



EERI Earthquake Reconnaissance Report:

M6.4 Albania Earthquake on November 26, 2019

Volume 1: Executive Summary



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1 INTRODUCTION

1.1 Organization of the EERI Earthquake Reconnaissance Report

This report is divided into four volumes. Volume 1 is the Executive Summary, which provides a brief overview of the key observations in all areas. The remaining volumes provide relevant background and in-depth descriptions of these observations.

- Volume 2, “Seismology and Geotechnical Effects,” describes seismological aspects of the earthquake and a summary of geotechnical impacts.
- Volume 3, “Resilience and Recovery,” describes response and recovery as well as the performance of lifelines and transportation infrastructure.
- Volume 4, “Building Performance,” focuses on the performance of major construction types: residential masonry buildings, cast-in-place reinforced concrete buildings, and prefabricated reinforced concrete buildings. Performance of special use buildings, including schools, hospitals, and heritage and religious structures, is also described. An overview of Albanian building codes and construction practices is also provided in this volume, along with damage assessment data collected by several of the reconnaissance teams.

1.2 Overview of Reconnaissance Teams

In the days and months following the M6.4 earthquake near Durrës, Albania, on November 26, 2019, several individuals and teams performed field reconnaissance to study the impacts of this earthquake. The Earthquake Engineering Research Institute (EERI) served as an intermediary between these groups by connecting them via conference calls. EERI did not send an independent reconnaissance team. This report is a collaborative effort that summarizes the observations of these teams and individuals. The teams and reconnaissance dates of contributing authors are summarized in Table 1.

EERI established [an event page](#) for this earthquake on the Learning for Earthquakes website.

Table 1: Summary of teams and reconnaissance dates.

Dates	Affiliation	Report Authors
November 26, 2019	Department of Dynamic Tectonic Applied Geology, National and Kapodistrian University of Athens	Panayotis Carydis, Efthymios Lekkas, Spyridon Mavroulis
November 27-28, 2019	Independent	Chiara McKenney
December 13-18, 2019	Earthquake Engineering Field Investigation Team (EEFIT)	Anton Andonov, Fabio Freddi, Federica Greco, Roberto Gentile, Viviana Novelli, Enes Veliu
December 14-15, 2019	Hellenic Society of Earthquake Engineering	Georgios Baltzopoulos, Christos Giarlelis, Olga Markogiannaki, Anastasios Sextos, Despoina Skoulidou, Sotiria Stefanidou
December 27-30, 2019	Serbian Association of Earthquake Engineering (SUZI-SAAE)	Nikola Blagojević, Svetlana Brzev, Marko Marinković, Ivan Milićević
December 28-29, 2019	Universidade NOVA de Lisboa	Brisid Isufi
February 9-16, 2020	L'Association Française du Génie Parasismique (AFPS)	Stéphane Brûlé
December 20, 2019-January 26, 2020	United Nations Development Programme (UNDP), Albania/ Resipro Engineering International Limited	Jitendra Bothara
Various	Faculty of Civil Engineering, Polytechnic University of Tirana	Markel Baballëku
Various	Department of Architecture and Engineering, Polis University	Merita Guri
Various	Institute of Geosciences, Energy, Water and Environment (IGEWE), Polytechnic University of Tirana, Institute of Engineering Seismology & Earthquake Engineering	Llambro Duni, Edmond Dushi, Grendas Ioannis, Rexhep Koçi, Nikolaos Theodoulidis

1.3 Overview of earthquake

On the morning of Tuesday, November 26, 2019, at 3:54 local time, an M_w 6.4 earthquake struck 16 km north of Durrës, a port city on the Adriatic coast and the second largest city in Albania. The epicenter was 33 km northwest of Tirana, the largest city and capital of Albania. Deaths and injuries were concentrated in Durrës and the village of Thumanë, though Tirana and several smaller municipalities in northwestern Albania were also affected. With 51 fatalities, the earthquake was the deadliest worldwide in 2019. At least 913 people were injured, including 255 individuals who were injured during the aftershock sequence.

The earthquake was preceded by an M_w 5.6 foreshock on September 21, 2019, at 14:04 local time, 12 km north of Durrës. The period after the November 26, 2019, earthquake was characterized by a great number of aftershocks. During the period from November 26, 2019, to June 30, 2020, over 2,000 events were recorded by the Albanian Seismological Network, including five aftershocks greater than M_5 .

The September 21, 2019, and the November 26, 2019, earthquakes are the strongest earthquakes that have affected Albania in the last 40 years. The strongest event to affect Albania in the 20th century occurred on April 15, 1979 (M_w 6.9). This event had an epicenter on the southern coast of Montenegro (approximately 75 km from Durrës), but it caused loss of life and building damage in the northern part of Albania.

2 SEISMOLOGY AND GROUND MOTION

Albania is located in southeastern Europe on the Balkan Peninsula. The Durrës region is situated in the Periadriatic Foredeep, an area where the Adriatic microplate subducts under the Eurasian Plate. The Outer Albanides geological structure, where the Durrës region is located, is characterized by an active and complicated geologic-tectonic structure (Aliaj et al., 1996).¹ The M_w 6.4 earthquake on November 26, 2019, was caused by an east dipping, blind, thrust fault located under the Durrës syncline. It is estimated that the subsurface fault rupture length was about 19 km.

The epicenter of the earthquake was 16 km from Durrës. The earthquake ground shaking lasted around 50 seconds; however, the strong motion recording in Durrës lasted only 15 seconds due to a loss of electricity. The peak acceleration measured was approximately 0.2g (192 cm/s²), and the maximum Intensity estimated in Durrës was VIII (severe) based on the Medvedev–Sponheuer–Karnik scale; see Figure 1. The Durrës basin has characteristics that amplify ground motion, and for periods between 0.3 seconds and 1.0 seconds, the spectral acceleration in Durrës was high with values around 0.5g, which contributed to the damage of mid-rise buildings (5 to 10 stories) in downtown Durrës (Figure 2).

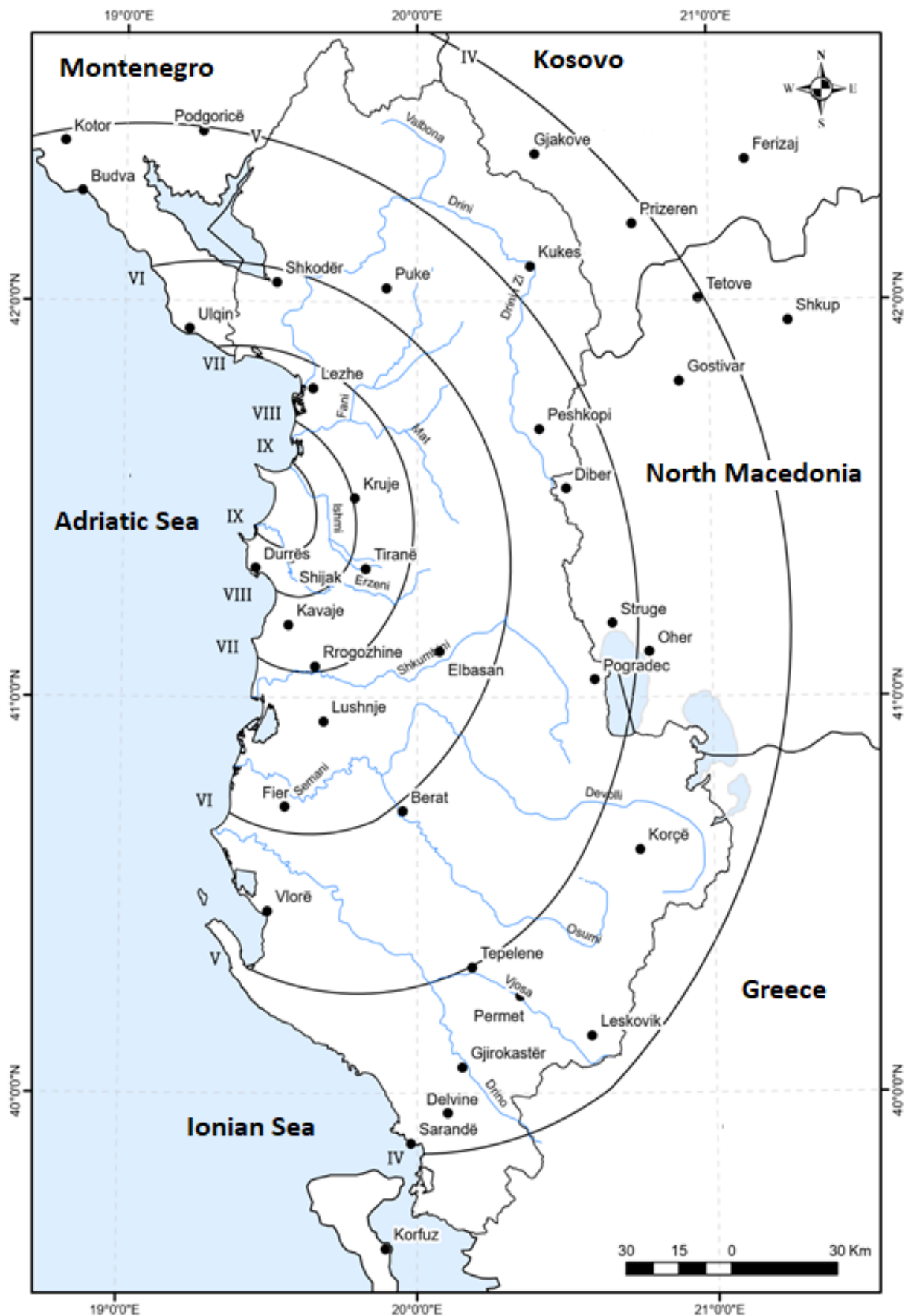


Figure 1. Observed MMI distribution related to the November 26, 2019, ($M_w6.4$) earthquake (source: Koci et al., 2019).²

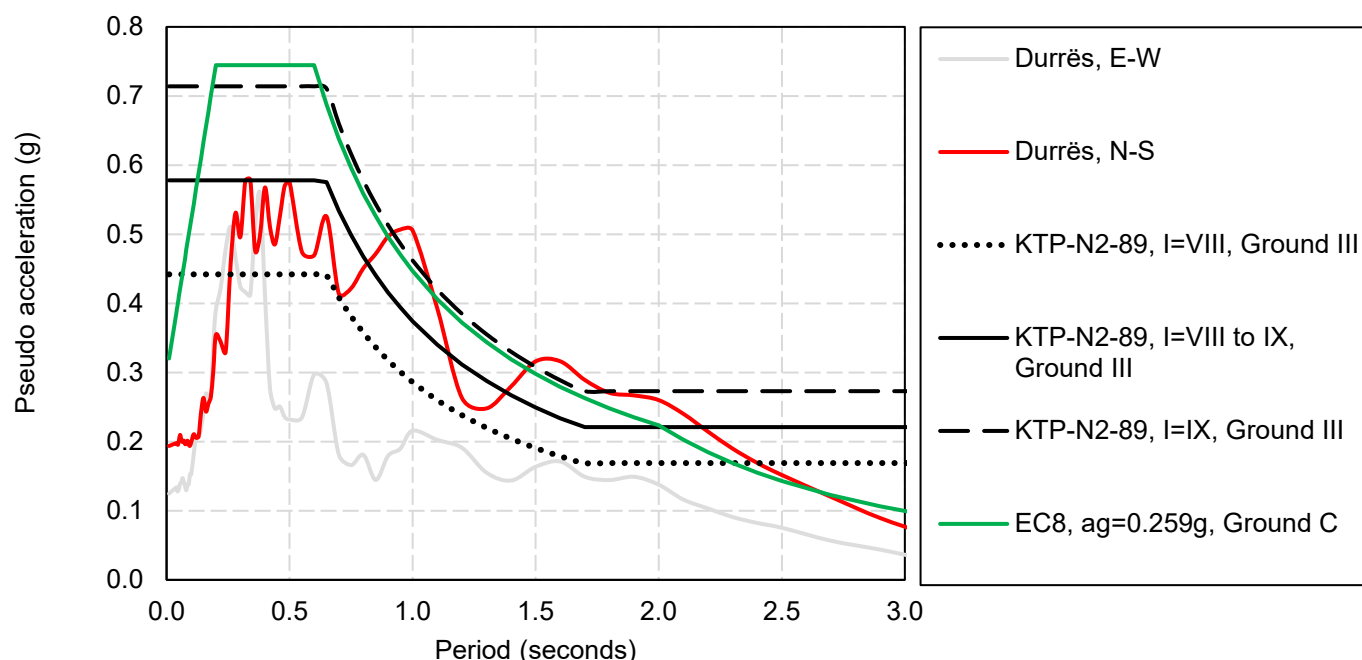


Figure 2. Elastic spectra according to KTP-N.2-89 and EC8 codes and the 5% damped horizontal pseudoacceleration response spectra for recorded motions at the Durrës station during the November 26, 2019, mainshock.

Figure 2 presents the 5% damped pseudoacceleration response spectra corresponding to the north-south and east-west oriented components of the recorded ground motion at the station in Durrës, along with the spectra corresponding to the 1989 Albanian seismic design code KTP-N.2-89 (Academy of Sciences and Ministry for Construction, 1989)³ for seismic intensities VIII, between VIII and IX, and IX, and soft soil conditions (category III) corresponding to the station site. Although KTP-N.2-89 is still the official code in Albania, in recent years, Eurocode 8 has been increasingly used for design applications on a voluntary basis. For comparison, a Eurocode 8 (European Committee for Standardization, 2004)⁴ elastic spectrum is also plotted for ground type C (based on the average value of propagation velocity of S waves in the upper 30 m of the soil profile at a shear strain of 10^{-5} or less, $v_{s,30} = 202$ m/s, for the Durrës station) and the reference peak ground acceleration on rock equals 0.259g for a return period of 475 years based on recent seismic hazard studies (IGEWE, 2021).⁵

It can be seen from Figure 2 that the spectral accelerations in the north-south direction are close to the KTP-N.2-89 spectra values for the frequency range corresponding to mid-rise buildings. The Eurocode 8 elastic spectrum developed for peak ground acceleration levels based on recent studies is close to the KTP-N.2-89 spectrum for intensity IX, but ground conditions are even worse in other parts of the city of Durrës, which indicates that the Eurocode 8 requirements combined with recent seismic hazard studies are more demanding for the structures in Durrës. For all periods except for those around 1s and those between 1.4s and 2.2s, it can be observed that the spectra corresponding to recorded ground accelerations are within the range of elastic spectra based on KTP-N.2-89 code for seismic intensity between VIII and IX corresponding to the epicentral area of the earthquake. The KTP-N.2-89 spectrum for the highest intensity (IX) envelops the recorded spectra for almost the entire range of periods, except for localized spikes in spectral values near 1s and 1.5s.

3 GEOTECHNICAL EFFECTS

Northwestern Albania is highly susceptible to geotechnical effects, including liquefaction and slope movement. This susceptibility has been assessed by relevant studies on the landslide and liquefaction susceptibility and the history of the Periadriatic Depression. The slope movements and liquefaction phenomena observed after the November 26, 2019 mainshock and the September 21, 2019 foreshock were characteristic of the region.

Liquefaction phenomena were triggered by the November mainshock in several sites, including the coastal part of southern Durrës, the Rinia-Fllakë Lagoon, the Erzen River estuary, and the area west of the town of Thumanë. The main

characteristic of these liquefaction-affected sites is the occurrence of recent Holocene deposits, including marshy, lagoonal, and river deposits. The main types of phenomena observed in the liquefaction-affected sites included individual sand boils, the ejection of liquefied material from ground cracks, the arrangement of sand boils along ground cracks, and water and sand fountains in still waters. The liquefaction observed in coastal Durrës affected an urban area at sites in close proximity to totally or partially collapsed hotels (Figure 3). In the Rinia-Fllakë Lagoon, liquefaction caused slight damage to the electric power supply system.



Figure 3. The liquefaction site in the southern part of Durrës was close to three hotels that experienced extensive structural damage: the totally collapsed Mira Mare Hotel, the partially collapsed Vila Verde hotel, and the Lubjana hotel (drone source: Lekkas et al., 2019).⁶

Slope movements were triggered in both the November mainshock and the September foreshock. Landslides and liquefaction in the Shkëmbi i Kavajës area affected the local road network.

4 LIFELINES AND TRANSPORTATION

The earthquake caused limited damage to infrastructures such as bridges, railways, airports, the power sector, telecommunication, water supply, and irrigation systems. Services and functions were restored shortly after the earthquake. The damage caused by the earthquake immediately triggered emergency response. Most services were restored within 24 hours after the earthquake, which shows the capability of local authorities in mobilizing manpower, materials, and equipment to cope with the impacts of a major earthquake disaster. Distributed infrastructure systems experienced limited damage, as the earthquake shaking was not severe enough to test their resilience or the infrastructure management systems.

The transport network suffered limited damage and disruption due to the earthquake despite the presence of a well-distributed transportation network in the area. The road network only suffered minor damage to road pavement due to cracking, which caused damage to the secondary elements of the two overpass bridges near Durrës (Figure 4) and damage to bridge deck seating. Similarly, in Durrës, a wagon repair workshop, one railway station, and one railway bridge suffered moderate to severe damage. Albanian civil aviation, including air transportation operations, did not report any damage.



Figure 4. A damaged highway overpass near Durrës (photo: J. Bothara)

Post-earthquake observations show that the water, sanitation, and solid waste management facilities/ systems suffered minimal damage or losses, though there was an extensive network of piped supply and sewer systems in the area. The earthquake caused damage to a sewage treatment plant and water supply pipes near Durrës (Figure 5) and one pumping station in Lezha. The damage to the pipeline was fixed within a day. Four water supply depots also suffered damage in Tirana.



