along with the first seismic zoning of Albania, were established in 1952. Subsequently, the 1963 revision heightened the requirements for seismic design, whereas the 1978 revision, known as KTP 2-78 [21], did not introduce substantial advancements [22]. In 1989, the country introduced a new seismic design code, KTP-N.2-89, which remains Albania's officially recognized seismic design code.

The KTP-N.2-89 incorporates various structural configurations and includes design provisions for each configuration. It follows the principle of ensuring sufficient ductility in the structure, enabling the absorption of seismic energy. It incorporates fundamental principles found in many contemporary seismic design codes for building structures. These principles encompass aspects such as maintaining plan and elevation regularity, considering mass and stiffness distribution, symmetry, simplicity, and more. The seismic hazard is characterized by macro-seismic intensity areas defined according to the MSK-64 scale [23], which divide the country into three major seismic zones with intensities VI, VII, and VIII. Additionally, there are specific regions near the epicenters of significant seismic events where the seismic intensity is elevated from VIII to IX, accounting for poor soil conditions. The code classifies three distinct soil types (I, II, and III) and assigns them to each of the identified seismic zones. Furthermore, it offers guidance on determining seismic design actions, load combinations specific to seismic design situations, and the application of partial factors within the load combinations.

The equation defines the horizontal design acceleration response spectrum as follows:

$$S_a = k_E * k_r * \xi * \gamma * g \quad (1)$$

where:

- k_E represents the seismic coefficient, which varies based on the earthquake intensity and soil category,
- k_r is the importance factor,
- The parameter ξ represents the structural response coefficient when subjected to earthquake forces. It is utilized to transform the elastic spectrum into the design spectrum, analogous to the concept of the behavior factor in EC 8 [24].
- The dynamic coefficient γ is determined based on the building's natural periods and the soil category.
- g denotes the gravitational acceleration.

The structural coefficient, ξ, varies depending on the construction materials and structural systems used. For example, it is 0.25 for RC bare frames, 0.2 for moment-resisting steel frames, and 0.33 for systems comprising a combination of dual systems.

For structures made of unreinforced masonry (URM), the mechanical properties of the materials must meet the minimum requirements specified in the code. The masonry walls are categorized into three distinct seismic strength classifications determined by the attributes of the mortar and masonry units utilized. The code establishes specific criteria regarding the heights of stories, taking into account the thickness of walls and the category of walls. Moreover, it imposes limitations on the maximum distances permitted between transverse walls. Additionally, the code imposes various constraints on the dimensions of openings, the spacing between consecutive openings, and other geometric parameters. These limitations are specified to ensure structural stability and integrity. Moreover, the code mandates the use of reinforced concrete (RC) tie beams in masonry structures. These tie beams must adhere to specific detailing rules concerning the diameter, spacing, and arrangement of stirrups and longitudinal rebars.

For reinforced concrete (RC) structures, the code recognizes multiple lateral resisting systems that can be employed. These systems comprise various configurations, including moment-resisting frames that interact with masonry infills, dual systems, and combinations of these approaches. The code also provides specific detailing rules for cast-in-situ RC members, such as beams, columns, and walls, with the objective of achieving local ductility. Regarding frame structures in general, the code specifies that plastic hinges should be developed on the beams. However, it does not offer specific recommendations on how to ensure compliance with this requirement. It is important for designers and engineers to carefully consider and apply appropriate design and construction techniques to limit plastic hinges to the designated beams in frame structures, ensuring proper performance and seismic resistance.

It is important to note that the above conditions primarily aim to protect structures from collapse, but they do not offer specific recommendations regarding damage limits. Notably, the code does not provide inter-story drift limits to protect infills from in-plane loads, despite requiring that infills maintain their integrity during seismic events. By considering these guidelines, designers can assess the seismic demands on structural and non-structural elements and implement appropriate measures to mitigate potential damage.

Upon examining the KTP-N.2-89 code, it becomes evident that it shares fundamental principles with contemporary seismic design codes, such as Eurocode 8. However, it does have some limitations in terms of detailed recommendations. One such example is the requirement for columns to be stronger than adjacent beams, but the code does not offer a specific quantitative formulation to facilitate this hierarchy check. To address these limitations, the structural engineering community has increasingly adopted good practices from Eurocode 8 as a supplement to the KTP-N.2-89 in their everyday work. By incorporating relevant provisions from Eurocode 8, engineers started to enhance the seismic design and detailing of structures, filling in the gaps left by the KTP-N.2-89 and ensuring more comprehensive and robust seismic performance, especially after the 2000s.

4. Field Survey on Building Damage after 26 November 2019 Earthquake

Despite restrictions imposed by the COVID-19 pandemic, a reconnaissance team was set up to visit the earthquake-affected region, including rural areas. The team conducted a post-disaster structural damage assessment utilizing a site surveying method. Due to the need for a building-specific approach, the assessment primarily relied on on-site inspections conducted by physically visiting each building. This approach involved detailed inspections of the buildings, which provided reliable and valuable information regarding the extent of damage, material behavior, and seismic performance of the building stock in the region. These in-situ structural observations continued beyond analyzing the failure mechanisms of individual buildings; they provided insights into the overall scale of damage across the stricken area. Special attention was given to local phenomena, such as increased damage observed in proximity to alluvial areas. This knowledge informed the team's decision to intensify inspections in those regions, allowing for a better understanding of the underlying causes of the damage. It is important to note that due to limitations and constraints, the team was unable to conduct inspections inside some of the severely damaged buildings or assess the foundations. However, the comprehensive foot-on-ground inspections still provided crucial information for assessing the overall damage condition and identifying patterns within the affected region.

Before conducting the site visit, data regarding the buildings in the vicinity was collected from official authorities and the Construction Institute of Albania. The data revealed the following distribution of buildings based on their construction period and adherence to seismic code provisions. Based on the 2001 census data provided by the Albanian Institute of Statistics (INSTAT), the building stock in Albania can be mainly classified into four categories according to the construction materials employed: bricks, prefabricated materials, stones, wood, and other construction materials. It is important to note that this information is based on the 2001 census and may not reflect the current state of the building stock [25].

In the 2001 census, the category of "bricks and stones" was found to represent the largest proportion of the building stock in the country. However, it is worth mentioning that this information is outdated, as the most recent census in 2011 [26] does not include data on construction materials but rather focuses on the height (low to high) and year of construction of the buildings.

Based on data from the 2011 census conducted by the Albanian Institute of Statistics (INSTAT), it is reported that approximately 85% of the total housing building stock consists of 1-story buildings. Assuming that each 1-story building corresponds to a single dwelling, this category represents approximately 50% of the reported dwellings in the latest census. The 1-story buildings encompass a range of construction types, including unreinforced masonry (URM) structures constructed with stone, clay, or silicate bricks, as well as reinforced concrete (RC) frames with masonry infills made of lightweight clay or concrete bricks. The roofs of these buildings commonly feature wooden trusses and rafters covered with clay tiles. In some cases, a flat RC slab may also be used as the roofing system. Similar structural systems are traditionally employed for 2-story buildings as well.

While the quantity of multi-story residential buildings in Albania is notably lower in comparison to single-story houses, they still account for the remaining 50% of dwellings. These multi-story buildings have been notably affected by the earthquake that occurred on 26 November 2019, as indicated by the higher levels of damage observed during field investigations.

Figure 3 provides an illustration of the usual multi-story housing buildings found in Albania. The most common types include unreinforced masonry (URM) and construction using clay or calcium silicate bricks (Figure 3a,b), as well as reinforced concrete (RC) structures with masonry infills (Figure 3c). Furthermore, prefabricated large-panel buildings (as shown in Figure 3d), which fall under the 'prefabricated' category in the 2001 census, are also widespread and form a significant part of the building stock in Albania. The roofs of these multi-story buildings are primarily constructed using flat reinforced concrete (RC) slabs. Also, it should be noted that all buildings taller than six stories are typically built using RC frames.

This information provides insights into the composition of the building stock in the area, indicating a mix of buildings designed without seismic considerations and those designed under progressively improving seismic code provisions.

Following the major earthquakes, the initial damage assessment conducted by public authorities in the first week revealed severe damage to several residential properties and public buildings in the Municipality of Durrës, Lezhë and Tirana. Table 1 depicts the results of the rapid post-earthquake examination conducted after the earthquakes by the Construction Institute of Albania [5]. A total of 44,582 buildings were inspected and categorized according to damage levels shown below.

(**a**)

(**b**)

(**c**)

(**d**)

Figure 3. Commonly encountered typologies for multi-story buildings in Albanian building stock: (**a**) Unreinforced masonry built by clay bricks; (**b**) Confined masonry made of silicate bricks; (**c**) newly constructed RC buildings; (**d**) Large panel Prefabricated buildings.

Table 1. Damage assessment results [5].

City/Damage Levels	No Damage	Immediate Occupancy (DS1, DS2, DS3)			Life Safety	Collapse Prevention	Total
Durrës	22,605	2761	2384	1735	1855	626	31,966
Lezhë	494	364	421	326	402	43	2050
Tirana	5651	1560	1258	737	974	386	10,566
TOTAL	**28,750**	**4685**	**4063**	**2798**	**3231**	**1055**	**44,582**

It highlights the need for the government to take action at a national level to identify earthquake-vulnerable buildings and implement measures to be earthquake-resistant against similar events.

5. Observed Damages on Built Environment

The earthquakes in Albania in November 2019 demonstrated a fundamental principle of seismic-resistant design: seismic shaking tends to expose the weak points of buildings. In general, the performance of RC buildings during the strong earthquakes and aftershocks was satisfactory and aligned with expectations considering the intensity of the shaking. Slight damage was seen primarily in non-structural components such as partition walls. The earthquakes also revealed the susceptibility of low-rise masonry dwellings constructed using clay-fired bricks and mortar joints possessing low bond strength. These structures demonstrated a higher susceptibility to damage during seismic events. It was evident that these buildings were particularly susceptible to the strong shaking in the country. This section presents a summary of the key observations and findings from the earthquake damage survey carried out in various areas of Albania. It provides a brief overview of the building typology prevalent in the region and highlights specific field observations.

5.1. RC Buildings

The behavior of RC buildings during earthquakes is influenced by the distribution of stiffness and mass in two orthogonal directions. Typical damage in these buildings is often associated with non-structural elements, particularly infill walls. A common form of damage observed is the detachment of infill walls from the concrete frame. This often leads to out-of-plane displacement and cracking caused by bending forces, as illustrated in Figure 4. Additionally, shear damage in columns can be observed, potentially caused by the influence of infill walls on the supporting columns.

Figure 4. Infill wall damage in an RC building due to out-of-plane bending and shear failure.

Figure 5 illustrates an instance of in-plane shear failure observed in a poorly confined masonry wall at a primary school in Durrës. The cracking observed in the masonry exhibits a characteristic diagonal shear crack pattern that follows a zigzag path.

Figure 5. In-plane shear failure of inadequately confined masonry wall due to windows opening.

Although a significant part of RC buildings experienced merely non-structural damage, there were instances of severe damage, as shown in Figures 6 and 7. The severe damage to RC buildings was primarily concentrated on soft-story ground floors. These buildings were predominantly designed and constructed before 2000. Due to the absence of shear reinforcement and reduced stiffness resulting from open ground floors, shear failures occurred in columns and beam-to-column joints. The lack of adequate shear reinforcement and the structural characteristics of open ground floors contributed to such failure patterns.

(**a**) (**b**)

Figure 6. Shear failure of columns on RC buildings in Durrës. (**a**) Typical shear failure of columns; (**b**) Buckling of rebars in plastic hinge regions of columns due to insufficient transverse reinforcement.

Figure 7. Short column failures due to bad window openings.

Insufficient horizontal reinforcement, such as stirrups, led to the buckling of longitudinal rebars in the columns (as shown in Figure 7). While the strong beams remained relatively unaffected, severe damage and the formation of plastic hinges were observed at the top of the columns. This highlights the importance of proper horizontal reinforcement to ensure the structural integrity and performance of columns during seismic events.

5.2. Masonry Buildings

Masonry, being a fragile and anisotropic material, displays a notable capacity for withstanding compressive forces but is notably deficient in tension resistance. The behavior of cracks in masonry can be non-uniform, meaning they may open and close depending on the applied stresses. Cracks wider than 0.2 mm are generally obvious without the aid of magnification. In the context of masonry buildings, walls are especially susceptible to horizontal seismic forces, which is a cause for concern in Albania, where a considerable number of buildings lack reinforcement. The preliminary damage assessment outlined here relies on the analysis of crack patterns and displacements observed externally on the buildings. Regrettably, in many instances during the site visit, access to the interior was restricted, limiting the assessment to external observations only.

5.2.1. Residential Buildings

Between 1945 and 1990, masonry buildings played a significant role in residential and public construction in Albania. During this period, the Albanian seismic design codes underwent multiple revisions. In the beginning, masonry buildings in Albania were primarily 1- or 2-story structures built using different types of masonry materials, such as stone and clay bricks. During the period from 1945 to 1963, construction practices relied heavily on engineering experience and simplified calculations. The first standardized design template for masonry buildings was approved by Albanian governmental authorities in the 1950s specifically for a 2-story adobe building. Subsequently, a range of standardized design templates for 3- to 5-story masonry buildings were built between 1963 and 1978. However, after the 1979 Montenegro earthquake along the border of Albania, which caused severe damage to many 5-story masonry buildings, the seismic design code was revised. The current seismic design code in Albania is KTP-N.2-89, which was published as a result of this revision [20].