Location of damaged water supply pipeline



Close view of pipeline



Damaged pipeline under repair

Figure 5. Damage to a water supply pipeline near Ishem, Durrës (photos: M. Baballëku).

5 RESPONSE AND RECOVERY

On November 27, 2019, the Government of Albania declared a state of emergency for Durrës and Tirana. A Civil Emergency Committee was formed to plan the immediate response and initiate rescue operations that started immediately after the earthquake and involved more than 8,500 responders, which included around 10% foreign rescue workers. In total, 48 victims were rescued from the damaged or collapsed buildings (Government of Albania, et al., 2020).⁷ Rescue operations were completed on November 29, 2019.

It was reported that 14,000 to 17,000 people needed temporary shelter (World Bank GPURL D-RAS Team, 2019).⁸ Tents and emergency supplies were provided to the displaced population less than 24 hours after the earthquake. Hotels, public buildings, and sport halls were also used as temporary shelters. Later, the majority of the displaced population was moved from tents to more permanent shelters, such as hotels and private housing. The earthquake occurred during a season of low tourism; therefore, most of the hotel capacities were not occupied and were able to take in the displaced population.

An estimated 9.2% of households in the epicentral area had to vacate their homes due to extensive damage. By the end of December 2019, approximately a month after the earthquake, two-thirds of the households returned to their homes.

In many cases, business interruption was caused by damaged infill walls in reinforced concrete buildings in which lower floors are often occupied by businesses (Figure 6). Infill wall damage was dominant in the lower floors of multistory buildings and limited access to the stairs, thereby hindering evacuation of the tenants (Figure 7). Business interruption losses are estimated at over 5 million euros.



Figure 6. Business interruption due to nonstructural damage in Durrës (photo: C. McKenney, 2019).⁹



Figure 7. Masonry infill debris blocking stairs in Durrës (source: C. McKenney, 2019).

Building inspections started immediately after the November 26 earthquake. Apart from local engineers, over 100 engineers from Greece, Italy, France, and Switzerland participated in building inspection. Based on discussions with the local authorities, it is estimated that approximately 500 engineers were involved in building inspections in the aftermath of the event. Due to a lack of centralized organization, engineers used different methodologies to classify damaged buildings, which led to inconsistent results, and certain buildings were examined several times. Since damage assessment forms were not prepared before the earthquake, the engineers responsible for surveying the buildings did not have prior training related to post-earthquake damage assessment. The lack of organization in the first two weeks prolonged the total time needed for building inspection and damage assessment, leading to a suboptimal use of available human and material resources.

Several GIS-based tools were developed after the earthquake to facilitate the response and recovery efforts. These tools were used to create a map of critical facilities in Durrës, to enable tenants to report building damage using their mobile phones, and to enable engineers to record damage survey data into a GIS database (AFPS, 2020; Esri, 2020).^{10,11} A centralized GIS database enabled an overview of the spatial distribution of building damage and was used as a tool to prioritize needs and resources in the aftermath of the earthquake.

On January 15, 2020, the government of Albania issued a decree (Ministrave, 2020)¹² that guided the detailed structural assessment of damaged buildings. According to this decree, the detailed structural assessment was to be based on Eurocode 8, Part 3 (European Committee for Standardization, 2005).¹³ However, the damaged structures and the strengthening or reconstruction designs had to be verified, at a minimum, for compliance with the Albanian code. Due to the differences between the Albanian design codes and the Eurocodes, some practical challenges emerged during the implementation of the decree.

The Academy of Sciences of Albania, the Institute of GeoSciences, Energy, Water and Environment (IGEWE), and the Faculty of Civil Engineering from Polytechnic University of Tirana took steps towards closing the gap between the Eurocodes and the Albanian codes by working on the National Annex of Eurocode 8, Part 1 (European Committee for

Standardization, 2004) and other Eurocode parts, as well as on the seismic hazard map for Albania in compliance with Eurocode 8. Several laws and decisions aiming to mitigate the risk for existing and new structures were prepared after the earthquake or are under development as of this writing.

Approximately 3 months after the earthquake, the first cases of COVID-19 were confirmed in Albania. The initial response of the government was to impose a strict curfew. Starting from May 2020, the restrictions were gradually eased. However, the construction activities were not significantly restricted by the curfew. Even during the period between March 2020 and May 2020, construction was allowed to proceed. Nonetheless, the economic effects of the pandemic on the construction industry in general and reconstruction in particular are yet to be assessed.

6 PERFORMANCE OF BUILDINGS

More than 95,000 housing units, which corresponds to 18% of all housing units in 11 affected municipalities, were damaged due to the earthquake. Out of these, 11,490 units suffered severe damage and have to be demolished, whereas the remaining 83,745 units experienced minor to moderate damage that prompted a need for repair (Government of Albania et al., 2020). The total losses were estimated at 985.1 million EUR, or 7.5% of Albania's gross domestic product for 2018. The estimated cost of recovery was 1,076 million EUR, of which around 80% was needed for the housing sector alone.

Housing construction practice in the affected area has changed over time. The majority of older (pre-1990) residential buildings were mid-rise multifamily (apartment) buildings that were either unreinforced masonry or prefabricated large-panel concrete buildings. To a lesser extent, cast-in-place reinforced concrete or prefabricated frame buildings were used from the 1980s onwards. After 1990, cast-in-place reinforced concrete became the technology of choice for residential buildings. Taller and larger structures started to be built in larger cities like Tirana and Durrës. This section summarizes observations on the performance of the most common building typologies in the affected area.

6.1 Residential Masonry Buildings

Considering the intensity of ground shaking, masonry buildings performed reasonably well. However, some unreinforced masonry buildings located in the epicentral area experienced minor to moderate damage, and a few buildings collapsed.

The majority of masonry buildings that were exposed to the earthquake were low-rise, single-family buildings, which constitute a significant portion of the building stock in Albania. These were mostly two-story, nonengineered, unreinforced masonry buildings designed and constructed by builders. In many cases, the damage was caused by building extensions (e.g., the construction of additional floors, irregular plan shapes (e.g., L-shapes), and/or use of low-strength masonry units (usually fired clay bricks)). Collapse was uncommon, but it was observed that buildings constructed using hollow, concrete blocks experienced more significant damage and even collapsed in a few cases. Only a few damaged confined masonry buildings were observed, so it is expected that most buildings of this typology remained undamaged. A severely damaged, unreinforced, single-family masonry building is shown in Figure 8(a)).



(a)



(b)

Figure 8. (a) low-rise masonry building in Bubq (source: (EEFIT, 2020; Freddi et al., 2021)^{14,15} and (b) a collapsed multi-story masonry building in Thumanë (source: <https://www.youtube.com/watch?v=2RXiG1KHC7k>).

Multi-family masonry buildings are very common in Albanian urban areas. These are typically unreinforced masonry buildings, are 3 to 5 stories high, and were constructed between 1960 and 1990 based on standardized designs prepared by government agencies. Confined masonry was also practiced since the 1980s, and hybrid systems (a reinforced concrete frame at the ground floor and confined masonry above) was practiced at a lower scale. Construction was executed by government agencies, but in some cases, volunteers participated in the construction. The quality of masonry materials in these buildings is variable. Most mid-rise unreinforced masonry buildings remained undamaged, even in cities that were severely affected by the earthquake, such as Durrës. Unreinforced masonry buildings with cast-in-situ reinforced concrete floor slabs performed well and did not experience severe damage. Buildings with prefabricated hollow core floor slabs generally performed poorly, and several buildings of this type collapsed in Thumanë (Figure 8(b)). These collapses can be attributed to simply supported hollow core slabs that lost bearing supports at one or more floor levels, which led to a partial or total progressive building collapse. Confined masonry buildings had regular plan configurations and elevations, and very few buildings of this construction experienced damage. Out-of-plane damage was observed in a confined masonry building with a relatively long exterior wall in which reinforced concrete tie columns were not provided at wall intersections. A few buildings with hybrid structural systems experienced severe damage or collapse at the ground floor levels; this can be attributed to open ground floors and increased seismic demands that exceeded the capacity of nonductile reinforced concrete columns. Most existing buildings with hybrid structural systems are vulnerable to earthquake effects and need to be retrofitted.

6.2 Cast-in-Place Reinforced Concrete Buildings

Cast-in-place reinforced concrete housing exposed to the earthquake generally performed well. Most buildings remained undamaged, but many buildings experienced light nonstructural damage, and a few buildings collapsed. Typical damage patterns included damage of the infill and partition walls and structural damage of reinforced concrete members.

Some reinforced concrete buildings, typically up to 6 stories high, experienced severe damage or collapse. Among the collapsed buildings were hotels and apartment buildings located in Durrës (Figure 9(a)). In many cases, the combination of an open ground floor with upper stories stiffened by infill walls created the conditions for a soft-story mechanism. Seismic vulnerability of these buildings was likely aggravated by the fact that many of these buildings were built as a result of informal developments and are considered as nonengineered or inadequately engineered.



(a)



(b)

Figure 9. Performance of cast-in-place reinforced concrete buildings like (a) a collapsed residential six-story building in Durrës (photo: Ch. McKenney) and (b) the extensive damage to infill and partition walls in a multi-story building in Durrës (source: Nikolić-Brzev et al., 2020).¹⁶

The damage of taller reinforced concrete buildings was widespread over a large area, including the capital Tirana. The most common damage pattern was cracking of the infill walls (Figure 9(b)), but in some cases, complete failure and collapse of the infills occurred due to excessive drifts and combined in-plane and out-of-plane seismic effects. Excessive lateral drifts and flexibility of these buildings can be attributed to the extensive use of wide/shallow beams in floor construction (sometimes over the entire floor, including perimeter frames) and the inadequate amount of shear walls. The design of flexible structures in the earthquake-affected area might have been the result of the fact that the seismic design code KTP N.2-89 (Academy of Sciences and Ministry for Construction, 1989) does not provide specific guidance for limiting damage by the control of inter-story drifts. Excessive lateral drifts also gave rise to other issues such as the interaction between adjacent building blocks.

Other structural damage in taller, reinforced concrete buildings can be explained by irregularities in plan configurations and elevations, detailing of steel reinforcement, geotechnical effects, and the poor quality of materials. In terms of regularity, the current design code KTP N.2-89 imposes rather strict requirements about the overall building shape, but the earthquake showed that special attention is needed for the distribution of shear walls and infills inside buildings. The combination of flexible reinforced concrete structures with masonry infills that are considered as nonstructural elements during design caused unintended irregularities in the plans, which led to a torsional response during seismic excitation, and the elevations, which led to large demands on certain vertical elements and the formation of soft-story mechanisms, short columns, etc. Such an interaction of the infills with the reinforced concrete frames was likely a major contributor to some of the collapses and member failures in reinforced concrete buildings, especially in the Durrës area. In the example shown in Figure 10(a), the lower two stories of the building did not have stiff infills and suffered significant structural damage, whereas the upper stories had masonry infill walls. Figure 10(b) shows a reinforced concrete column that experienced damage due to poor detailing and interaction with infill walls (which were likely not considered in the design).



(a)



(b)

Figure 10. Structural damage in cast-in-place reinforced concrete buildings in (a) a building in Durrës with structural damage concentrated in the lower two stories and the stiff infills in the upper stories (photo: Ch. McKenney) and (b) a damaged column with poor detailing (photo: M. Baballëku).

6.3 Prefabricated Reinforced Concrete Buildings

Prefabricated reinforced concrete structures generally performed well in the earthquake. There are two types of prefabricated reinforced concrete buildings in Albania: large-panel buildings and prefabricated reinforced concrete frame buildings. These two prefabricated building typologies have different structural systems and dynamic properties and demonstrated different damage patterns in the earthquake.

Although a significant number of large-panel buildings were exposed to the earthquake, they performed well; that is, they either remained undamaged or experienced minor damage. Satisfactory seismic performance of large-panel buildings can be attributed to significant redundancies due to a large amount of structural walls, particularly in a transverse (short) direction. These are also rigid structures characterized by short fundamental periods of vibration, which usually experience less damage in earthquakes, especially in soft-soil areas, than flexible structures characterized by longer fundamental periods (such as prefabricated reinforced concrete frame buildings). It was observed that the damage was concentrated within panel connections, whereas the panels remained undamaged (Figure 11). It is expected that, if experienced to a higher seismic demand, a failure mechanism for these buildings would be characterized by more extensive damage of the connections due to shear-induced sliding behavior (“strong panels-weak joints”), whereas the panels would remain mostly undamaged.



Figure 11. Cracking pattern at the interface between horizontal and vertical panels and also at the wall intersections in a building in Tirana (photos: M. Guri).

Prefabricated reinforced concrete frame buildings were mostly used for the construction of public buildings in Albania; hence, fewer buildings of this type were exposed to the earthquake compared to large panel buildings. Based on the post-earthquake building inspections as well as seismic evaluations, it can be concluded that the structural performance of these buildings was generally satisfactory. These buildings experienced moderate nonstructural damage and only minor structural damage in the connections between prefabricated elements due to considerable lateral drifts. In many cases, the damage of these structures in the Tirana area initially occurred in the September 2019 foreshock.

7 PERFORMANCE OF CRITICAL FACILITIES

7.1 Schools

Based on a briefing by the Minister of Education 2 months after the earthquake (Komisioni për Edukimin dhe Mjetet e Informimit Publik, 2020),¹⁷ 56 school buildings were heavily damaged and were assigned Damage State (DS) 4 and 5 (where DS 5 denotes irreparable damage). Although none of the buildings collapsed, the damages were severe enough to declare these buildings unsafe, which required either demolition or major repair. According to the same briefing, another 66 school buildings experienced damage classified into DS 2 and 3, whereas further evaluation was required for 151 buildings, which experienced light damage.

The earthquake brought to light issues related to the safety of school buildings in Albania. Although collapses were not reported, a considerable number of schools in the earthquake-affected area around Durrës and Tirana were severely damaged and were deemed unsafe after the earthquake. Masonry buildings, which were the oldest and most common, suffered the most extensive damage, but some reinforced concrete schools were also damaged. The common damage patterns were:

- diagonal cracking of loadbearing masonry walls and damages near window/door openings in severely damaged masonry schools (Figure 12(a) and (b));
- damage to buildings with extensions (e.g., addition of stories, extension of floor areas, and new openings or closures of existing openings) without seismic design considerations;
- light cracking of masonry walls and damage to plaster, parapets and other nonstructural elements;
- pounding of adjacent building blocks due to inadequate seismic joints;
- deterioration of materials and lack of maintenance; and
- a few reinforced concrete school buildings with damage patterns similar to those observed in residential buildings, including damage to infills and structural damage to columns (Figure 12(c)).



(a)



(b)



(c)

Figure 12. Damage patterns in school facilities, including (a) cracking above classroom doors in a masonry school building in Shijak, (b) structural damage of masonry walls in a school building in Thumanë, and (c) a damaged reinforced concrete column in a reinforced concrete school building in Durrës (photos: M. Baballëku).

Although prefabricated hollow core reinforced concrete slabs were widely used in the construction of Albanian masonry schools, especially those built based on template designs, failures such as those encountered in residential masonry buildings in Thumanë (Figure 8(b)) were not observed. This can be explained by a few factors, including the higher lateral stiffness of school buildings compared to otherwise similar residential buildings due to building height limits for schools (a maximum of four stories), a higher importance factor applied in the seismic design of schools, and the use of higher quality workmanship and materials. It is worth noting that, in general, past renovations of existing school buildings in Albania have not been focused primarily on seismic safety but on the improvement of conditions for use (heating, architectural aspects, replacement of deteriorated materials, etc.).

7.2 Hospitals

Initial medical response after the earthquake was immediate and effective. Significant delays or inability to help the injured inhabitants were not reported because the majority of healthcare facilities did not suffer significant damage due to the earthquake. Besides this, the primary healthcare facilities, which are larger in number and well distributed in the affected areas did not suffer significant damage and remained functional after the earthquake. Only in a few peripheral areas medical assistance to panic-affected citizens was provided outside the healthcare buildings. At the Ishmi healthcare center near Durrës, medical services were transferred to a temporary shelter due to damaged hospital buildings.

Although heavy damages did not occur, some healthcare facilities that experienced slight and moderate damages were deemed unsafe. The common damage patterns were

- shear cracks in structural and nonstructural masonry walls, especially near the window and door openings;
- interaction of adjacent buildings due to inadequate seismic gaps;
- damage of buildings with extensions (e.g., storage in the upper stories, addition of stories, new openings adjacent to the existing ones, and removal of structural or nonstructural walls in the ground floor) without seismic design considerations;
- deformations of steel connections between prefabricated elements and small concrete cracks;
- reinforcing steel deterioration due to lack of concrete cover;
- sliding of adjacent slab panels as a result of inadequate floor and roof diaphragms;
- nonstructural damage to plaster, parapets, and installation shafts; and
- issues related to a lack of maintenance and the deterioration of materials and elements.

Similar to residential reinforced concrete buildings, most reinforced concrete hospital buildings have masonry infills that were not considered in seismic design or detailed for in-plane and out-of-plane seismic actions. As a result, these damaged infills limited the functionality of the buildings that did not experience any structural damage.

8 CLOSING REMARKS

The November 26, 2019 earthquake was the strongest to hit Albania since 1979. The earthquake put to test the emergency response capabilities of Albania and the seismic safety of the building stock and critical infrastructure.

With regards to seismology, the level of earthquake shaking was within the expectations of the seismic hazard studies conducted over the years for the Durrës region. Unfortunately, a strong motion recording station was not available close to the Thumanë village that suffered significant damage and casualties, and the strong motion record from the Durrës station was not available for the full duration of ground shaking. These records would have been useful for gaining a better understanding of the earthquake and its consequences. For this reason, further investments into the Albanian Seismological Network are recommended. In addition, updated seismic hazard maps need to be approved and used for seismic design purposes in the near future.