Masonry buildings and RC buildings continue to be in use and represent a significant portion of the dwellings in Albania. These buildings can be categorized into two primary typologies: (1) unreinforced masonry (URM) buildings with load-bearing walls, as illustrated in Figure 8a, and (2) confined masonry (CM) buildings with load-bearing walls reinforced using RC tie-elements, as depicted in Figure 8b.

(**a**)

(**b**)

Figure 8. Typical masonry buildings (**a**) URM; (**b**) Confined masonry.

Typical masonry buildings in Albania are characterized by unique compositions with regular floor plans and uniform elevations. Many of these buildings exhibit either a rectangular plan or an irregular plan with symmetrically distributed load-bearing walls. The size of the building's plan can change, while the story height is typically 2.8–3.0 m.

The openings in these buildings are typically arranged in a regular layout, and concrete lintels are commonly employed to bear the vertical loads. The floor systems can be either reinforced concrete (RC) slabs or prefabricated concrete panels with hollow cores. The RC slabs are usually 15 cm thick, while the hollow core panels consist of a 22 cm thick slab placed on top of prefabricated RC joints.

Generally, the thickness of the load-bearing walls is 38 cm for the first two stories and 25 cm for the upper floors. Infill walls, on the other hand, have a thickness of 12 cm. The masonry materials commonly used are solid red clay bricks with dimensions of 25 × 12.5 × 6 cm^3 or silicate white bricks with dimensions of 25 × 12.5 × 6.5 cm^3. These bricks are joined together using cement or silicate mortar, depending on the construction method. The on-site observations revealed several common types of masonry, as illustrated in Figure 9a–c.

Figure 9. Typical solid bricks and details of the confinement elements used for masonry walls: (**a**) Silicate bricks; (**b**) Red clay bricks; (**c**,**d**) RC beams and column reinforcements.

In CM buildings (as shown in Figure 9c,d), tie elements are utilized. These tie elements include reinforced concrete (RC) columns with a typical cross-section size of 38 × 38 cm^2, as well as RC beams with a depth of either 25 cm or 38 cm. The choice of beam depth depends on the thickness of the walls at their respective locations. The concrete used in these tie elements is generally of class C16 or lower. Similarly, the steel grade typically employed in these buildings is S220, as reported [27].

Residential masonry buildings in the country have experienced significant damage (Figure 10). The extent of damage fluctuates between different buildings as well as across various regions. These buildings constructed before 1990 were built either by following pre-modern code requirements or without following any structural regulations, and their age and lack of maintenance have contributed to their vulnerability. Pre-existing ground settlements and minor out-of-plane deformations could have also affected some structures, potentially contributing to the observed damage and compromising their structural integrity.

Figure 10. Masonry dwelling with large openings and wooden lintels above openings in Vore. The 1st and 2nd floors are constructed of stone brick while the 3rd story is built of clay bricks.

During the inspections, it was observed that both unreinforced masonry (URM) and confined masonry (CM) buildings constructed with fired clay bricks and reinforced concrete (RC) solid slabs displayed favorable performance. These buildings did not exhibit severe damage, and they were not deemed unsafe based on the assessments conducted.

In the case of URM buildings, the good seismic performance was attributed to the effective interlocking of the load-bearing walls, as evidenced by the absence of cracks along the frames of the facades. In contrast, masonry buildings with inadequate connections between adjacent walls exhibited a different performance during the inspections. These buildings demonstrated greater vulnerability to seismic forces, resulting in more significant damage and a higher classification of structural risk. Furthermore, the favorable earthquake behavior can be attributed to the box-like response facilitated by the strong link and stiffness of the RC slabs, which distribute horizontal loads to the resistant walls.

CM buildings, on the other hand, incorporate a combination of masonry walls and RC frame members. Their positive earthquake performance is well-documented and has been monitored in previous seismic shakings. The effectiveness of these buildings is achieved through the interaction between the masonry walls and the confining elements provided by the concrete poured after the construction of the walls. This interaction creates effective connections that allow confined masonry (CM) buildings to function as interlocked structures. As a result, these buildings are capable of withstanding more significant deformations, displaying enhanced strength, and exhibiting high levels of ductility during seismic events.

The survey identified several significant deficiencies in these buildings, primarily related to unauthorized interventions and modifications carried out by owners without proper engineering consultation. These interventions included closure and creation of new openings, the use of unique types of masonry for repairs, and the addition of extra stories [28]. Examples of these irregularities are shown in Figure 11a,b. Such alterations, combined with a lack of preservation, degradation of material properties over time [29], and changes in load paths [30,31], can contribute to damage and deterioration, ultimately increasing the structures' seismic vulnerability throughout their lifespan.

(**a**) (**b**)

Figure 11. Intervention examples on URM buildings: (**a**) expanded overhangs as balconies and use of different construction materials; (**b**) Interventions done after its construction on the ground floor (New openings).

Although buildings constructed with fired bricks and reinforced concrete (RC) slabs generally demonstrated good performance, there were reported instances of structural failures in Thumanë town. In Thumanë town, three unreinforced masonry (URM) buildings, comprising one 3-story and two 5-story structures, constructed with solid silicate bricks and hollow core prefabricated concrete slabs, experienced collapse, as depicted in Figure 12. The structural failure of these buildings was ascribed to the insufficient mechanical attributes of the silicate bricks and the lack of proper connections between the prefabricated concrete slabs and the load-bearing walls. These deficiencies led to overturning failures, ultimately resulting in the structural collapse of the buildings.

Figure 12. Collapsed building in Thumanë (1- added story before the collapse).

The evaluation disclosed that the buildings flagged as unsafe by local engineers had already undergone substantial deterioration prior to the earthquake owing to a lack of maintenance. The existence of corroded and exposed reinforcements, crushed brick units, and peeling paint served as indicators of the poor condition of these buildings. These signs of deterioration further contributed to their vulnerability and increased the likelihood of damage during the earthquake. Furthermore, these buildings had undergone multiple structural modifications over time, which likely significantly affected their extensive damage. The construction of additional floors and the creation of large openings at the ground level may have caused alterations in the load distribution and load-bearing paths within the structures. These modifications could have weakened the overall structural integrity and made the buildings more susceptible to the effects of the earthquake.

The lack of essential structural elements further contributed to the vulnerability of buildings in the country [32]. Most buildings did not have a ring beam below the roof, which is an important element for distributing seismic forces and providing stability to the structure. Furthermore, the lack of rigid in-plane diaphragms at the floor and roof levels further compromised the overall structural integrity of the buildings. Figure 13 depicts buildings with loosely connected walls and the absence of a sturdy top floor or reinforced concrete (RC) ring beam. The weak connection between the walls and the roof, coupled with the poor quality of stone arrangement and weak mortar, significantly heightened the risk of collapse during the earthquake.

Figure 13. Separation of walls because of improper connection between the roof and the underlying masonry and flexible top floor.

The aspect ratio of URM elements is a critical factor that influences their response to seismic forces [33–36]. Elements with excessive bending and shear may experience in-plane failure. Diagonal shear cracks were observed during the earthquake in walls with openings, as evident from the visual survey. Typically, these cracks originate from the center of the pier and propagate towards the corners. Various factors, including mortar quality, influenced the development and propagation of diagonal shear cracks in masonry walls. In certain instances, the cracks passed through the mortar joints, while in other cases, they extended through both the masonry units and mortar joints. This indicates the vulnerability of the masonry walls to diagonal shear forces during the earthquake.

The strengths and weaknesses of masonry structures are quantified based on the determination of the inherent characteristics of its constituents. As an important parameter, the determination of compressive strength in masonry structures stands as a paramount characteristic that must consistently be ascertained for a given masonry configuration. Nevertheless, the feasibility of performing destructive compression tests on masonry is not always viable. In contrast, compressive strength values for individual components of masonry, such as bricks and mortar, are typically accessible within design codes or attainable through testing protocols. As a result, scholarly endeavors have arisen in the literature [37,38] to establish empirical correlations linking the compressive strengths of masonry, brick, and mortar. These empirical relationships have found widespread adoption among researchers [39]. In the context of Eurocode 6 [37], the interrelation of the three compressive strengths is formulated as follows:

$$f_k = K \times f_b^{\alpha} \times f_m^{\beta} \quad (2)$$

Here, K, α, and β represent constants. The value of K exhibits variability within the range of 0.4 to 0.6. Meanwhile, α and β are distinctly defined as 0.7 and 0.3, respectively.

In response to this critique, the mortar's compressive strength stands as a vital parameter as shown above from the definition of European norms and is predominantly utilized for prognosticating masonry compressive strength [40]. Numerous investigations have addressed this topic and devised an empirical relationship by juxtaposing masonry composed of both resilient and robust mortar with bricks, thereby establishing a connection between masonry strength and the properties of brick and mortar. Diverse mortar grades were employed to generate stress-strain profiles for mortar cubes [41], with the primary challenge often being the irregularity exhibited by mortar specimens, resulting in non-compliance with mechanical testing prerequisites. Consequently, various experiments and computational models were executed and formulated to evaluate the impact of non-uniform mortar dimensions on its compressive strength [42,43].

By incorporating these suggested improvements, we believe that our revised article will contribute more comprehensively to the scientific understanding of masonry structures. We greatly value your input and thank you for guiding us toward enhancing the quality and impact of our work. Your feedback is an integral part of the scientific discourse.

A significant number of masonry buildings in the region displayed damage to walls in the form of double-diagonal shear (X) cracking. This type of cracking is a typical vulnerability observed in unreinforced masonry walls subjected to shear forces. When a complete diagonal shear crack develops during an earthquake, the triangular sections created by the cross-diagonal crack become unstable and pose a risk of collapse, particularly when subjected to subsequent aftershocks.

Figure 14 provides typical patterns of diagonal shear failures observed in load-bearing walls as a result of the earthquake in Albania. These cracks highlight the vulnerability of unreinforced masonry walls to shear forces and emphasize the need for appropriate seismic design and reinforcement measures to improve their resistance to such failures.

Figure 14. Shear cracks stemming from diagonal tension in residential masonry buildings in Albania.

Figure 15 depicts an example of pounding, which refers to the collision or impact between adjacent buildings during an earthquake. In this case, the reinforced concrete (RC) building slab is seen to have penetrated the masonry wall of the adjacent building at the corner where the wall meets the roof.

Figure 15. Pounding failure b/w adjacent masonry and RC buildings.

Pounding can occur when there is insufficient separation distance between buildings or when the buildings have different dynamic characteristics during the earthquake. As a result of pounding, significant damage can be inflicted on the structures involved, as seen in the image. The impact of the RC building slab on the masonry wall at the wall-to-roof connection caused damage to both the slab and the masonry. This type of interaction between different building materials can lead to structural failures, compromise the stability of the affected buildings, and increase the overall damage caused by the earthquake. To mitigate the risk of pounding, it is important to consider appropriate separation distances between buildings, incorporate appropriate structural details to accommodate differential movements, and employ suitable design measures to ensure the integrity of the building envelope during seismic events.

Over the past five decades, the majority of structures in Albania have been designed in accordance with the Albanian national code. This code was last revised in 1989 and remains in effect (referred to as KTP-N.2-89), primarily due to Albanian construction legislation that mandates adherence to the Albanian Technical Codes (KTPs) for building construction. The adoption of Eurocode standards has only recently begun, with several construction firms incorporating Eurocodes into their practices. However, the utilization of Eurocodes still remains optional. According to KTP-89 guidelines, the calculation for determining the minimum seismic joint is derived using the following formula:

$$SG = u_i + u_j + 2\ \text{cm} \quad (3)$$

where SG is the separation gap, u_i is the maximum displacement of building 1 and u_j is the maximum displacement of building 2.

According to KTP-89, the SG should fulfill the following:

$$SG \geq h/250 \text{ and } SG \geq 3\ \text{cm} \quad (4)$$

where h is the height of the shortest building.

This earthquake led to minor damages in several buildings attributed to pounding, a phenomenon stemming from inadequately sized or absent seismic gaps, alongside variations in story heights. The structure depicted in Figure 15 encountered damage from pounding, primarily resulting from its proximity to an adjacent masonry building and an inadequate seismic gap.

To effectively mitigate pounding effects between neighboring buildings during earthquakes, a range of strategies can be employed. These include creating seismic gaps to allow for relative movement, utilizing seismic isolation devices to absorb energy and introduce flexibility, implementing tuned mass dampers to counter vibrations, and designing setbacks to minimize direct contact. Incorporating damping systems, strengthening existing structures, improving planning and zoning regulations, and conducting clearance analyses are also effective measures. Raising awareness among professionals, updating building codes, and fostering collaborative design further enhance prevention. By combining these strategies, the risk of pounding effects can be significantly reduced, bolstering overall structural safety and resilience in seismic-prone areas.

Figure 16a,b showcase significant vertical cracks and gaps that have developed and spread along the height of the intersections of bearing walls. This particular type of damage can be attributed to the absence of horizontal diaphragms. Horizontal diaphragms are structural components that provide rigidity and distribute forces within a building. Without these diaphragms, the building's ability to withstand and distribute seismic forces is compromised, leading to the formation of such vertical cracks and gaps.