The earthquake highlighted the importance of geotechnical aspects related to the seismic response of buildings and other engineering structures. The earthquake damage was widespread in soft-soil areas, and clustering of damaged buildings was observed near liquefaction sites, particularly in the Durrës area.

The housing sector suffered the most significant damage and losses, whereas lifelines, transportation, and critical infrastructure systems remained generally functional. A major issue related to housing, especially in suburban areas, is the informal construction during the post-1990 period, which resulted in a large stock of nonengineered low-rise buildings. Among taller reinforced concrete buildings, those with inadequately engineered renovations or extensions (e.g., the addition of stories, floor extensions, and demolition or addition of structural and nonstructural walls) experienced more extensive damage compared to other buildings. These issues need to be addressed by relevant authorities to mitigate the risk in existing building stock from the effects of future earthquakes.

Low-strength multifamily unreinforced masonry buildings with prefabricated hollow core slabs of the pre-1990 vintage proved to be life-threatening during this earthquake; hence, existing buildings of this type need to be urgently identified and retrofitted.

The damage patterns in reinforced concrete buildings include extensive cracking of infills and partition walls, interaction of infills with concrete frames, and the hazards associated with infills due to out-of-plane failures. The damage can be attributed to excessive lateral drifts due to flexible frame systems with shallow beams, inadequate amount of shear walls, irregularities in plan and elevation (even when shear walls are present), interaction with infills, inadequate detailing of reinforced concrete elements, and substandard quality of materials. It is important to review current construction practices associated with these buildings and provide guidance to prevent similar damage from occurring during future earthquakes.

It is recommended to pay more attention to the seismic safety of school facilities alongside the improvement of their condition. It is particularly important to evaluate the seismic safety of facilities that were not initially designed as schools with the appropriate “importance factor”. It is also very important to create a detailed database of the condition of existing school buildings, a program for continuous monitoring of the condition of these buildings, and detailed studies on the seismic vulnerability and risk of school buildings.

Most reinforced concrete hospital buildings have masonry infills that were not considered in seismic design and were not detailed for in-plane and out-of-plane seismic actions. As a result, even though the buildings did not experience any structural damage due to the earthquake, these damaged infills limited the functionality of these hospital buildings. Special attention is needed to mitigate this issue in hospital buildings and protect them from future earthquakes.

Response and recovery are areas where important lessons were learned by the local authorities. Significant assistance from several European countries, including the neighboring countries, was received during the immediate response stage. The damage assessment process was initially challenging due to the lack of standardized damage assessment procedures. Challenges during the preparation of detailed structural assessment reports for damaged buildings arose due to the differences between Eurocode 8 (Part 3), which was required by the government decree, and the Albanian design codes and practice.

Finally, it should be noted that the current seismic design code in Albania KTP N.2-89 (issued in 1989) is outdated because it was developed at a time when the construction typologies and technology were quite different from today. In this context, it is urgently needed to either update the Albanian seismic design code or adopt Eurocodes. In addition, measures need to be taken to ensure the enforcement of the building design codes in practice and to minimize or eliminate altogether future informal construction developments.

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REFERENCES

- ¹ Aliaj, S., Melo, V., Hyseni, A., Skrami, J., Mehilla, L., Muço, B., Sulstarova, E., Prifti, K., Pasko, P., and Prillo, S., 1996. *Neotectonic structure of Albania (in Albanian)*. Final report, Archive of Seismological Institute of Academy of Sciences, Tirana.
- ² Koci, R., Duni, L., Kuka, N., and Dushi, E., 2019. *Intensity distribution map of November 26, 2019 (Mw6.4) Durrës Earthquake, based on MSK-64 macro-seismic scale. IGEWE Internal Report*. Tirana, Albania.
- ³ Academy of Sciences and Ministry for Construction, 1989. *Kusht teknik projektimi per ndertimet antisizmike KTP-N.2-89*. Tirana, Albania.
- ⁴ European Committee for Standardization, 2004. *EN 1998-1. Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*.
- ⁵ Institute of Geosciences, Energy, Water and Environment (IGEWE), 2021. *Probabilistic seismic hazard assessment maps and values for each administrative unit [in Albanian]*, available at <https://www.geo.edu.al/newweb/?fq=brenda&gj=gj1&kid=44> (accessed February 15, 2021).
- ⁶ Lekkas, E., Mavroulis, S., Papa, D., and Carydis, P., 2019. The November 26, 2019 Mw 6.4 Durrës (Albania) earthquake. Newsletter of Environmental, Disaster, and Crises Management Strategies, (15), ISSN 2653-9454, 1–80.

- ⁷ Government of Albania, European Union, United Nations agencies, and World Bank, 2020. *Albania Post-Disaster Needs Assessment, Volume A Report*. Tirana, Albania.
- ⁸ World Bank GPURL Disaster-Resilience Analytics and Solutions (D-RAS) Team. (2019). *M 6.4 Albania Earthquake Global Rapid Post Disaster Damage Estimation (Grade) Report*, available at https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/assessments/2019-12-16_grade_alb_eq_nov2019_final.pdf (accessed November 17, 2021).
- ⁹ McKenney, C., 2019. *Reconnaissance Observation Report: Albania M6.4 Earthquake on November 26, 2019*, available at http://www.learningfromearthquakes.org/images/earthquakes/2019_Albania_Earthquake/Albania_EQ_Report_-_Chiara_McKenney.pdf (accessed November 17, 2021).
- ¹⁰ L'Association Française du Génie Parasismique (AFPS), 2020. Rapport de la mission post-sismique sur le séisme d ' Albanie.
- ¹¹ Esri, 2020. *Real-Time GIS Apps Quicken Response to Earthquake in Albania*, available at <https://www.esri.com/about/newsroom/arcnews/real-time-gis-apps-quicken-response-to-earthquake-in-albania/> (accessed February 1, 2021).
- ¹² Ministrave, Këshilli I., 2020. Vendim Nr. 26, Datë 15.1.2020 Për Kryerjen e Aktekspertizës së Thelluar në Ndërtesat e Dëmtuara, Tirana.
- ¹³ European Committee for Standardization, 2005. *Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings*.
- ¹⁴ Earthquake Engineering Field Investigation Team (EEFIT), 2020. The Mw6.4 Albania Earthquake on the 26th November 2019 - A field report by EEFIT. London.
- ¹⁵ Freddi, F., Novelli, V., Gentile, R., Velu, E., Andreev, S., Andonov, A., Greco, F., and Zhuleku, E., 2021. Observations from the 26th November 2019 Albania earthquake: the earthquake engineering field investigation team (EEFIT) mission. *Bulletin of Earthquake Engineering*, 19(5), 2013–2044, (DOI: 10.1007/s10518-021-01062-8).
- ¹⁶ Nikolić-Brzev, S., Marinković, M., Milićević, I., Blagojević, N., and Isufi, B., 2020. *Posledice zemljotresa u Albaniji od 26.11.2019. godine na objekte i infrastrukturu [Consequences of the 26.11.2019 Albania earthquake on buildings and infrastructure]*. Belgrade: Serbian Association for Earthquake Engineering (SUZI-SAE).
- ¹⁷ Komisioni për Edukimin dhe Mjetet e Informimit Publik, 2020. *Minutes of the meeting, Tirana, 05/02/2020 at 10AM [in Albanian]*, available at https://www.parlament.al/Files/Procesverbale/20200309140101Komisioni_i_Medies_datë_05.02.2020.pdf (accessed September 1, 2020).



EERI Earthquake Reconnaissance Report: M6.4 Albania Earthquake on November 26, 2019



Volume 2: Seismology and Geotechnical Effects

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April 2021

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PREFACE

This Earthquake Engineering Research Institute (EERI) Earthquake Reconnaissance Report for the M6.4 Albania earthquake on November 26, 2019, is divided into four volumes. Volume 1 is the Executive Summary, which provides a brief overview of the key observations in all areas. The remaining volumes provide background and in-depth descriptions of these observations.

- Volume 2, “Seismology and Geotechnical Effects,” describes seismological aspects of the earthquake and a summary of geotechnical impacts.
- Volume 3, “Response and Recovery,” describes response and recovery, as well as the performance of lifelines and transportation infrastructure.
- Volume 4, “Building Performance,” focuses on the performance of major construction types: residential masonry buildings, cast-in-place reinforced concrete buildings, and prefabricated reinforced concrete buildings. The performance of special use buildings, including schools, hospitals, and heritage and religious structures, is also described. An overview of Albanian building codes and construction practices is also provided in this volume, along with damage assessment data collected by several of the reconnaissance teams.

1 SEISMOLOGY AND GROUND MOTION

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1.1 Overview of the November 26, 2019, (Mw 6.4) Seismic Sequence

On the morning of Tuesday, November 26, 2019, at 03:54 am local time (02:54 am UTC), an Mw 6.4 earthquake occurred 16 km north of Durrës, a port city on the Adriatic coast of Albania, and 33 km northwest of Tirana, the capital of Albania. It was subsequently followed by intense aftershock activity. This earthquake was the strongest seismic event to strike Albania in the last 40 years, since the Montenegro-Albanian border Mw 6.9 earthquake of 1979

Unless otherwise noted, data provided by the Department of Seismology (DS) in the Institute of Geosciences, Energy, Water and Environment (IGEWE) of Polytechnic University of Tirana ([Link](#)), will be referred to throughout this report to describe the seismic sequence. This strong earthquake was preceded by an Mw 5.6 (local magnitude (M_L) 5.8, local Richter scale) foreshock on September 21, 2019, at 15:04 pm (UTC), 12 km north of Durrës, which had its own sequence of aftershocks that lasted for 5 days. It is interesting to note that the seismicity rate abruptly decreased to the background level, almost disappearing until November 25. Immediate foreshock activity started on November 25, 2019, at 03:22 am (UTC), characterized by eight seismic events between magnitudes 2.0 to 4.6 M_L . The mainshock occurred nearly 1 hour after the 01:47 am (UTC) M_L 4.6 foreshock with an epicenter 4 km north of that foreshock’s location. The seismic sequence that followed the November 26 earthquake was characterized by a large number of aftershocks (Figure 1).

Between November 26, 2019, and June 30, 2020, over 2,000 events were recorded by the Albanian Seismological Network (ASN), and nearly 1,000 of them were located. In Figure 1, the spatial distribution of epicenters of the Durrës seismic sequence since the September 21 earthquake is shown. The focal mechanisms of both September 21 and November 26 are shown, and their magnitude and temporal distribution are described with the respective histograms.

Based on analysis by IGEWE DS of felt reports and field observations, the distribution of the felt intensity per the Medvedev-Sponheuer-Karnik scale (MSK-64) macroseismic intensity scale is plotted on the isoseismal map (Figure 2). Based on the map, the largest intensity was “destructive” (IX).

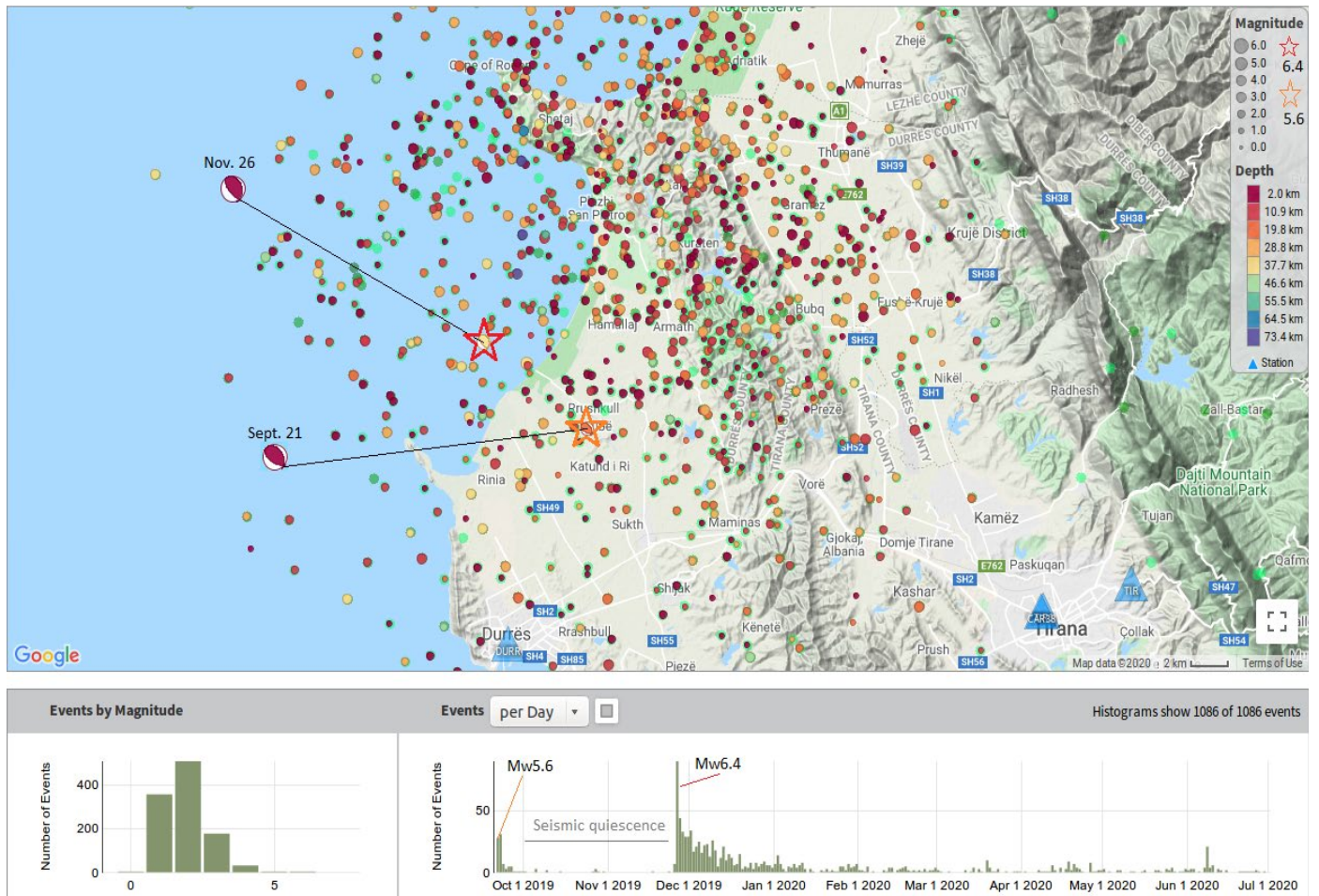


Figure 1. Distribution of the seismic sequence of September 21 (M_w 5.6) to November 26, 2019 (M_w 6.4) (top) and magnitude and time histograms for this sequence (bottom) (source: map generated with Athena Web Server 3.11.20.2).

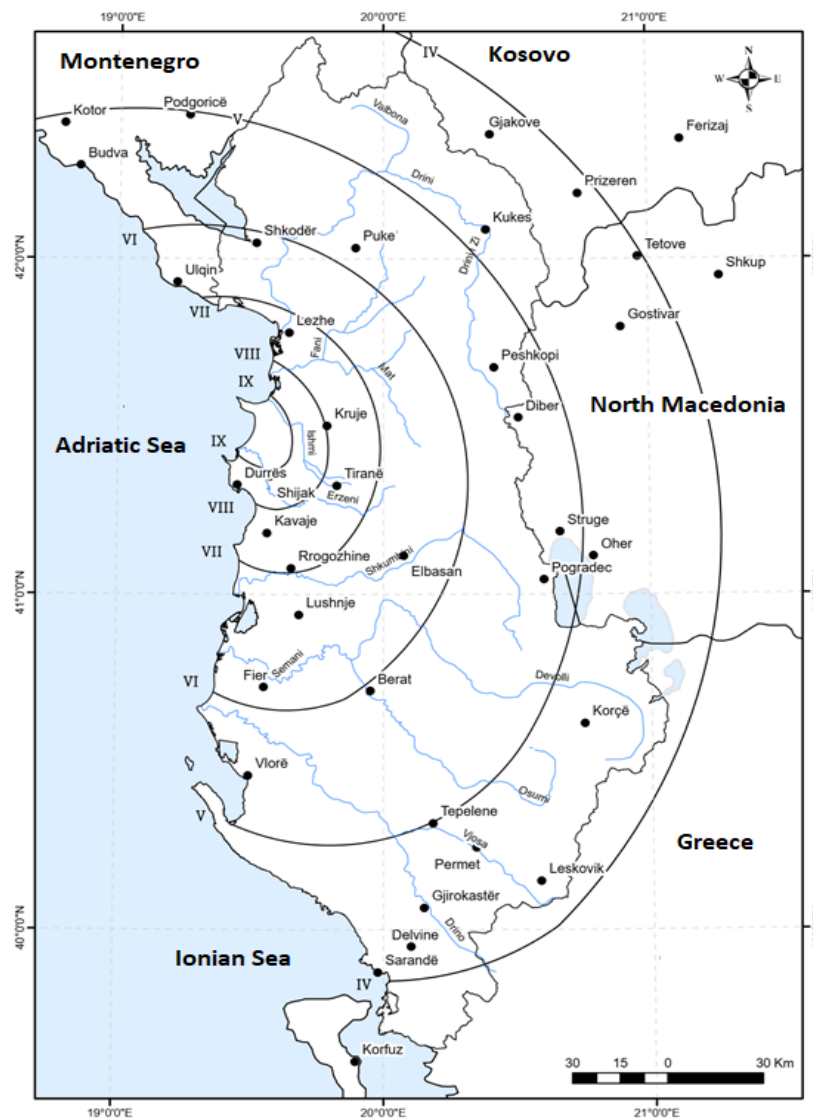


Figure 2. Observed intensity distribution (MSK-64 scale) related to the November 26, 2019, effects (source: DS, IGEWE).