The lack of proper connections between the load-bearing walls at the intersections and between the load-bearing walls and the roof leads to compromised structural stability. Consequently, the walls act individually along the in-plane and out-of-plane directions during the earthquake, as indicated by the absence of diagonal shear cracks. The vertical cracks and gaps indicate significant distress and compromised load-bearing capacity in the masonry walls. This type of damage can lead to instability, reduced structural strength, and potential collapse if the load-bearing capacity is further compromised. To enhance the seismic performance of masonry buildings, it is crucial to incorporate effective horizontal diaphragms that can distribute forces and provide structural continuity. Proper design and construction of connections between bearing walls and diaphragms are essential to ensure the effective transfer of forces and maintain the structural stability of the building during earthquakes.

(**a**) (**b**)

Figure 16. Vertical cracks on corners of the building indicates the lack of rigid diaphragm action of the roof and floor systems. (**a**) Loosely connected walls; (**b**) Absence of a sturdy toop roof or lack of RC ring beam.

5.2.2. School Buildings

In Albania, school structures are commonly characterized by their spaciousness and symmetry. These buildings have been designed with enhanced craftsmanship, featuring well-executed linkages between walls, appropriately positioned lintels above doors and windows, beams, and horizontal bands at different elevations. Despite these details, the observed failures in school buildings follow a similar pattern to that of residential masonry buildings.

Figure 17 depicts the extent of damage in a school building located in the NW Durres. Fortunately, all students and teachers were unharmed, as the collapse of some local masonry walls did not result in casualties since the earthquake hit in the early morning. The damage in the school building includes localized out-of-plane failures of the load-bearing walls and diagonal shear cracks between the window openings on the ground floor (Figure 18).

Figure 17. The extent of damage on a school building.

Figure 18. Showing shear cracks and in-plane failure of the masonry walls.

Significantly, the school's front facade experienced more damage than the backside. This discrepancy can be attributed to the higher concentration of openings at the front, where the classrooms were situated, in contrast to the back side, which primarily consisted of a corridor leading to the classrooms. Upon inspection inside the building, prominent diagonal shear failures were observed in the masonry walls, along with the separation of coating materials from the walls and the toppling of furniture and equipment (Figure 19). The overall structural condition of the building was deemed unsuitable, leading to its demolition a few weeks after the initial strong earthquake. These observations highlight the vulnerability of masonry school buildings in Albania and emphasize the importance of implementing proper seismic design and retrofitting measures to ensure the safety of students and staff during earthquakes.

Figure 19. Damage pattern observed on load-bearing wall of the masonry school building.

6. Analytical Modeling of Masonry

Masonry material is a compound of bricks or blocks arranged in a specific pattern, linked or not with mortar. The longevity of this construction technique highlights its advantages; however, masonry presents a complex challenge in terms of modeling. Structural engineers grapple with the numerical modeling of these structures due to the prominence of joints as primary sources of vulnerability, interruption, nonlinearity, and the inherent material characteristics' uncertainties. A comprehensive model must account for two essential structural behaviors: (1) the response of masonry units, such as bricks and (2) the response of joint material, like mortar. In the pursuit of a suitable model, extensive research has been conducted involving theoretical approaches, laboratory experiments, and field investigations. Analytical methodologies in this context can be classified into three tiers of refinement for masonry models, as outlined by [44,45].

Micro-modeling represents a distinct approach, wherein micromechanics assume a pivotal role in predicting both localized and overall responses of the masonry while considering interface behavior and damage across different components. This method involves characterizing units and mortar within joints using continuum elements, whereas the interface between units and mortar is modeled using discontinuum elements [46,47]. While this approach indeed offers higher accuracy, its level of complexity and the computational demands it imposes restrict its applicability to scenarios such as small-scale laboratory specimens and structures.

Meso-modeling is an intermediate modeling strategy between the detailed micro-modeling and macro-modeling approaches. This approach is based on a repetitive regular pattern of masonry units, which can be replicated and extended throughout the structure. In this method, the individual units, like bricks, are simulated using hypothetical extended units, represented by continuum elements sized to match the original brick dimensions, combined with the real joint thickness. Simultaneously, the mortar joint is represented as an interface with negligible thickness. This technique effectively reduces computational costs and results in a model that holds applicability across a broader spectrum of structural scenarios. The main practical drawback of this approach is that it is not implemented in common software packages, as they mainly adopt hybrid numerical techniques from discrete and finite elements; however, they are preferable among the scientific community [48–50].

Macro-modeling is an approach where bricks, mortar, and the brick-mortar interface are blended into a uniform continuum. In this approach, masonry is treated as a uniform material, whether homogeneous, isotropic, or anisotropic, lending itself to representation through phenomenological models. It is worth highlighting that the approaches assumed for this strategy impede accounting for the significant influence of existing mortar joints, which serve as primary sources of weakness and inelasticity. Nevertheless, this method may suit the analysis of extensive masonry structures, [51] and has been a valuable tool for structural analysis and seismic safety estimation of new and existing masonry structures.

In the past years, the interest in studying masonry structures has grown, affected by many reasons but mainly by the causes of earthquakes worldwide. In the Albanian context, the literature dealing with this matter was very poor, and the instruments of investigation were limited. Based on the best practices, many authors have adopted macro-modeling strategies as a fast and reliable approach. Those recent studies furnished insights into the mechanical properties of masonry, structural detailing typologies, and global structural analysis [5,6,8,19,29].

7. Lessons Learned from Reconnaissance

The earthquakes of 2019 in Albania brought attention to the vulnerability of existing masonry dwellings in the country. The lessons learned from the damage survey conducted after the earthquake provide valuable insights into improving buildings' seismic resilience in similar regions. Some key lessons can be summarized as follows:

- The effectiveness of new design codes and standards is evident in the limited damage observed in RC buildings compared to severe damage in masonry buildings. This highlights the importance of adhering to and continuously improving seismic design regulations. However, it is crucial to remain cautious as future earthquakes may present greater challenges that need to be considered in design practices.

- The poor performance of masonry buildings can be attributed to various factors, including inadequate construction typologies, low-quality materials, and a lack of maintenance. Addressing these issues through improved construction practices, material quality control, and regular maintenance programs is essential to enhance the seismic resilience of masonry structures.
- The localized nature of building damage within the same region of Durrës indicates the influence of local soil characteristics and structural weaknesses. Conducting micro-zonation studies to better understand the local site characteristics would provide valuable insights for future construction and retrofitting strategies.
- Out-of-plane failures were frequently observed in masonry structures, especially when the roof diaphragm was insufficient. Strengthening measures, such as improving roof diaphragm connections and enhancing the out-of-plane strength of walls, should be considered in retrofitting strategies.
- Urgent action is needed to futureproof public buildings' seismic vulnerability, including schools and hospitals, with particular attention given to older masonry structures. These buildings play a crucial role in community safety and must be prioritized for rehabilitation and strengthening measures.
- Fortunately, there are available rehabilitation strategies for strengthening existing masonry structures. These strategies focus on improving connections, stiffening floor diaphragms, and enhancing masonry material properties. Information on seismic retrofitting techniques for masonry can be found in relevant research studies and publications [5,19].