1.2 Tectonic Setting and Seismic Activity

The Durrës region is situated in the Periadriatic Foredeep, in direct continental subduction contact with the eastern margin of the Adria microplate (Mihaljevic et al., 2017; Jouanne et al., 2012).^{1,2} The direct convergence has structured the Albanides with numerous tectonic faults belonging to different geological ages (Figure 3(left, right)). The Durrës region, located in the outer Albanides, is characterized by an active and complicated geologic-tectonic structure (Aliaj et al., 1996a).³ The whole region is cut through by backthrust faults of the Durrës and Preza monocline, active since the Pliocene-Quaternary period, and by several older thrusts, active since lower Miocene period, traced along Durrës and Tirana synclines (Figure 3(left, right)). Thrust faults crossing the Durrës syncline plunge to the east with dip angles that decrease with depth (Dushi et al., 2016).⁴

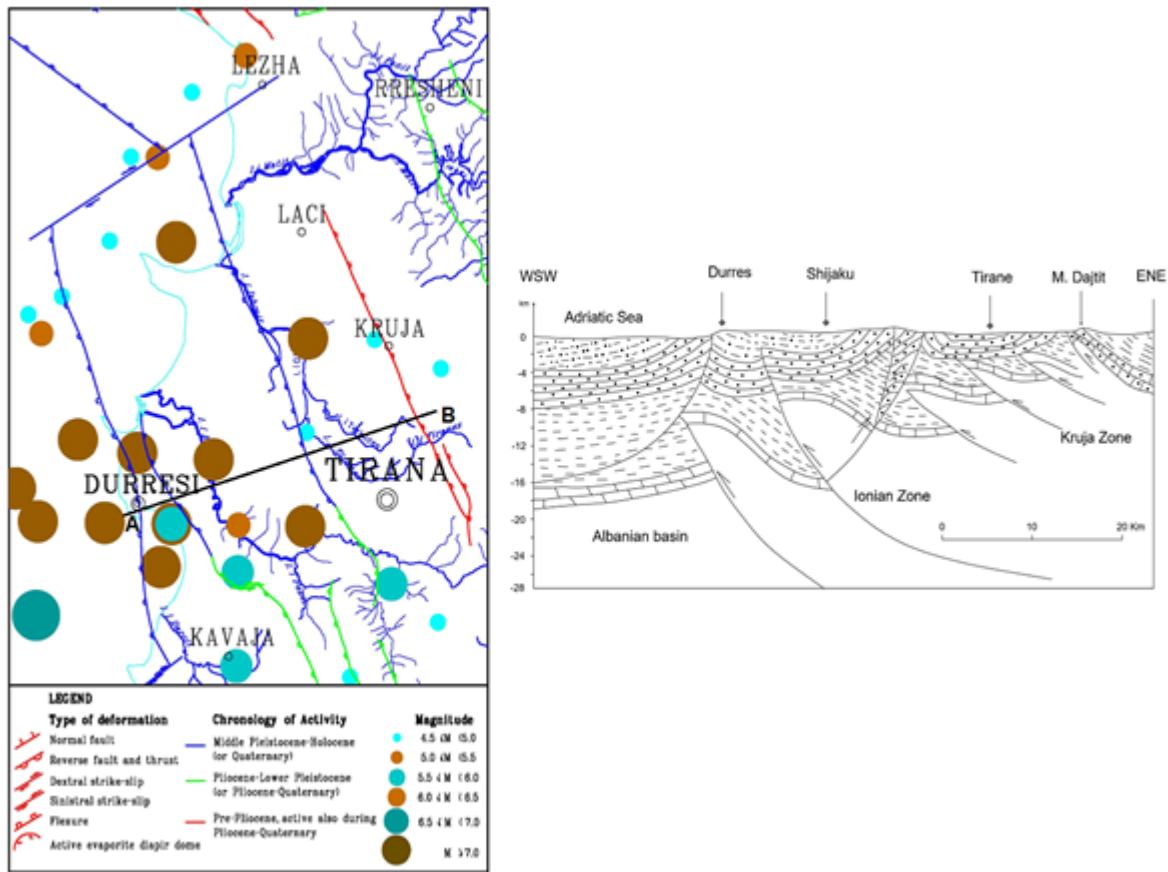


Figure 3. Section of seismotectonic map of Albania in scale 1:500 000 (left) and a schematic tectonic profile of the Adriatic Sea and Dajti Mountain (right) (source: Aliaj et al., 2000; DS, IGEWE).⁵

There is evidence of many strong historical and very damaging earthquakes with an intensity VIII to IX degree on the MSK-64 scale (surface-wave magnitude (M_s) > 6.0), afflicting the town of Durrës throughout history (Sulstarova and Koçiaj, 1975).⁶ The town of Durrës was destroyed in A.D. 334, 506, 1273, and 1279 by earthquakes. It was strongly affected by the Kruja earthquake of 1617 and the Rodon Cape earthquake of 1852, which destroyed the St. Antoni's Church. Durrës was also hit by earthquakes in 1860, 1869, 1870, and 1894. The 1870 earthquake was characterized by numerous aftershocks during the period from September 1870 to April 1871. Durrës was also affected by the 1895 earthquake, located 10 km southwest of Kavaja and around 25 km south of Durrës, causing damage in the city of Durrës.

Based on the instrumental seismicity evidence during the 20th century, the Durrës region and its surrounding areas were hit by a number of strong earthquakes (UNDP Albania, 2003).⁷ The following are of particular note: the strong earthquake of 1926 (M_s 6.2), which is shown with the isoseismal map Figure 4 (Papazachos et al., 2001);⁸ the Ndroqi earthquake of 1934 (M_s 5.6); the Durrës earthquake of 1958 (M_s 5.4); and the Vrapë earthquake of 1970 (M_s 5.5).

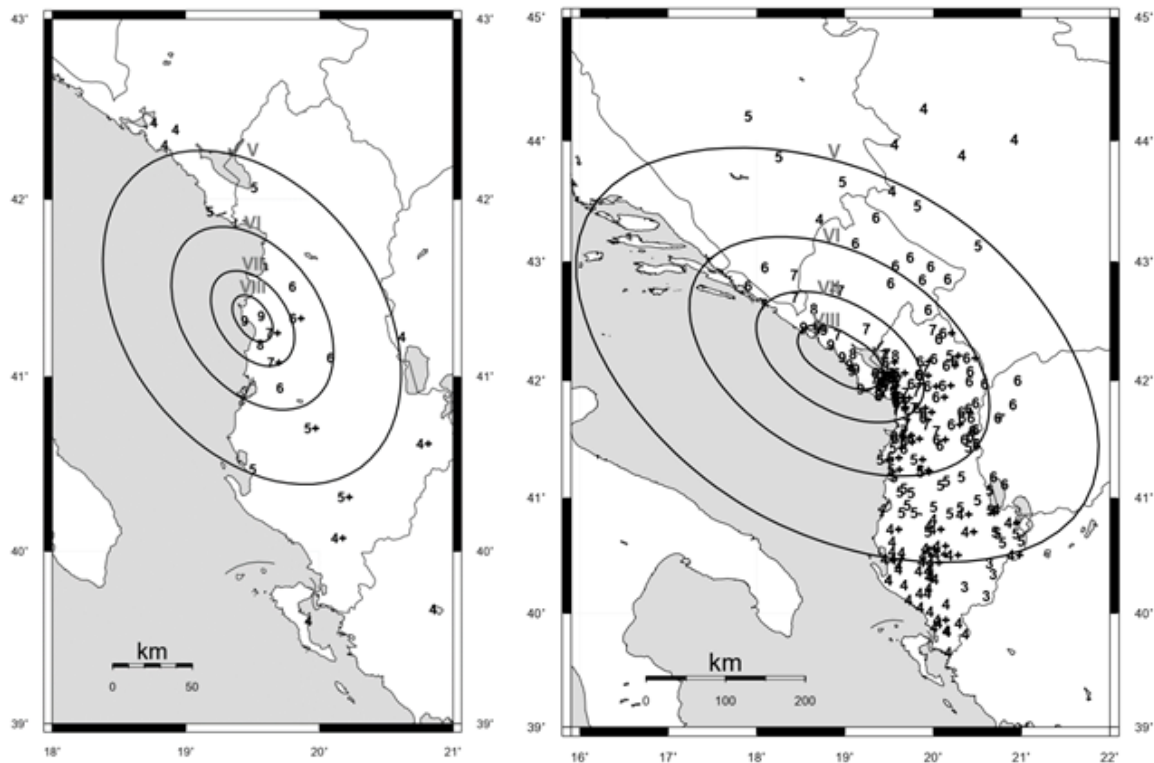


Figure 4. *Isoseismal map of (M6.2) Durrës earthquake in 1926 (left) and isoseismal map of (Mw6.9) Montenegro earthquake on April 15, 1979 (right) (source: Sulstarova and Koçiaj, 1975; Papazachos et al., 2001).*

The Durrës region was also affected by the strongest earthquake in the region of the 20th century (Figure 4(right)); the strong event of April 15, 1979 (M_w 6.9), located in the Montenegro coastal area (ISC-GEM). This event was generated by the thrust fault's system northwest of Lezha. The earthquakes of September 21, 2019 (moment magnitude (M_w) 5.6), and the November 26, 2019 (M_w 6.4), are the strongest earthquakes that have occurred in the Durrës area during the 21st century.

Seismological evidence for the (M_w 6.4) earthquake of November 26, 2019 supports the connection of this seismic event with an east-dipping, blind, thrust fault located under the Durrës syncline that is characterized by a strike of 141° , dip of 65° and rake of 80° , according to the IGEWE DS solution. Nearly the same result was obtained by the Institute of Geodynamics of the National Observatory of Athens jointly with DS, given as a strike of 155° , dip of 72° , and rake of 85° , in the special report, published by the European Mediterranean Seismological Center (Moshou et al., 2019).⁹ Compressional stress regime is supported, also, from the formal stress inversion that is applied for the Durrës earthquake as in Delvaux and Sperner (2003),¹⁰ giving the maximum compressional stress σ_1 (strike 248° /dip 26°), the minimum compressional stress σ_3 (strike 58° /dip 63°), and a stress index R' of 2.5 as a result. These parameters of the reduced stress tensor confirm the thrust fault mechanism, as referred to on the World Stress Map (Basili et al., 2013).¹¹

The causative thrust fault, in contact with the adjacent backthrust fault traced on the east of Preza monocline, shows a “palm tree” pattern (Figure 3(right)) and heads up to the basement of the upper Miocene at around 3 km of depth with a sharp dip angle, smoothly decreasing with the depth, to the upper Moho discontinuity.

1.3 Seismic Network Performance

The earthquake of November 26, 2019, was recorded by the ASN operated by IGEWE ([Link](#)). The master station, known by the code “TIR”, is also a part of the Euro-Mediterranean Seismic Network ([Link](#)) and is equipped with a STS-2 VBB sensor. All other stations are equipped with broadband sensors. Two broadband weak-motion stations belonging to Bankers Petroleum Ltd. Albania, respectively, BPA1 and BPA2, are also used, transmitting remotely to the Data Center of the DS at IGEWE. The nearest station to the epicentral area was TIR, 33 km to the east. The station geometry influenced, to some degree, the inaccuracy of the source parameters' determination. Several stations of the Italian National Institute of Geophysics and Volcanology of Rome ([Link](#)) and Aristotle University of Thessaloniki ([Link](#)) were also included in the analysis. The configuration of these stations is given in the map presented in Figure 5.

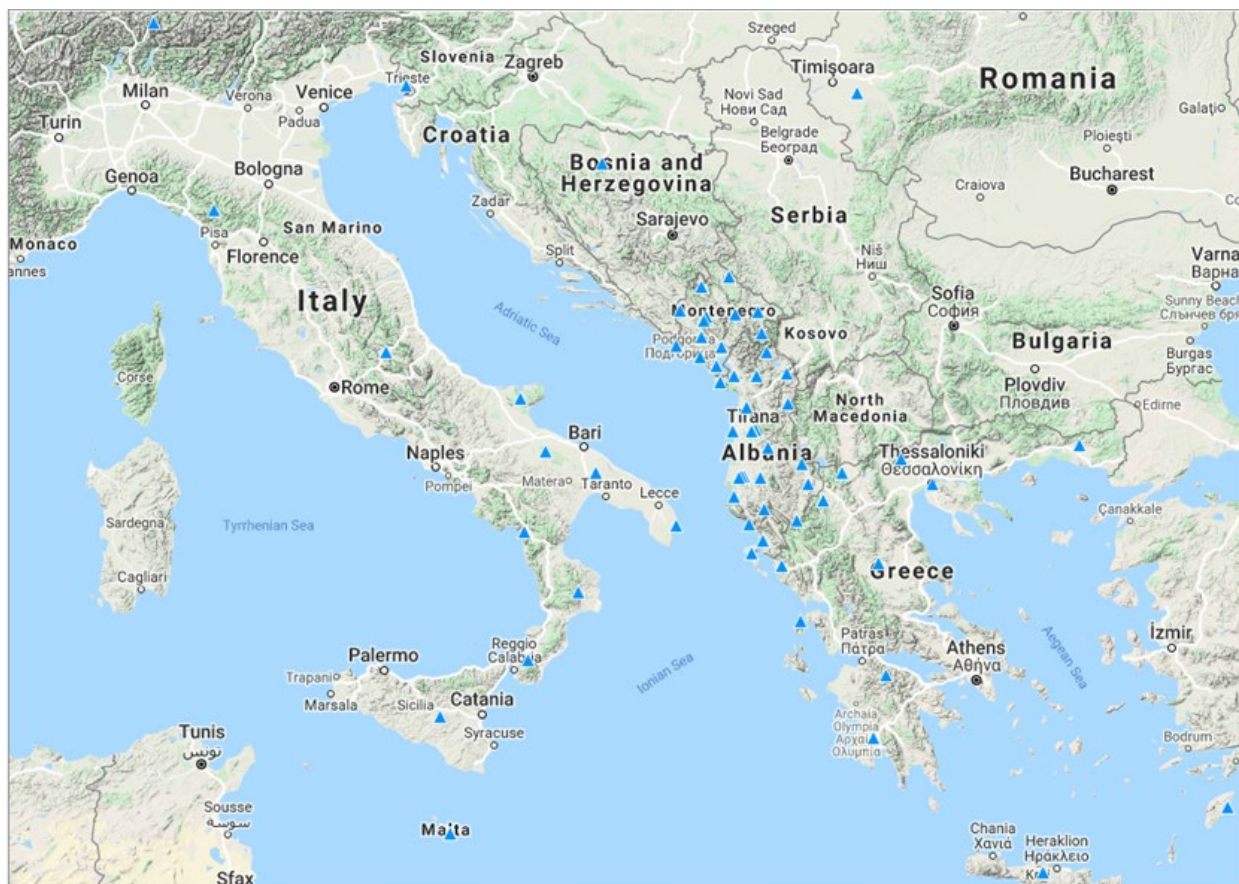


Figure 5. The Albanian and regional seismic stations constituting the physical and virtual seismic monitoring network (source: DS, IGEWE).

The Strong Motion Network recovered important recordings. The earthquake was recorded by seven accelerometric stations, including one installed in Durrës 15 km from the hypocenter of the earthquake on November 26, 2019.

1.4 Aftershock Sequence

Based on the IGEWE database ([Link](#)), around 1,000 aftershocks were located during a period of 7 months following the mainshock. This number is a lower bound, constrained by the detection capability and the small number of the operational stations of the ASN around Durrës. During this period, a mobile seismic network of Deutsches Geoforschungs Zentrum of Potsdam, comprising of 30 short-period stations, was installed in the field, and it was operational until September 2020 (Schurr et al., 2019)¹² with the goal of understanding the faulting responsible for this mainshock. According to the ASN database, around 90 seismic events were located within the first 24 hours of the mainshock. Data for the statistical analyses, to describe the Gutenberg-Richter distribution of the sequence include the following: 1 event within a magnitude interval from 5.0 to 6.0 M_L ; 9 events within the magnitude interval from 4.0 to 5.0 M_L ; 44 events within the magnitude interval from 3.0 to 4.0 M_L ; and 34 events within the magnitude interval from 2.0 to 3.0 M_L . The strongest aftershock with M_L 5.5 occurred at 07:08 am local time with a focal depth of 33.5 km located 18 km north of the mainshock.

An aftershock forecasting model (Wiemer, 2001),¹³ based on Omori-Utsu law, fit well with the observations from a forecasting period of 150 days after being applied on 1,000 aftershocks (Figure 6). The decay rate parameter of $p = 1.0 (\pm 0.07)$ explains the long-lasting seismic sequence.

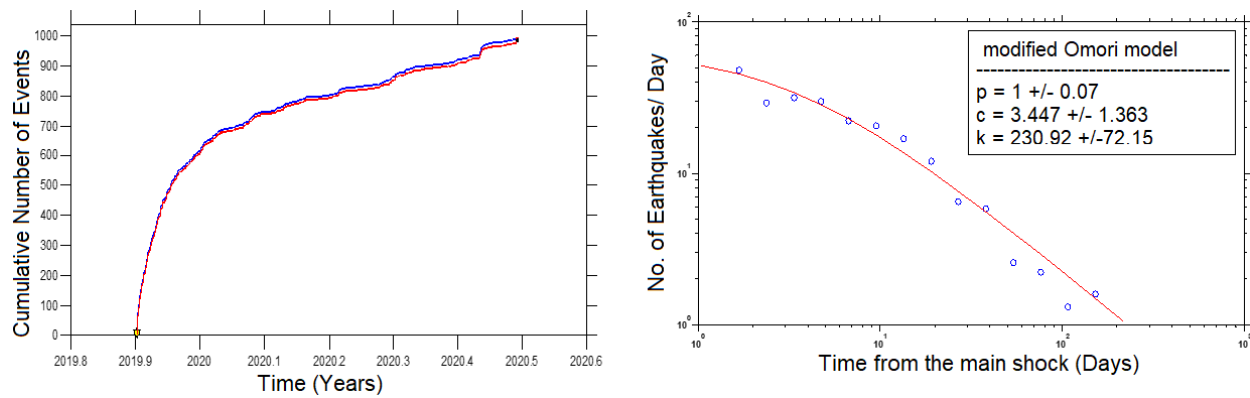


Figure 6. Aftershock decay rate (left) and modified Omori law parameters (right) for the seismic sequence on November 26, 2019 (source: DS, IGEWE).

1.5 Aftershock Hazard

A notable characteristic of the seismic sequence on November 26, 2019, was the significant number of moderate magnitude aftershocks. In total, there were 51 aftershocks recorded with a magnitude M_L greater than 4.0 (10 after the September event and 41 after the November mainshock). The average depth was 19 km. They were widely felt, and generally posed an additional risk to the already affected dwellings in the areas north of Durrës, Juba, Hamallaj, Ishem, and Thumana, considering the vicinity to the densely populated urban and suburban areas. Based on the Post-Disaster Needs Assessment report, around 255 people were injured during the aftershock sequence (Government of Albania, 2020).¹⁴

1.6 Seismic Hazard Assessment in Albania

The first seismic hazard map of Albania was published in 1941 (Morelli, 1941).¹⁵ Later, a revised map was prepared in 1952 (Sulstarova et al., 1980)¹⁶ by the specialists of the former Institute of Sciences and Ministry of Construction (Figure 7), together with the general anti-seismic criteria, which were gradually improved throughout the years.

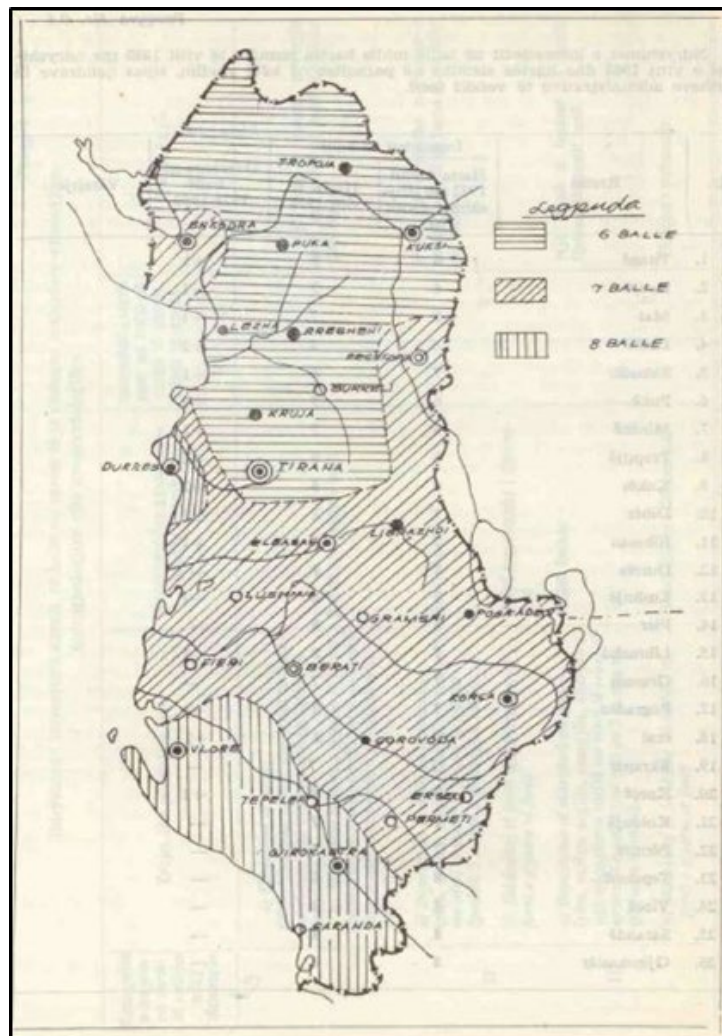


Figure 7. Seismic hazard map of Albanian in terms of Intensities of 1952 (source: Sulstarova et al., 1980).

From 1989 to 2003, the practice in Albania for assigning the earthquake load for the design of structures used the seismic zonation map published by the Seismological Institute in 1980 (Figure 8) and various maps compiled during microzonation studies carried out during the 1980s for the seven largest urban areas of the country. The map presented is based on the intensities of strong historical earthquakes and the earthquakes of the 20th century and on seismotectonic synthesis. The territory of Albania was then divided into three main zones with intensities of VI, VII, and VIII degrees on the MSK-64 scale for average soil conditions. In some parts, because of poor soil conditions, the seismic intensity was set to intensity IX. For the average soil condition, thick, stiff Quaternary sediments with deep groundwater levels were considered (Duni and Kuka, 2004).¹⁷ Soil category II, as described in Table 2, is considered as “average soil condition”. The Durrës city, according to this map, is included within the zone of IX degree, according to the MSK-64 scale.

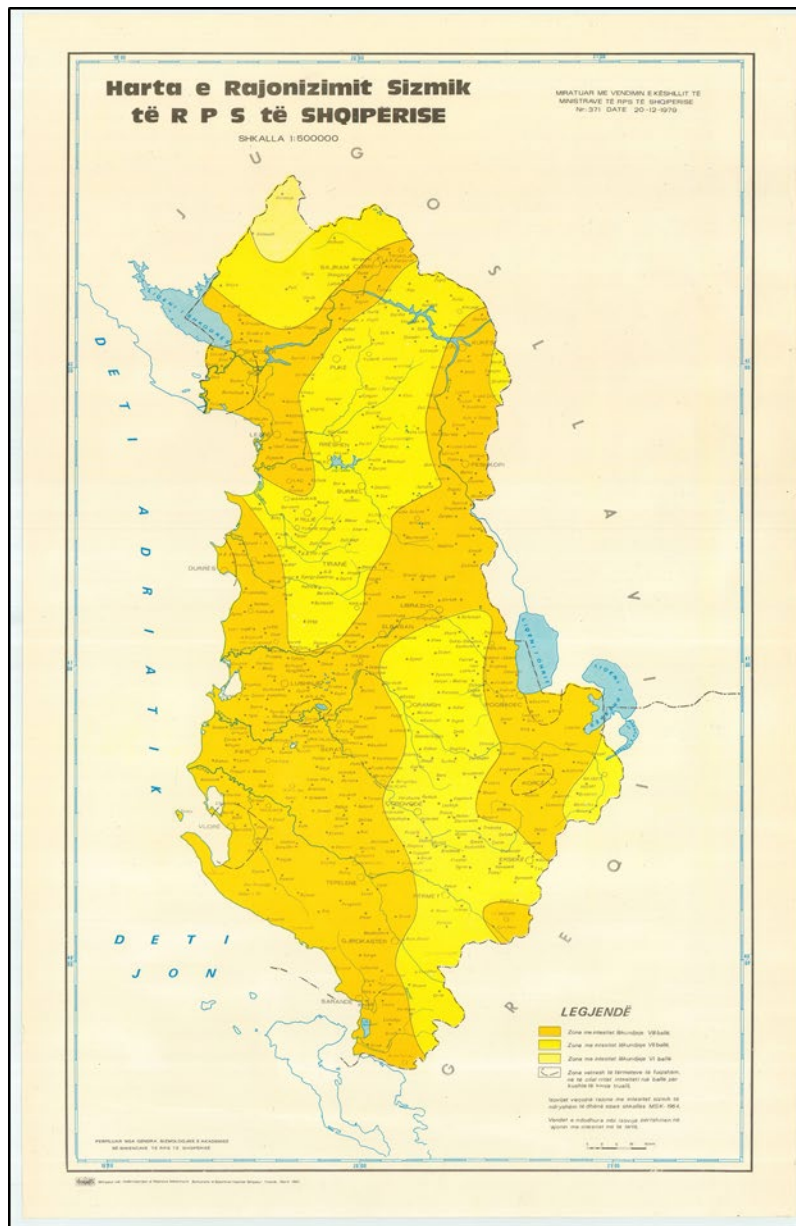


Figure 8. Seismic zonation map of Albania (source: Sulstarova et al., 1980).

The first probabilistic peak ground acceleration (PGA)-based seismic hazard map was formulated in 2003 (Kuka et al., 2003),¹⁸ which served as the base map for seismic risk assessment in Albania in 2003. The map currently in use by IGEWE is that of Kuka and Duni (2007), which is shown in Figure 9.

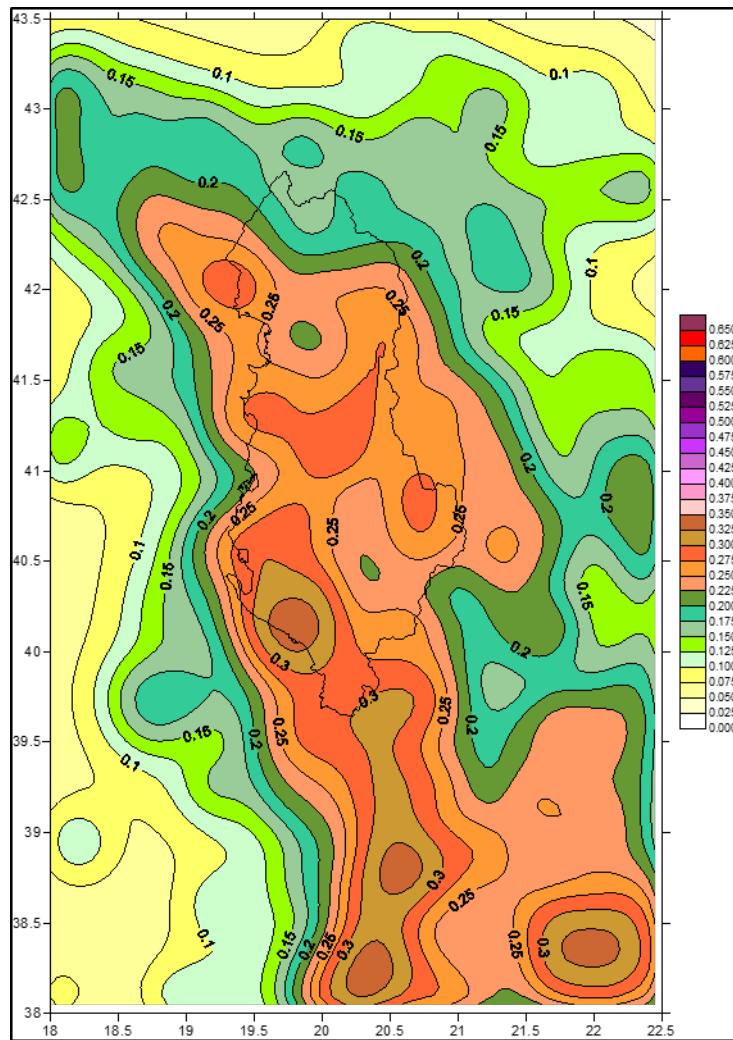


Figure 9. Probabilistic seismic hazard map of Albania in terms of PGA for 475 years of return period (10% exceedance probability in 50 years) using the Boore et al. (1997)¹⁹ ground motion prediction equation (GMPE) with rock site conditions (source: Boore et al., 1997; Kuka and Duni, 2007).²⁰

The 2015 hazard map of the Western Balkan countries in the framework of the North Atlantic Treaty Organization Science for Peace project (NATO Science for Peace Program, SPS Reference 984374) generally agreed with the 2007 version of the hazard map shown in Figure 9. A new version of the seismic hazard map of Albania is under development that will consider the new seismicity data in Albania and surrounding area for the period from 2015 to 2019, with the M6.4 Durrës earthquake included.

1.7 Strong Ground Motion Records of November 26 (M6.4) Durrës Earthquake

The earthquake on November 26, 2019, was recorded at seven accelerometric stations of the Albanian Strong Motion Network in a range of epicentral distances from 15 to 130 km. The geographic distribution of the stations that recorded the earthquake is shown in Figure 10. In Table 1, information from the recording accelerometric stations, as well as recorded PGA, peak ground velocities (PGV), and peak ground displacements (PGD), is given. All the strong motion records gathered were processed by the ART software and published on the IGEWE website (Duni, 2019).²¹

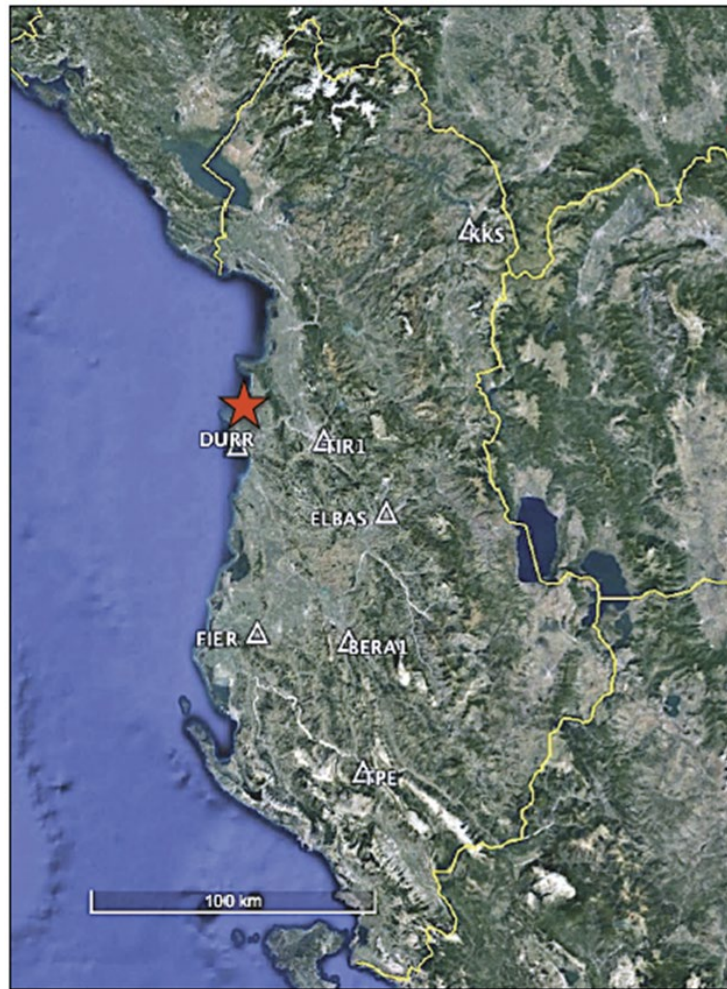


Figure 10. Strong motion stations in Albania that recorded the earthquake (M6.4) on November 26, 2019. The epicenter is given as a red star (source: DS, IGEWE).

Table 1: Recording accelerometric stations, as well as recorded PGA, PGV, and PGD (source: Duni and Theodoulidis), 2019

Recording Station				November 26, 2019 Event (M6.4)									
				Epi c. Dis t. (km)	E-W Component			N-S Component			Z Component		
					PGA cm/s ²	PGV cm/s	PG D cm	PGA cm/s ²	PGV cm/s	PG D cm	PGA cm/s ²	PGV cm/s	PG D cm
BER A1	Free field	Guralp: CMG-DM24	1010	93. 7	15.1 0	0.92	0.2 9	10.6 5	0.68	0.1 6	7.91	0.53	0.1 3
DUR R	Free field	Guralp: CMG-DM24	200	15. 6	122. 3	14.4	4.5 2	192. 0	38.5 5	14. 0	114. 5	7.18	4.3 9
ELBA S	2 story building (with a pillar)	Guralp: CMG-DM24	405	65. 8	13.6 9	0.87	0.2 2	19.7 5	1.70	0.4 4	11.8 8	0.96	0.2 3
FIER	2 stories building (without pillar)	Guralp: CMG-DM24	375	83. 2	17.3 9	1.50	0.5 9	17.8 3	1.20	0.5 7	8.80	0.74	0.3 5
KKS	Small 1-story build (with a pillar)	Guralp: CMG-DM24	750	105	7.87	0.95	0.5 1	7.87	0.79	0.4 0	-	-	-
TIR1	Free field	Guralp: CMG-DM24	310	33. 7	113. 9	7.57	1.8 0	110. 0	6.65	1.7 7	43.4 9	2.16	0.7 3
TPE	2 stories building (with pillar)	Guralp: CMG-DM24	690	128 .2	5.36	0.72	0.2 6	6.28	0.79	0.2 2	3.88	0.37	0.1 1

In Figure 11, the two largest amplitude acceleration time histories, recorded at the DURR and TIR1 stations, are presented (see Table 1).