By incorporating these lessons and recommendations into future building practices, disaster management plans, and seismic retrofitting efforts, the region can enhance its resilience to earthquakes and protect the lives and infrastructure of the communities.

8. Conclusions

The careful analysis of the earthquake that occurred on 26 November 2019 in Albania is crucial for a better understanding of its impact on our built environment. Although contemporary seismic codes offer substantial protection against significant earthquakes for buildings, the vulnerability persists for rural structures, public edifices constructed with reduced or no seismic regulations (like schools), and historical buildings when facing medium to large magnitude earthquakes. Although there is a lack of strong ground motion records due to the electricity cut in Durres station, initial indications suggest that the acceleration response in short periods could be higher than anticipated. It is important to consider these factors in future seismic design and assessment. This paper presents valuable field observations of earthquake damage in Albania following the consecutive earthquakes with magnitudes of $M_w = 5.6$ and $M_w = 6.4$ on 21 September and 26 November, respectively. The damage investigation data were collected after several site visits to the earthquake-stricken areas. To better understand the observed damage in the region, the regional seismicity in the area was reviewed, and available data, as well as ground motion data, were analyzed and discussed. These efforts contribute to enhancing our knowledge of the earthquake response of structures in the region and can inform future mitigation strategies and building practices. Overall, this comprehensive analysis of the Durres (Albania) earthquake provides valuable insights into the vulnerability of masonry buildings and highlights the need for continued research, improved design standards, and enhanced seismic resilience in the affected region.

During the Durres earthquake, the primary form of collapse seen in masonry buildings involved the tilting or overturning of the longer sides of the structures, both within the plane of the walls and outward from the plane of the walls. Total collapse of buildings was also observed in some cases. In instances of double-leaf stonework, a process of masonry wall layers separating, known as delamination, was witnessed, subsequently leading to the out-of-plane collapse of a single layer. This delamination phenomenon is attributed to the absence of proper interlocking between the two layers of the wall. On the short sides of the buildings, in-plane shear cracks were commonly observed in the masonry walls, while out-of-plane failure was relatively rare. The lack of sufficient diaphragm action at the floor and roof levels was also identified as a problem. Within timber floors, such issues might arise due to insufficient links between wooden beams and the walls, or it could be a result of diminished rigidity within the wood flooring, often caused by decay or deterioration. Regarding the roof, insufficient roof connectivity was observed in two scenarios. First, there was a complete lack of a timber or reinforced concrete belt at the crown of the masonry walls. Second, in cases where a half-width band existed, it was only present on the inner leaf of the masonry to maintain architectural aesthetics, leaving the outer leaf disconnected from the roof diaphragm. As a result, the masonry experienced delamination, causing the outer leaf to fail out-of-plane. These observations highlight the importance of proper interlocking between masonry leaves, adequate diaphragm action, and appropriate roof connectivity to ensure the structural integrity of masonry buildings during earthquakes. Addressing these deficiencies through improved construction practices and retrofitting techniques can enhance the seismic resilience of masonry structures.

The poor quality of bonding mortars played a significant role in the failures observed in masonry buildings. Over time, these mortars deteriorate and lose their strength, especially in the case of clay mortar. The lack of maintenance further contributed to the decline in mortar quality, making the masonry walls more susceptible to damage. Another factor that led to failures was the interaction between masonry buildings and newer reinforced concrete (RC) buildings without proper seismic joints. In cases where masonry buildings were in contact with RC buildings, damage occurred due to pounding. The differential stiffness and fundamental periods of vibration between the two structures resulted in pounding effects during the earthquake. This phenomenon was also observed in cases where masonry buildings were horizontally extended with RC additions. A specific case worth mentioning is the semi-open entrance area added to several buildings, which was constructed using reinforced concrete. This supplementary framework generally comprises columns that uphold a reinforced concrete slab, frequently without incorporating beams. Given that this slab is commonly situated at a level lower than the building's roof, there is a potential for a pounding effect to transpire in the event of an earthquake. These observations highlight the importance of considering the compatibility of different construction materials and techniques when extending or modifying existing buildings. Proper seismic joints, maintenance of bonding mortars, and appropriate design measures can help mitigate the risks associated with differential stiffness and pounding effects, ensuring the structural integrity of buildings during seismic events.

It is essential to emphasize that the paper's discussions on post-earthquake structural observations do not encompass the reactions of foundations or their potential contribution to the overall extent of damage. Understanding the behavior of foundations during earthquakes is crucial as they provide the base support for the entire structure. The performance of foundations can significantly impact the overall stability and structural integrity of a building during seismic events. Factors such as soil conditions, foundation design, and construction quality can all influence the response of foundations to ground shaking. Given the importance of foundations, further investigations and assessments of the foundation elements are necessary to comprehensively understand the overall structural behavior during the earthquake. These investigations may include site-specific geotechnical studies, assessments of foundation types, and evaluations of their adequacy and potential vulnerabilities. It is recommended that future research and assessments consider the response of foundations in order to provide a more complete analysis of the seismic performance of buildings and to inform appropriate mitigation strategies for future earthquakes.

The Albanian governmental entities tasked with overseeing building regulations should take the initiative to either update the existing Albanian seismic design code, KTP-

N.2-89 or establish Eurocodes as mandatory design standards, enforcing their application in practical scenarios. For instance, Eurocode 8 (EN 1998-1:2005) incorporates guidelines pertinent to the factors contributing to damage in reinforced concrete (RC) buildings affected by the 2019 earthquakes in Albania. These provisions encompass aspects like robust reinforcement detailing, constraining inter-story drifts, and mandating the explicit management of irregularities in both plan and elevation configurations.

Author Contributions: Conceptualization, H.B. and M.L.; methodology, H.B.; software, H.B.; validation, H.B., R.S. and R.O.; formal analysis, H.B.; investigation, H.B.; resources, H.B., M.L., R.S., H.B.Ö., A.H.D., R.O.; data curation, M.L., H.B.; writing—original draft preparation, H.B., M.L.; writing—review and editing, H.B., R.S.; supervision, H.B.; project administration, H.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: All authors declare that the research conducted herein was in the absence of any commercial or financial relationship that could be constructed as a potential conflict of interest.