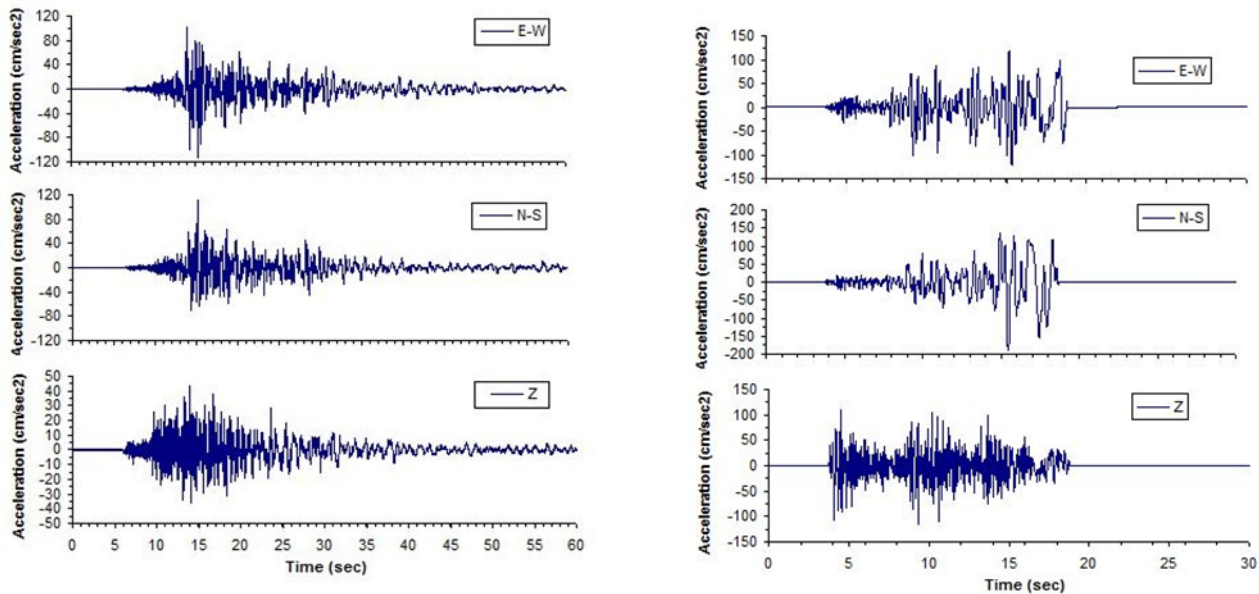


Figure 11. Acceleration time histories recorded at DURR (left) and TIR1 (right) during the M6.4 Durrës earthquake of November 26, 2019. (Source: DS, IGEWE)

Figure 12 provides a comparison of recorded PGAs and predicted values based on a regional ground motion prediction equation (GMPE) (Skarlatoudis et al., 2003)²² as presented by Duni and Theodoulidis (2019).²³ For the applied GMPE, thrust fault and stiff soil conditions (National Earthquake Hazards Reduction Program Category C) were applied. The PGAs of both horizontal components at the closest to the epicenter DURR station are indicated for reasons explained in the next section.

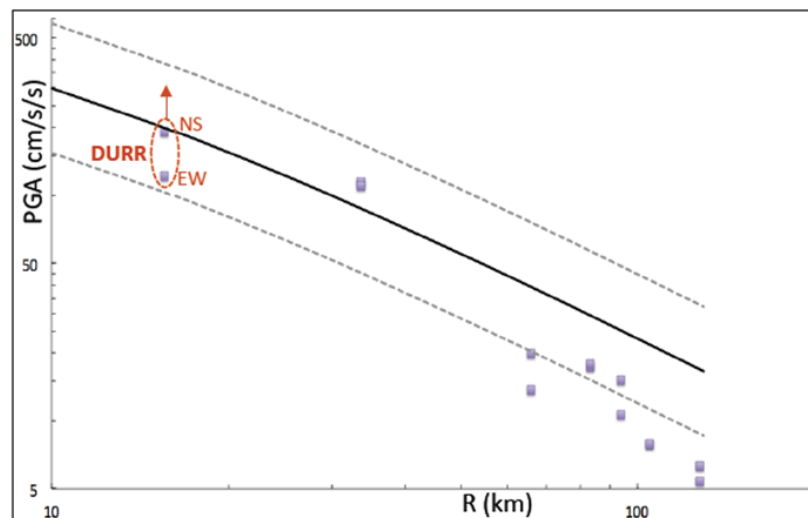


Figure 12. Comparison of recorded PGAs of the earthquake (M6.4) on November 26, 2019, with a regional GMPE of Skarlatoudis et al. (2003) (solid line: mean, dashed lines: 1 standard deviation) as a function of Epicentral Distance (R) (source: Duni and Theodoulidis, 2019).

Although there were a limited number of recorded PGA values, in general, the predictive relation seems to be sufficient for distances shorter than 35 km, whereas for distances greater than 65 km, it systematically overestimates the actual values by approximately one standard deviation. A possible cause of this trend could be attributed to higher anelastic attenuation of the broader epicentral area compared to data used to derive the selected GMPE (Duni and Theodoulidis, 2019).

1.8 Analysis of Strong Motion Record on DURR Station

The accelerometric station DURR, as is shown in Figure 13(left, right), is installed on soft soil (Holocene marshy deposits, clays, sands, and peat) in an area highly susceptible to liquefaction in the southwestern part of the basin (Figure 17).

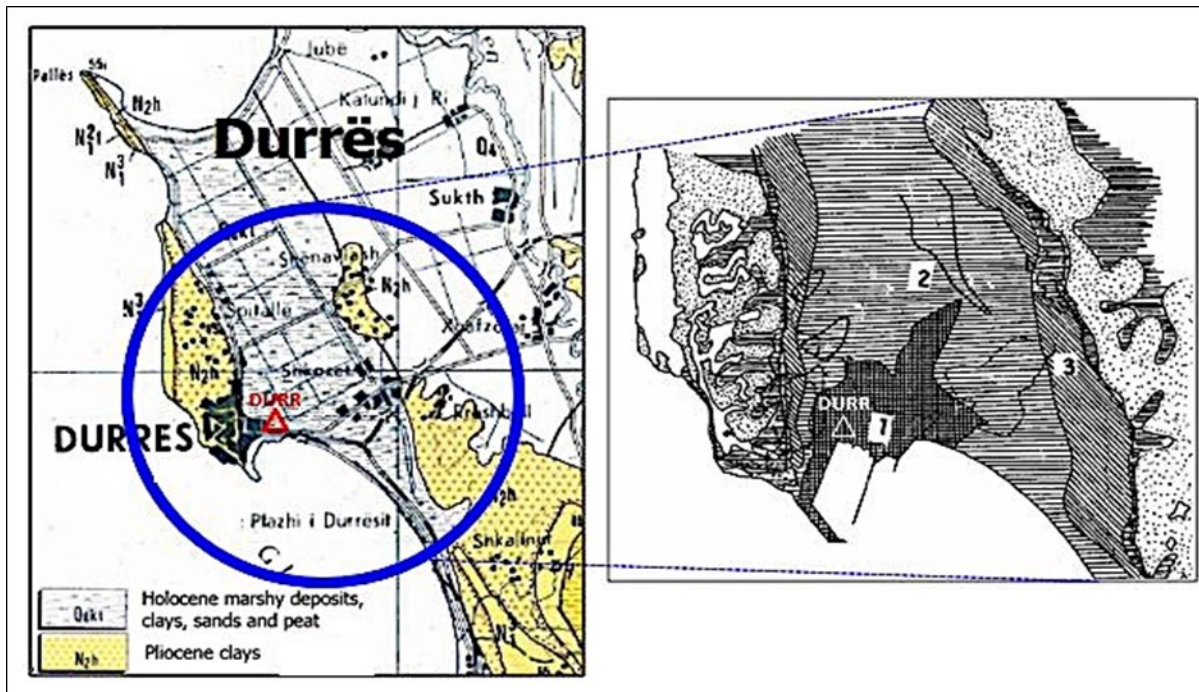


Figure 13. Geological Map of Albania (1983), Scale 1:200.000 (left) and liquefaction potential in the Durrës city: [1] Areas highly susceptible, [2] Areas moderately susceptible, and [3] Areas with low susceptibility (right) (source: Shehu et al., 1983; Kociu, 2004).^{24,25}

Because of a loss of electricity during the mainshock, time history after the first 15 seconds was not recorded at the DURR station, as shown in Figure 11 and Figure 14. In the first part of 15 seconds, 3 different types of waves are apparent: the P-waves, the S-waves, and secondary wave train of S-waves or/and surface waves. The latter waves are larger than and have a longer period than the initial S-waves. In Figure 15, the pseudo-acceleration response spectra for a damping of 2%, 5%, 10%, and 20% for the first 15 seconds of the recording are presented. High acceleration spectral values exceeding 500 cm/s/s are observed for a wide period range between 0.3 seconds and 1.0 seconds. Spectral values remain higher than 300 cm/s/s for an even wider period range between 0.2 seconds and 1.5 seconds. This characteristic, in combination with the fact that the bracketed duration in horizontal components is at least 11 seconds with a ground acceleration greater than 50cm/s/s, indicates the severity of strong ground motion in the city of Durrës. Considering the acceleration time history was interrupted about 15 seconds after its first P-waves arrivals, a higher peak ground or/and spectral values during the subsequent 36 seconds cannot be excluded. For this reason, recorded peak ground values at DURR are highlighted in Table 1 and Figure 12 (Duni and Theodoulidis, 2019).

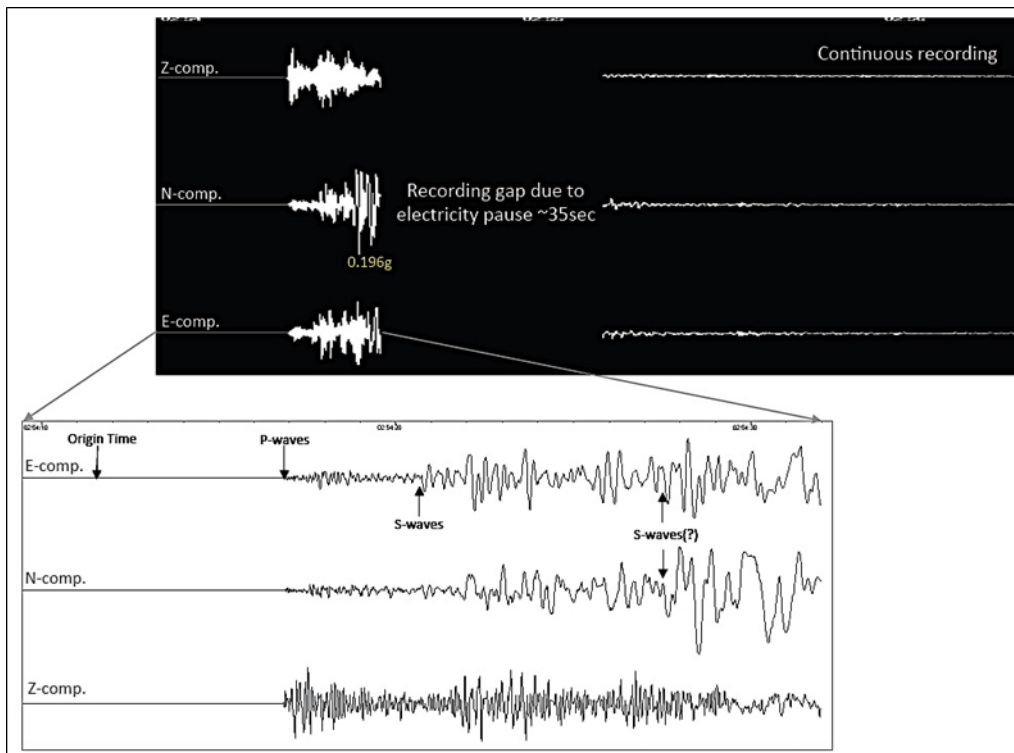


Figure 14. Raw acceleration time history at the DURR station (top) and a zoom of the initial portion (approximately 15 seconds) of the recording (bottom) (source: DS, IGEWE).

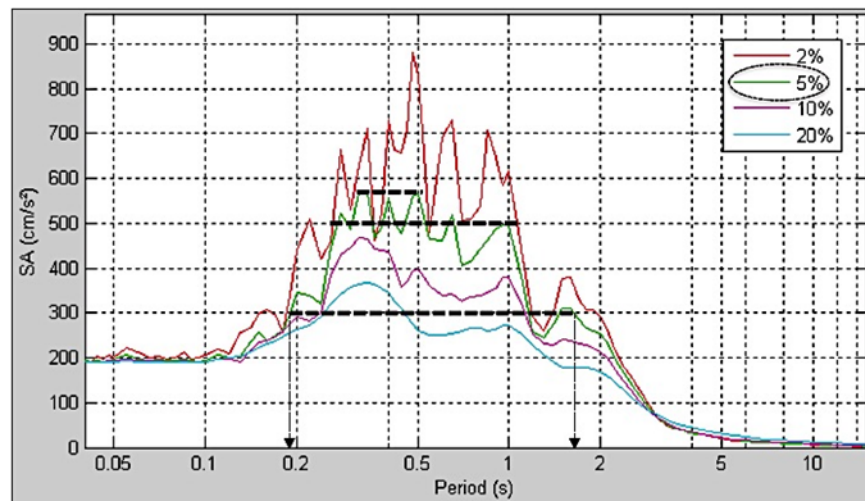


Figure 15. Pseudoacceleration response spectra ($D=0.02, 0.05, 0.1, 0.2$) for the first 15 seconds of the acceleration time history recorded at the DURR station (source: Duni and Theodoulidis, 2019).

1.9 Durrës Basin Configuration

Koçiu et al. (1985) produced an equal depth contour map for the city of Durrës showing a 3-dimensional (3D) bedrock morphology that implied a 3D basin structure (Figure 16). The basin is mainly built on recent Holocene marshy deposits, clays, sands, and peat, with a portion of it on Pliocene clays with a liquefaction potential of the broader residential area (Kociu, 2004). The maximum thickness of sediment layers reaches up to 130 m in the central part of the basin.

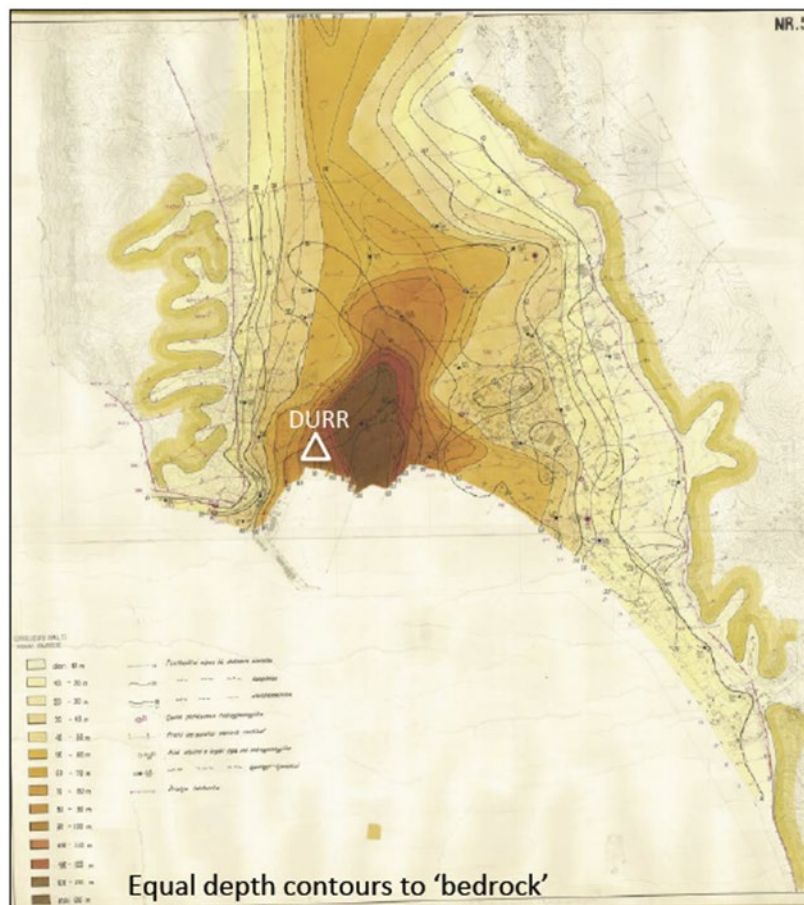


Figure 16. Equal depth to 'bedrock' contours map for the city of Durrës according to the microzonation project of Durrës. The red line shows the position of geological profile IV-IV (source: Koçiu et al., 1985).²⁶

Figure 17 shows the location of the geologic cross section IV-IV developed in the framework of the Durrës microzonation project in the early 1980s (Koçiu et al., 1985) with the position of several boreholes, notably BH5, with a depth of about 120 m. This cross section passes through the Durrës accelerometric station's location. In July 2020, a profile was performed using the multichannel analysis of surface waves (MASW) method for measuring shear waves velocities (Vs), shown in the Figure 17, with the yellow pin in the center of the cross section (Duni et al., 2020).²⁷ The measured point is 75 m west of the Durrës station.



Figure 17. Location of geologic cross section IV-IV. The position of Durrës station and several bore holes are presented. The yellow arrow indicates the MASW Vs measurement profile carried out (source: Duni et al., 2020).

In Figure 18, the 2-dimensional extension of this geologic cross section is presented. In Figure 19, the Vs profile is shown. A 5-layer S-wave velocity model was used, and the Vs₃₀ parameter estimation was equal to 167 m/sec. The first 10-m

thick layer, composed of sand and sandy clays with peat content, is characterized with a V_s equal to 120 m/sec, the second 20-m thick layer, composed of silty clays, is characterized with a V_s equal to 200 m/sec, and the third layer which extends up to the bedrock at a depth of more than 130 m and is composed of argil, is characterized with a V_s in the range 230 to 240 m/sec.

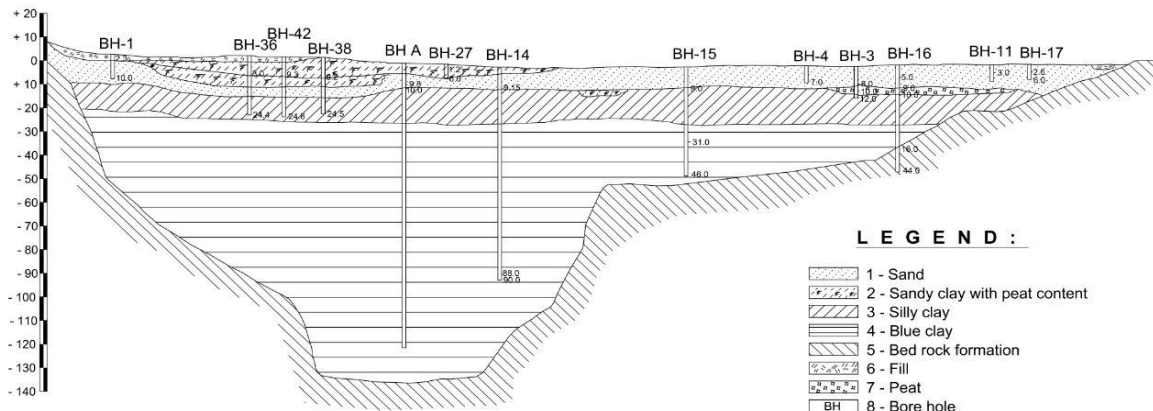


Figure 18. Geologic cross section IV-IV according to microzonation study of Durrës (source: Koçiu et al., 1985).