References

1. Elnashai, A.S.; Di Sarno, L. *Fundamentals of Earthquake Engineering: From Source to Fragility*; John Wiley & Sons: Hoboken, NJ, USA, 2008; Volume 43.
2. Aydinoğlu, M.N.; Önem, G. Evaluation of Analysis Procedures for Seismic Assessment and Retrofit Design. *Geotech. Geol. Earthq. Eng.* **2010**, *17*, 171–198. https://doi.org/10.1007/978-90-481-9544-2_8.
3. Chopra, A.K. *Dynamics of structures: Theory and Applications to Earthquake Engineering*, 4th ed.; Prentice Hall: Hoboken, NJ, USA, 2011; ISBN 013156174X.
4. Shehu, R.; Angjeliu, G.; Bilgin, H. A simple approach for the design of ductile earthquake-resisting frame structures counting for P-Delta Effect. *Buildings* **2019**, *9*, 216. https://doi.org/10.3390/buildings9100216.
5. Bilgin, H.; Shkodrani, N.; Hysenlliu, M.; Baytan Ozmen, H.; Isik, E.; Harirchian, E. Damage and performance evaluation of masonry buildings constructed in 1970s during the 2019 Albania earthquakes. *Eng. Fail. Anal.* **2021**, *131*, 105824. https://doi.org/10.1016/j.engfailanal.2021.105824.
6. 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 .
7. Republic of Albania Council of Ministers. *Albania Post-Disaster Needs Assessment Report*; Republic of Albania Council of Ministers: Tirana, Albania, 2020.
8. Bilgin, H.; Huta, E. Earthquake performance assessment of low and mid-rise buildings: Emphasis on URM buildings in Albania. *Earthq. Struct.* **2018**, *14*, 599–614.
9. Valente, M.; Milani, G. Damage assessment and partial failure mechanisms activation of historical masonry churches under seismic actions: Three case studies in Mantua. *Eng. Fail. Anal.* **2018**, *92*, 495–519. https://doi.org/10.1016/j.engfailanal.2018.06.017.
10. Sorrentino, L.; Cattari, S.; da Porto, F.; Magenes, G.; Penna, A. Seismic behaviour of ordinary masonry buildings during the 2016 central Italy earthquakes. *Bull. Earthq. Eng.* **2019**, *17*, 5583–5607. https://doi.org/10.1007/s10518-018-0370-4.
11. Bru, D.; Ivorra, S.; Baeza, F.J.; Reynau, R.; Foti, D. OMA dynamic identification of a masonry chimney with severe cracking condition. In Proceedings of the 6th International Operational Modal Analysis Conference, IOMAC 2015, Gijon, Spain, 12–14 May 2015.
12. Foti, D. A new experimental approach to the pushover analysis of masonry buildings. *Comput. Struct.* **2015**, *147*, 165–171. https://doi.org/10.1016/j.compstruc.2014.09.014.
13. Clementi, F.; Gazzani, V.; Poiani, M.; Lenci, S. Assessment of seismic behaviour of heritage masonry buildings using numerical modelling. *J. Build. Eng.* **2016**, *8*, 29–47. https://doi.org/10.1016/j.jobe.2016.09.005.
14. Lagomarsino, S.; Camilletti, D.; Cattari, S.; Marino, S. Seismic assessment of existing irregular masonry buildings by nonlinear static and dynamic analyses. In *Geotechnical, Geological and Earthquake Engineering*; Springer: Berlin/Heidelberg, Germany, 2018; Volume 46.
15. Foti, D. On the numerical and experimental strengthening assessment of tufa masonry with FRP. *Mech. Adv. Mater. Struct.* **2013**, *20*, 163–175. https://doi.org/10.1080/15376494.2012.743634.
16. Freddi, F.; Novelli, V.; Gentile, R.; Veliu, E.; Andreev, S.; Andonov, A.; Greco, F.; Zhuleku, E. Observations from the 26th November 2019 Albania earthquake: The earthquake engineering field investigation team (EEFIT) mission. *Bull. Earthq. Eng.* **2021**, *19*, 2013–2044. https://doi.org/10.1007/s10518-021-01062-8.