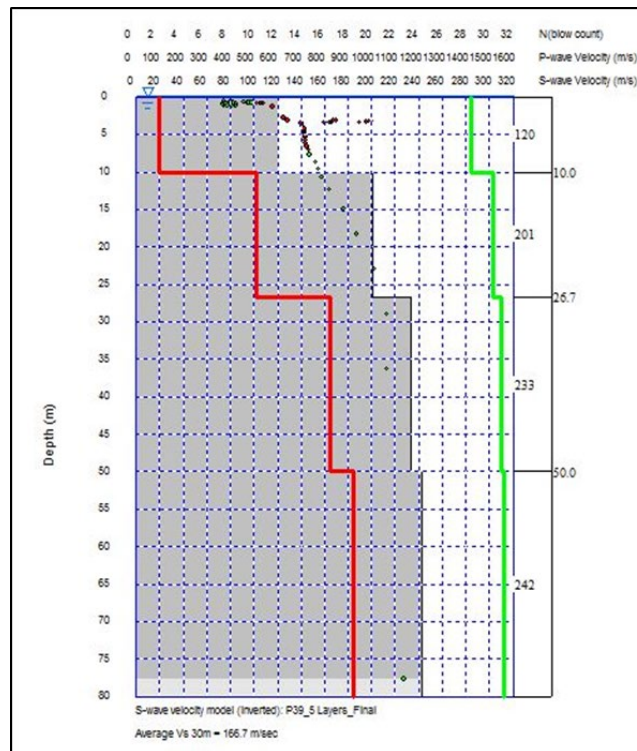


Figure 19. V_s measurement at the center of profile IV-IV (75 m west of DURR station). The curve in green represents the P-waves velocity (V_p), and the line in red represents the values of the standard penetration test, assessed according to the relationship $V_p=f(V_s)$ and $N=f(V_s)$ implemented on the SeisImager/SW software (source: Duni et al., 2020).

The investigated depth with this profile was 75 m, as shown in Figure 19. As Figure 17 and Figure 18 show, the measurement presented in Figure 19 represents the velocity distribution in the center of the basin. Different velocities of shear waves in the uppermost 30-m part of the cross section, but close to this average V_{s30} value, are observed in various places along this profile.

The improved knowledge of the 3D Durrës basin model will substantially contribute to future realistic simulations of ground motion in various seismic scenarios.

1.10 Ground Motion Amplification at the Accelerometric Station in Durrës (DURR)

For the city of Durrës, there was no reference ‘rock’ station nearby to facilitate estimation of an empirical transfer function or to investigate possible soil nonlinear phenomena developed during the mainshock’s strong ground motion. For this reason, only the horizontal-to-vertical spectral ratio (HVSr) (or receiver function) method is applicable. It can be expected that the basin can amplify ground motions at low to moderate shaking levels due to the low shear wave velocities from 120 to 240 m/s (Duni et al., 2020). To investigate particularities of the dynamic properties of geologic formations beneath the DURR station, Duni and Theodoulidis (2019) and Theodoulidis et al. (2020)²⁸ applied the HVSr method separately using two techniques: a) recording the first S-wave window for the stronger part of S-waves (or possibly surface waves) of the strong motion at DURR and b) performing 76 single station ambient noise measurements in the city of Durrës, with an emphasis on heavily affected areas by the earthquake on November 26, based on the Geopsy software ([Link](#)).

For the first S-wave window, three HVSr peaks prevail at frequency ranges from 0.3 to 0.45 Hz, 0.55 to 0.65 Hz, 0.8 to 1.0 Hz, and 1.1 to 1.5 Hz with corresponding amplitudes of up to 7, 6, 10 and 6, respectively (Figure 20). For the fundamental frequency of 0.35 Hz, its amplitude is preferentially higher in azimuths between 40° and 90°. For the second, stronger part of the S-wave, the fundamental frequency of 0.35 Hz disappears, and several HVSr peaks appear at frequency ranges from 0.5 to 0.7 Hz, 1.0 to 1.2 Hz, and 1.4 to 1.6 Hz with corresponding amplitudes up to 15, 17, and 13, respectively. That is, for the second part of S-waves, in the low frequency range ($0.5 \text{ Hz} < f < 0.7 \text{ Hz}$), HVSr amplitudes increase 2 to 3 times in comparison to the corresponding frequency range of the first S-wave window. It is noteworthy that in the second part of S-waves, an additional frequency peak appears at 1.1 Hz with a corresponding amplitude of up to 17 in azimuths between 0° and 30° and 150° and 180°.

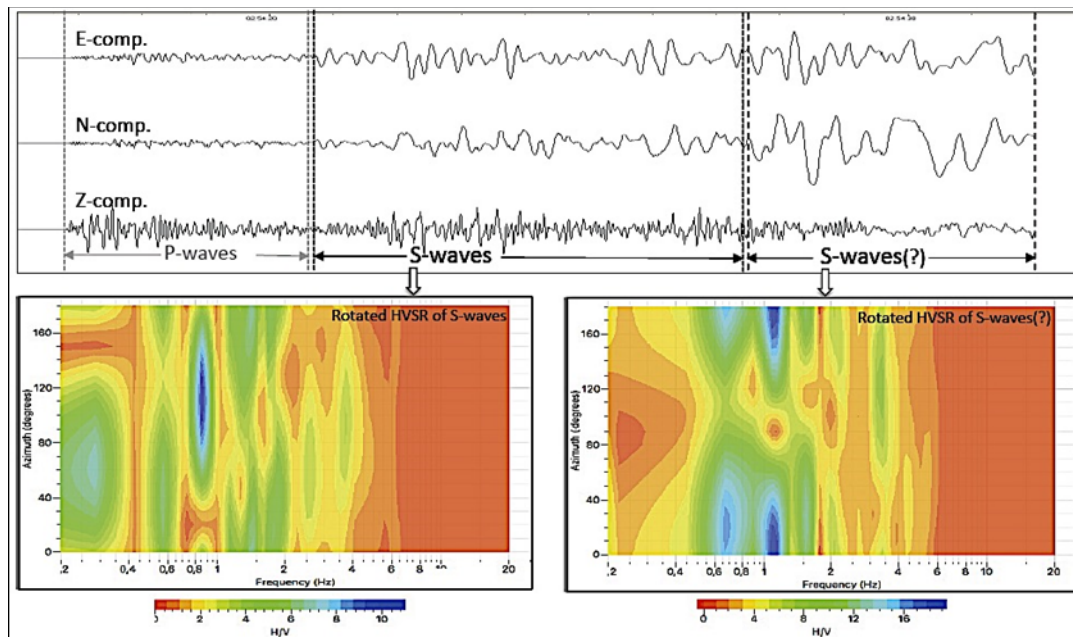


Figure 20. HVSr (receiver function) at the DURR station estimated for the first S-wave window and the second stronger part of S-wave (undefined phase) window of the mainshock (source: Duni and Theodoulidis, 2019).

In Figure 21, the HVSrs for three time windows of the mainshock are presented; namely, the first S-wave is a window of 7 seconds, the second S-wave is a window of 4.5 seconds, and the entire available record length is 15 seconds. The striking difference between the HVSr of the first S-wave window and the other two windows is the lack of a frequency peak at 0.3 Hz with an amplitude of 5 that appears in the former. In addition, the amplitudes of the HVSr peaks for the second stronger S-wave window are almost double compared to the ones of the first S-wave window; however, by using the entire available record length of 15 seconds, the clear HVSr peaks reduce to 3 at 0.65 Hz, 1.4 Hz, and 3.5 Hz, with corresponding amplitudes 12, 10, and 3, respectively.

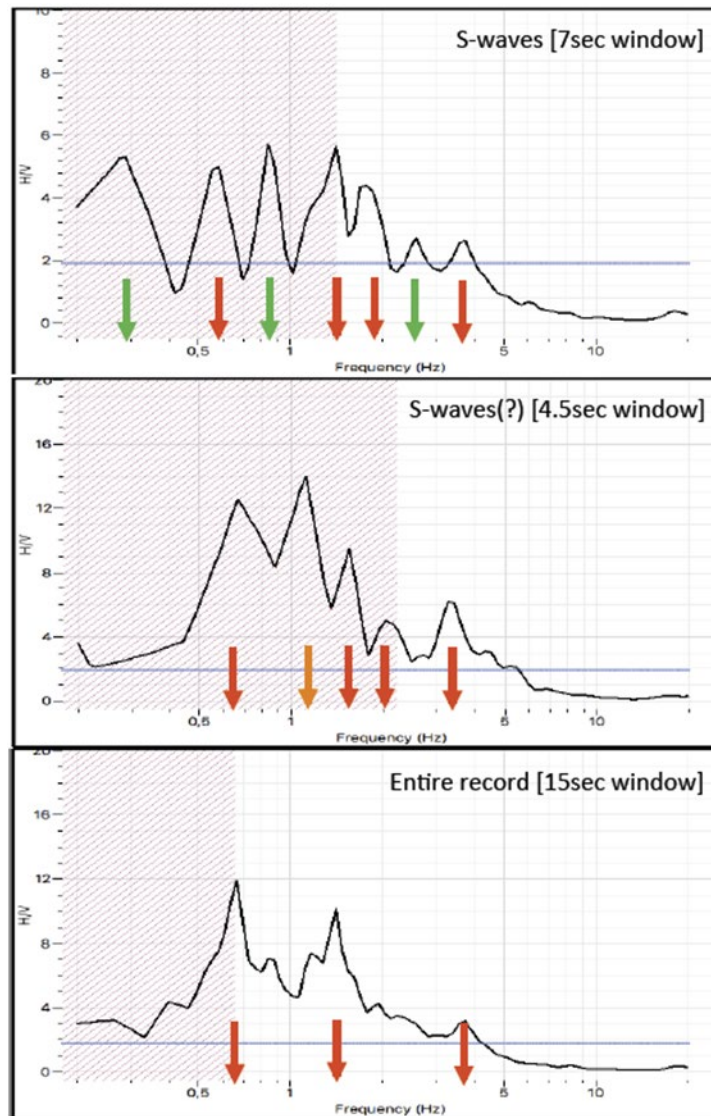


Figure 21. HVSR (receiver function) at the DURR station estimated for the first S-wave window (top) the second S-wave (undefined phase) window (middle), and the entire record length of the mainshock (bottom) (source: Duni and Theodoulidis, 2019).

In order to examine the HVSR at the DURR station based on low-amplitude ground motions, an aftershock (earthquake of November 28, 2019, at 10:52:42GMT, 41.47° north, 19.35° east, M4.9) recording with a PGA of 72 cm/s/s in the east-comp., 45cm/s/s in the north-comp., and 17cm/s/s in the Z-comp. was selected. For the HVSR analyses, an S-wave window of 20 seconds and surface and coda wave window of 60 seconds were selected (Figure 22). For both windows, two prominent peaks appear from 0.3 to 0.35 Hz and 0.5 to 0.6 Hz with amplitudes about 30% reduced compared with the surface and coda waves window. These two peaks are also apparent in the case of the first S-wave window of the mainshock (Figure 23), whereas the second peak from 0.5 to 0.6 Hz is apparent in all three windows of the mainshock. For the case of the S-wave window of the aftershock, another three HVSR peaks appear from 0.8 to 0.9 Hz, 1.5 to 2.5 Hz, and 4.5 to 5.5 Hz with relatively low amplitudes of 3 to 4.

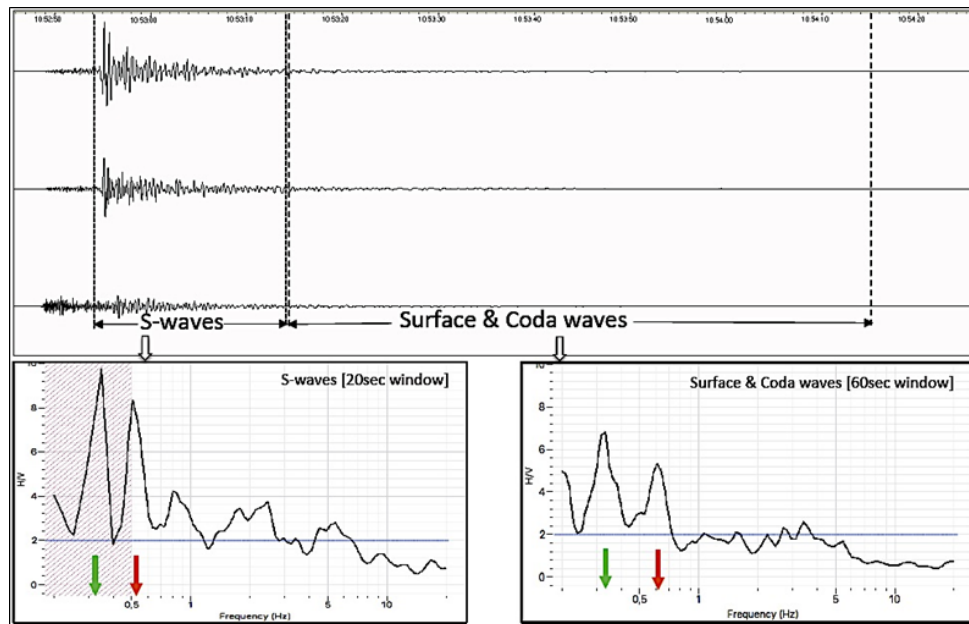


Figure 22. HVSR (receiver function) at the DURR station estimated for the S-wave window and the surface and coda waves window of the aftershock on November 28, 2019, 10:52:44 UTC (M4.6) (source: Duni and Theodoulidis, 2019).



Figure 23. Distribution of fundamental frequency (f_0) in the city of Durrës. For sites in areas with the red dashed line, the distribution is $[0.3 \text{ Hz} \leq f_0 < 1 \text{ Hz}]$, for the orange dashed line $[1 \leq f_0 < 2 \text{ Hz}]$, and for the yellow dashed line $[2 \text{ Hz} \leq f_0 \leq 5 \text{ Hz}]$. The blue dashed line includes a site with flat HVSR. Background layer isodepth contours per 10 m (see Figure 16) (source: Theodoulidis et al., 2020).

In February 2020, Theodoulidis et al. (2020) performed 76 single station ambient noise measurements in the city. Data processing and analyses based on the horizontal-to-vertical (H/V) spectral ratio method showed that an extended part of the Durrës city shows a low fundamental frequency ($f_0 < 1.0 \text{ Hz}$; Figure 23). This part is mainly in the center-west side of the city, whereas fundamental frequency decreases towards the edges of the basin. The vast majority of examined sites (95%) exhibited an amplitude of fundamental and dominant frequency greater than 2 Hz, reaching the value of about 6 Hz

(Figure 24). Taking into account the scientific consensus (among others; Haghshenas et al., 2008)²⁹ that H/V peak amplitude represents a lowest threshold of actual ground amplification estimated by classical methods (e.g., standard spectral ratio method), one would expect equal and/or higher amplification due to basin excitation by a seismic wavefield.



Figure 24. Distribution of fundamental frequency corresponding amplitude (A_o) in the city of Durrës. For sites in areas with the red dashed line, the distribution is $[A_o \geq 3.0]$, for the orange dashed line $[2 < A_o < 3]$, and for the blue dashed line $[A_o \leq 2]$. Background layer isodepth contours per 10 m (see Figure 16) (source: Theodoulidis et al., 2020).

The HVSR (receiver function) analyses showed several peaks with high amplitudes for both the mainshock and aftershock recordings and ambient noise measurements in the city. From these analyses, it seems that nonlinear soil behavior was not apparent at the site of the DURR station.

Apart from the ambient noise measurements on the ground in the city of Durrës (Theodoulidis et al., 2020), a 30-minute ambient noise measurement was performed at the center of the top of a 10-story building (Figure 25) that did not suffer any damage, although it is situated in the part of the city where serious damage was observed.



Figure 25. Top view of a 10-story reinforced concrete building (source: Theodoulidis et al., 2020).

Ambient noise was recorded in both the longitudinal and the transversal directions of the building. The power spectral density in both directions is presented in Figure 26. The fundamental frequencies of the building in both the longitudinal and transversal directions were observed to be 1.93 Hz and 1.35 Hz, respectively. As expected, in the longitudinal direction, the building appears stiffer than transversal direction. However, in both directions, the fundamental period ranges between 0.52 seconds to 0.75 seconds, which fall in the period range in which the recorded spectral acceleration exhibited the highest values.