17. Métois, M.; Benjelloun, M.; Lasserre, C.; Grandin, R.L.; Barrier, L.; Dushi, E.; Koçi, R. Subsidence associated with oil extraction, measured from time series analysis of Sentinel-1 data: Case study of the Patos-Marinza oil field, Albania. *Solid Earth* **2020**, *11*, 363–378. https://doi.org/10.5194/se-11-363-2020.
18. Duni, L.; Theodoulidis, N. Short note on the November 26, 2019, Durres (Albania) M6.4 Earthquake: Strong Ground Motion with Emphasis in Durres City. 2019. Available online: http://www.ssis.org.al/wp-content/uploads/2020/01/Short-Note_EMSC_Duni-Theodoulidis-1.pdf (accessed on 29 August 2023).
19. Bilgin, H.; Hysenlliu, M. Comparison of near and far-fault ground motion effects on low and mid-rise masonry buildings. *J. Build. Eng.* **2020**, *30*, 101248. https://doi.org/10.1016/j.jobe.2020.101248.
20. Publication of Academy of Sciences and Ministry of Constructions. *KTP 2-89, "Technical Design Regulations for Construction Works in Seismic Regions"*; Publication of Academy of Sciences and Ministry of Constructions: Tirana, Albania, 1989.
21. Publication of Academy of Sciences and Ministry of Constructions. *KTP 2-78, "Technical Design Regulations for Construction Works in Seismic Regions"*; Publication of Academy of Sciences and Ministry of Constructions: Tirana, Albania, 1978; pp. 12–48.
22. UNDP. *Disaster Management and Emergency Preparedness Project, Risk Assessment of Albania*; UNDP: Tirana, Albania, 2003.
23. Medvedev, S.V., Spohneuer, W. and Karnik, V. (1965) Seismic Intensity Scale Version MSK 1964. Akad. Nauk SSSR, Geofiz. Kom., 10. (In Moscow).
24. *EC-8-P-1*; Eurocode 8: Design of Structures for Earthquake Resistance—Part 1; European Standard: Geneva, Switzerland, 2014; Volume 3.
25. Albanian Institute of Statistics (INSTAT). *Population and Housing Census 2001*; INSTAT: Tirana, Albania, 2001.
26. Albanian Institute of Statistics (INSTAT). *Population and Housing Census 2011*; INSTAT: Tirana, Albania, 2011.
27. Bilgin, H.; Korini, O. Seismic capacity evaluation of unreinforced masonry residential buildings in Albania. *Nat. Hazards Earth Syst. Sci.* **2012**, *12*, 3753–3764. https://doi.org/10.5194/nhess-12-3753-2012.
28. Shkodrani, N.; Bilgin, H.; Hysenlliu, M. Influence of interventions on the seismic performance of URM buildings designed according to pre-modern codes. *Res. Eng. Struct. Mater.* **2021**, *7*, 315–330. https://doi.org/10.17515/resm2020.197ea0331.
29. Hysenlliu, M.; Bidaj, A.; Bilgin, H. Influence of material properties on the seismic response of masonry buildings. *Res. Eng. Struct. Mater.* **2020**, *6*, 425–437. https://doi.org/10.17515/resm2020.177st0120.
30. Işık, E.; Avcil, F.; Harirchian, E.; Arkan, E.; Bilgin, H.; Özmen, H.B. Architectural Characteristics and Seismic Vulnerability Assessment of a Historical Masonry Minaret under Different Seismic Risks and Probabilities of Exceedance. *Buildings* **2022**, *12*, 1200. https://doi.org/10.3390/buildings12081200.
31. Manos, G.C. The 30th of october samos-greece earthquake. Issues relevant to the protection from structural damage caused by strong earthquake ground motions. *Archit. Eng.* **2021**, *5*, 3–17. https://doi.org/10.23968/2500-0055-2020-5-4-03-17.
32. Borri, A.; Sisti, R.; Corradi, M.; Giannantoni, A. Experimental analysis of masonry ring beams reinforced with composite materials. In Proceedings of the Brick and Block Masonry: Trends, Innovations and Challenges—Proceedings of the 16th International Brick and Block Masonry Conference, IBMAC 2016, Padova, Italy, 26–30 June 2016.
33. Calderoni, B.; Cordasco, E.A.; Del Zoppo, M.; Prota, A. Damage assessment of modern masonry buildings after the L'Aquila earthquake. *Bull. Earthq. Eng.* **2020**, *18*, 2275–2301. https://doi.org/10.1007/s10518-020-00784-5.
34. Günaydin, M.; Atmaca, B.; Demir, S.; Altunişik, A.C.; Hüsem, M.; Adanur, S.; Ateş, Ş.; Angin, Z. Seismic damage assessment of masonry buildings in Elazığ and Malatya following the 2020 Elazığ-Sivrice earthquake, Turkey. *Bull. Earthq. Eng.* **2021**, *19*, 2421–2456. https://doi.org/10.1007/s10518-021-01073-5.
35. Yön, B.; Onat, O.; Emin Öncü, M.; Karaşïn, A. Failures of masonry dwelling triggered by East Anatolian Fault earthquakes in Turkey. *Soil Dyn. Earthq. Eng.* **2020**, *133*, 106126. https://doi.org/10.1016/j.soildyn.2020.106126.
36. Godínez-Domínguez, E.A.; Tena-Colunga, A.; Pérez-Rocha, L.E.; Archundia-Aranda, H.I.; Gómez-Bernal, A.; Ruiz-Torres, R.P.; Escamilla-Cruz, J.L. The September 7, 2017 Tehuantepec, Mexico, earthquake: Damage assessment in masonry structures for housing. *Int. J. Disaster Risk Reduct.* **2021**, *56*, 102123. https://doi.org/10.1016/j.ijdrr.2021.102123.
37. *EC-6-P-1*; EN1996 Eurocode 6: Design of Masonry Structures. European Standard: Geneva, Switzerland, 2005.
38. *ACI 530-02/ASCE 5-02/TMS 402-02*; Building Code Requirements for Masonry Structures. American Concrete Institute: Indianapolis, IN, USA; Structural Engineering Institute of the American Society of Civil Engineers: Reston, VA, USA; The Masonry Society: Longmont, CO, USA, 2002.
39. Derakhshan, H.; Visintin, P.; Griffith, M.C. Case studies of material properties of late nineteenth-century unreinforced masonry buildings in Adelaide. *Aust. J. Civ. Eng.* **2017**, *15*, 109–116. https://doi.org/10.1080/14488353.2017.1401196.
40. Gumaste, K.S.; Rao, K.S.N.; Reddy, B.V.V.; Jagadish, K.S. Strength and elasticity of brick masonry prisms and wallettes under compression. *Mater. Struct.* **2007**, *40*, 241–253. https://doi.org/10.1617/s11527-006-9141-9.
41. Kaushik, H.B.; Rai, D.C.; Jain, S.K. Stress-Strain Characteristics of Clay Brick Masonry under Uniaxial Compression. *J. Mater. Civ. Eng.* **2007**, *19*, 728–739. https://doi.org/10.1061/(ASCE)0899-1561(2007)19:9(728).
42. Kandymov, N.; Masha, A.; Durdyev, S.; Yardim, Y. Construction materials' properties: Investigation of unreinforced masonry buildings in the cities of Tirana, Durres and Elbasan. *Case Stud. Constr. Mater.* **2020**, *13*, e00395. https://doi.org/10.1016/j.cscm.2020.e00395.
43. Drdácký, M.; Mašín, D.; Mekonone, M.; Slížková, Z. Compression tests on non-standard historic mortar specimens. In Proceedings of the Historical Mortars Conference HMC08, Lisbon, Portugal, 24–26 September 2008.
44. Lourenço, P.B. Computations on historic masonry structures. *Prog. Struct. Engng Mater.* **2002**, *4*, 301–319. https://doi.org/10.1002/pse.120.

45. Asteris, P.G.; Chronopoulos, M.P.; Chrysostomou, C.Z.; Varum, H.; Plevris, V.; Kyriakides, N.; Silva, V. Seismic vulnerability assessment of historical masonry structural systems. *Eng. Struct.* **2014**, *62–63*, 118–134. https://doi.org/10.1016/j.engstruct.2014.01.031.
46. Lotfi, H.R.; Shing, P.B. Interface Model Applied to Fracture of Masonry Structures. *J. Struct. Eng.* **1994**, *120*, 63–80. https://doi.org/10.1061/(ASCE)0733-9445(1994)120:1(63).
47. Lourenço, P.B.; Rots, J.G.; Blaauwendraad, J. Two approaches for the analysis of masonry structures—Micro and macro-modeling. *Heron* **1995**, *40*, 313–340.
48. Minga, E.; Macorini, L.; Izzuddin, B.A. A 3D mesoscale damage-plasticity approach for masonry structures under cyclic loading. *Meccanica* **2018**, *53*, 1591–1611. https://doi.org/10.1007/s11012-017-0793-z.
49. D'Altri, A.M.; Sarhosis, V.; Milani, G.; Rots, J.; Cattari, S.; Lagomarsino, S.; Sacco, E.; Tralli, A.; Castellazzi, G.; de Miranda, S. Modeling Strategies for the Computational Analysis of Unreinforced Masonry Structures: Review and Classification. *Arch. Comput. Methods Eng.* **2020**, *27*, 1153–1185. https://doi.org/10.1007/s11831-019-09351-x.
50. Vadalà, F.; Cusmano, V.; Funari, M.F.; Caliò, I.; Lourenço, P.B. On the use of a mesoscale masonry pattern representation in discrete macro-element approach. *J. Build. Eng.* **2022**, *50*, 104182. https://doi.org/10.1016/j.jobe.2022.104182.
51. Lagomarsino, S.; Giovinazzi, S. Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. *Bull. Earthq. Eng.* **2006**, *4*, 415–443. https://doi.org/10.1007/s10518-006-9024-z.