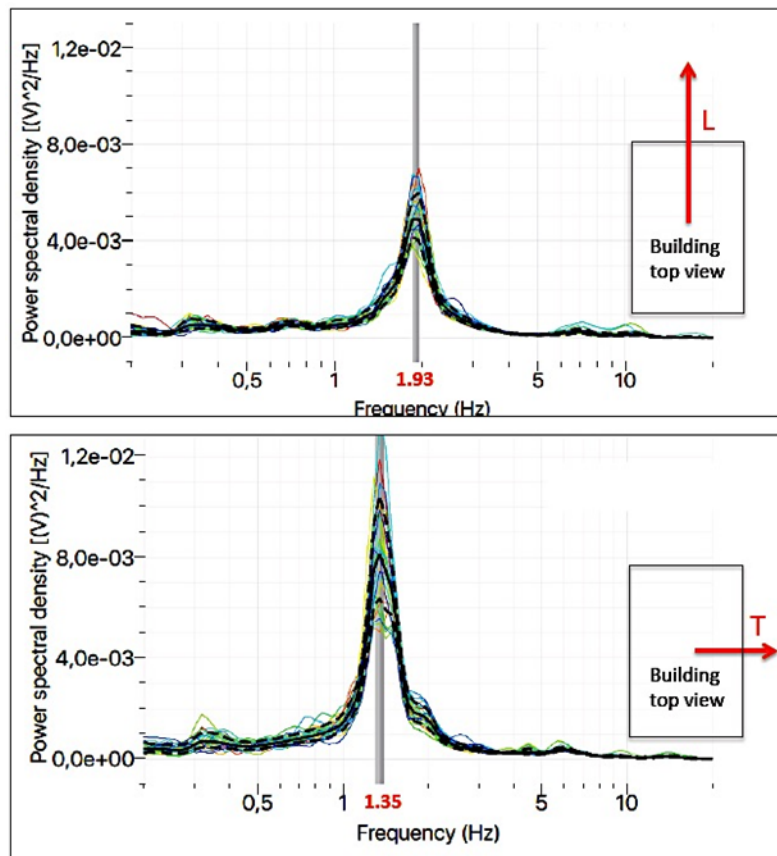


Figure 26. Power spectral density based on ambient noise measurements at the top of the 10-story building (source: Theodoulidis et al., 2020).

1.11 KTP-N.2-89 Code Design Spectra and Comparison with Observed Spectra in Durrës and Tirana

In Table 2, we present the soil classification that is applied in the KTP-N.2-89 Albanian design code. Table 2 indicates that site conditions in this code are specified only on the basis of lithological description of the subsoil profile without considering other parameters like, for example, the time averaged shear wave velocity in uppermost geologic layers ($V_s=30$ m/sec).

Table 2: Global description of subsoil conditions within the scope of KTP-N.2-89.

Soil Category	Lithological Description of Subsoil Conditions
I	<ul style="list-style-type: none"> Hard rocks, magmatic, partly metamorphized and sedimentary rocks with high static and dynamic stability, not being disturbed by the tectonics or other alteration phenomena Average strength flysch formations not influenced by tectonic or alteration phenomena, sandstones, conglomerate etc.
II	<ul style="list-style-type: none"> Rock formations with developed jointing and alteration phenomena Stiff or semi-stiff silty clay formations independently of water content, Loose formations: Sandy and silty clays, clays in the strong plastic and elastic state with saturation, Stiff or semi-stiff sands and gravels with saturation.
III	<ul style="list-style-type: none"> Loose formations: Large, middle and small grain size sands, dusty sands with near surface water level, Clays and soft up to flowing state plastic silty clays

The seismic action in the KTP-N.2-89 design code is expressed by an elastic acceleration response spectrum $SA(T)$ defined by the relation (KTP-N.2-89; Duni and Kuka, 2003; Duni and Kuka, 2004):

$$SA(T) = k_E \beta(T) g,$$

where k_E is the so-called seismic coefficient, $\beta(T)$ is the dynamic coefficient (depending on the vibration period T and 5% damping) with the shape shown in Figure 27, and g is the acceleration of gravity. Introducing the coefficients k_r (building importance coefficient) and ψ (ductility and damping structure's coefficient), the design acceleration values are obtained. Both k_E and $\beta(T)$ are dependent on local soil conditions and are classified into three categories.

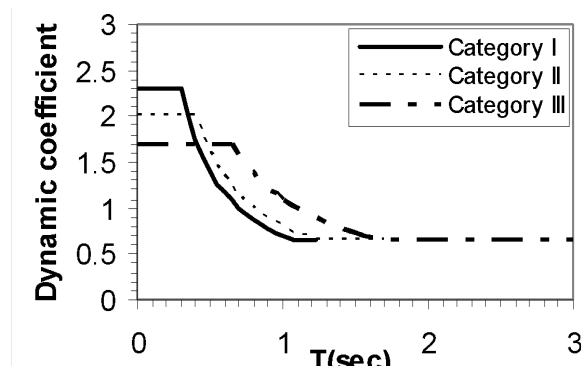


Figure 27. Dynamic coefficient $\beta(T)$ source: KTP-N.2-89.

The values for the seismic coefficient k_E are shown in Table 3, whereas the values that determine the shape of the dynamic coefficient $\beta(T)$ curves are shown in Table 4. By definition, in KTP-N.2-89, the product $k_E g$ is the PGA.

Table 3: Values of seismic coefficient kE . (source: KTP-N.2-89)

Soil Category	Seismic Intensity (MSK-64)		
	VII	VIII	IX
I	0.08	0.16	0.27
II	0.11	0.22	0.36
II	0.14	0.26	0.42

Table 4: Values of various parameters defining the spectral shape of $\beta(T)$ curves. (source: KTP-N.2-89)

Soil category	TC(sec)	TD(sec)	β ($0 \leq T \leq TC$)	β ($TC \leq T \leq TD$)	β ($TD \leq T$)
I	0.30	1.08	2.3	$0.7/T$	0.65
II	0.40	1.23	2.0	$0.8/T$	0.65
II	0.65	1.69	1.7	$1.1/T$	0.65

On the bases of parameters given in Tables 3 and 4 and relation (1), the site-dependent acceleration response spectra for three different levels of seismic intensity can be constructed (Figure 27 to Figure 30).

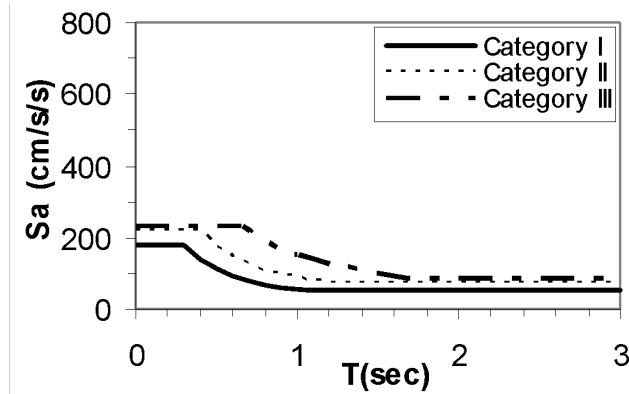


Figure 28. Site-dependent response spectra for seismic intensity VII .(source: Duni and Kuka, 2003).

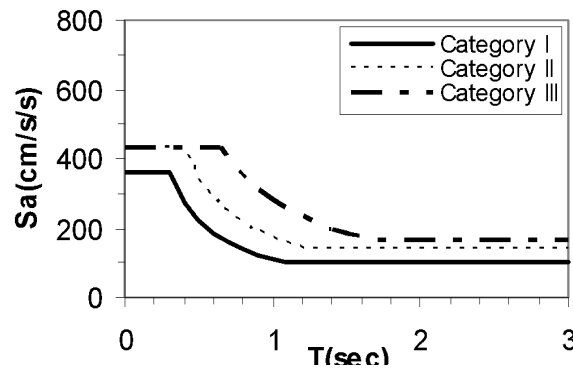


Figure 29. Site-dependent response spectra for seismic intensity VIII.(source: Duni and Kuka, 2003).

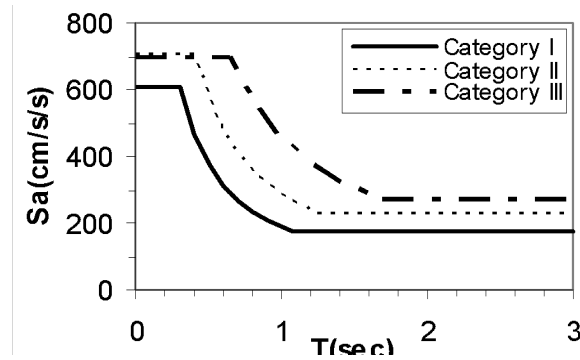


Figure 30. Site-dependent response spectra for seismic intensity IX. (source: Duni and Kuka, 2003).

In Figure 31 and Figure 32, the elastic design spectra are presented for different intensities according the MSK-64 seismicity scale for Durrës and Tirana areas. The seismicity coefficients are taken from Table 3. In these two figures, the design spectra according to Eurocode 8 is presented for ground type C of type 1 spectral shape. According to the seismic hazard map shown in Figure 9, PGA (a_{gR}) values for Durrës and Tirana for mean return period of 475 years, corresponding to the “no-collapse” requirement, are 0.286 g and 0.274 g, respectively; for a 95-year return period corresponding to the “damage limitation” requirement, these values are 0.189 g and 0.184 g, respectively. The two horizontal components’ acceleration response spectra recorded at the DURR and TIR1 station are also shown in these figures.

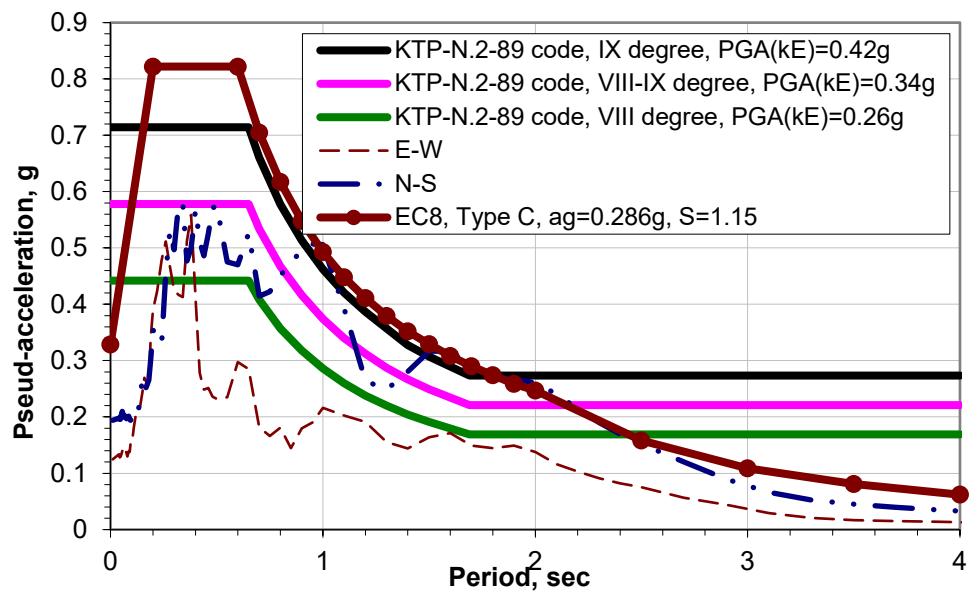


Figure 31. Elastic spectra according to KTP-N.2-89 and EC8 codes with the 5% damped horizontal pseudoacceleration response spectra at the DURR station from the M6.4 event (source: DS, IGEWE).

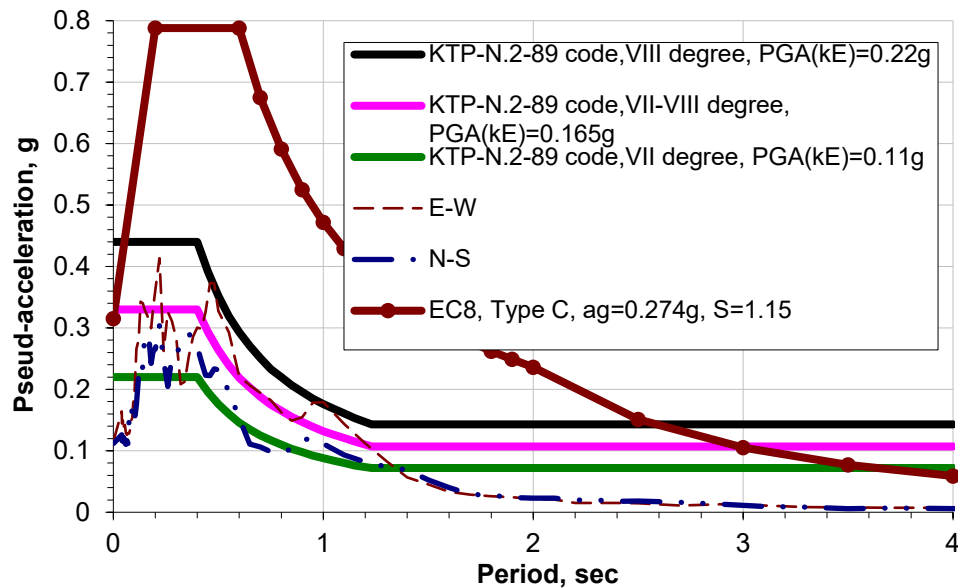


Figure 32. Design spectra according to KTP-N.2-89 and EC8 codes with the 5% damped horizontal pseudoacceleration response spectra recorded at the TIR1 station from the M6.4 event (source: DS, IGEWE).

From Figure 31, it can be seen that the recorded spectral acceleration in Durrës was high relative to the KTP-N.2-89 code elastic spectra for seismic intensity VIII: it was at least 500 cm/s/s for a wide range of periods between 0.3 seconds and 1.0 second, possibly with a decisive impact on a wide range of buildings, especially mid-rise structures (5 to 10 stories).

For both Durrës and Tirana, as shown in Figure 31 and Figure 32, it is apparent that elastic design spectra according to Eurocode 8 are more conservative than those imposed by the KTP-N.2-89 seismic code currently in force in Albania. It should also be noted that the ground type conditions in the DURR station were even worse than those corresponding to Type C Eurocode 8 spectrum, which means that the actual difference between Eurocode 8 and the KTP-N.2-89 was even larger than what is shown in Figure 31 for Durrës.

1.12 Summary and Conclusions

The earthquake of November 26, 2019, in Albania struck a modern urban environment—the metropolitan area of Durrës—and caused extended damage downtown as well as in several villages in the epicentral region. Certainly, it is not the first time that the city of Durrës was hit by strong shaking. Historically, the last one took place during the earthquake in 1926 (M6.2), but at that time, Durrës was a small town restricted at the southwest hills of the basin, and there existed a different class of buildings.

Based on the nearest epicentral strong motion record (DURR station), the strong motion duration (with PGA exceeding 50 cm/sec/sec) was at least 11 seconds. However, the recording ceased because of loss of electricity. Based on the relation between the subsurface reverse fault length and earthquake magnitude (Coppersmith et al., 1994), it is estimated that the subsurface fault length was about 19 km. In the case of unilateral rupture with a rupture velocity of about 2.5 km/sec (the rupture duration that is related to strong motion duration in the near fault area), 7.5 seconds of motion would be estimated. This value is shorter than the observed on the DURR station record. This observation implies either a complex rupture or a duration lengthening of ground motion due to basin effects.

Based on H/V spectral ratio from both earthquakes and ambient noise measurements, it appears that the Durrës basin has the potential to drastically amplify ground motions in future events. However, since no liquefaction phenomena were observed downtown (liquefaction in Durrës was limited to the beach area), the map of liquefaction susceptibility proposed in 2004 should be revisited. Although a low surface shear wave velocity (i.e., less than 200 m/sec) was measured in the Durrës basin, surprisingly, soil nonlinearity was not exhibited at the DURR station. Since the latter observation is based solely on earthquake HVSR measurements, further investigation (*in situ* or in lab) is needed to confirm this conclusion.

The recorded spectral acceleration in Durrës was high relative to the code elastic spectra for a wide range of periods between 0.3 seconds and 1.0 seconds, possibly with a decisive impact on a wide range of buildings, especially mid-rise buildings (5 to 10 stories). This observation may partly explain the degree of damage to downtown Durrës. Before any final conclusion regarding the damage on the built environment is reached, one should consider the fact that during the September 21, 2019, earthquake (M5.6), 2 months prior, buildings were also damaged close to the city of Durrës. It is possible that damage in the September earthquake may have reduced the seismic capacity of some buildings in the November earthquake.

Comparisons between the KTP-N.2-89 and Eurocode 8 seismic code provisions elastic spectra showed that the latter is more conservative than the one currently in force in Albania, indicating the need to revisit the design seismic demands of KTP-N.2-89 if harmonization with European standards is desired.

The evolution of seismicity a few months before the mainshock of November 26 suggests that a dense seismic network around extended metropolitan areas, like Durrës and Tirana, would allow for better monitoring of lower magnitude seismicity. Such an evolution based on solid data would help decision makers mitigate earthquake risk before an event and during the first critical hours of the seismic sequence.

2 GEOTECHNICAL EFFECTS

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2.1 Geotechnical Setting

The Mw 6.4 Durrës earthquake of November 26, 2019, caused significant damage to the coastal Durrës metropolitan area located in the coastal portion of the Periadriatic Depression of central-western Albania and to the Thumanë town located along the eastern margin of the Tirana Depression (Figure 33). Damage was also reported in Laç town, the town of Fushë-Krujë, Kamëz, and the city of Tirana, which is also located along the eastern margin of the Tirana Depression (Figure 33). Based on the spatial distribution of damage, two ellipses are defined (Figure 33) with major axes oriented NW-SE (Lekkas et al., 2019b).³⁰ The western ellipse is observed along the coastal Durrës area, whereas the eastern one is along the eastern margin of the Tirana Depression (Figure 33). Their NW-SE direction coincides with the strike of the seismogenic fault derived from the fault plane solutions provided by several seismological institutes and observatories.



Figure 33. Based on the distribution of damage induced by the November 26, 2019, Durrës earthquake, two ellipses are formed with NW-SE trending major axis. The western ellipse is observed along the coastal Durrës area (city of Durrës), whereas the eastern one is observed along the eastern margin of the Tirana Depression (Laç, Thumanë, Fushë-Krujë, Kamëz, and Tirana). The red star corresponds to the epicenter provided by the National Observatory of Athens and the yellow star to the one provided by the European Mediterranean Seismological Center (source: Lekkas et al., 2019b, modified).

The surficial geology of the areas affected by the Durrës earthquake of November 26, 2019, is comprised of recent deposits (Figure 34). Their age ranges from Oligocene to present based on data presented on the geological map of Albania (1:200000 Geological map of Albania; MMKS, 1983).³¹

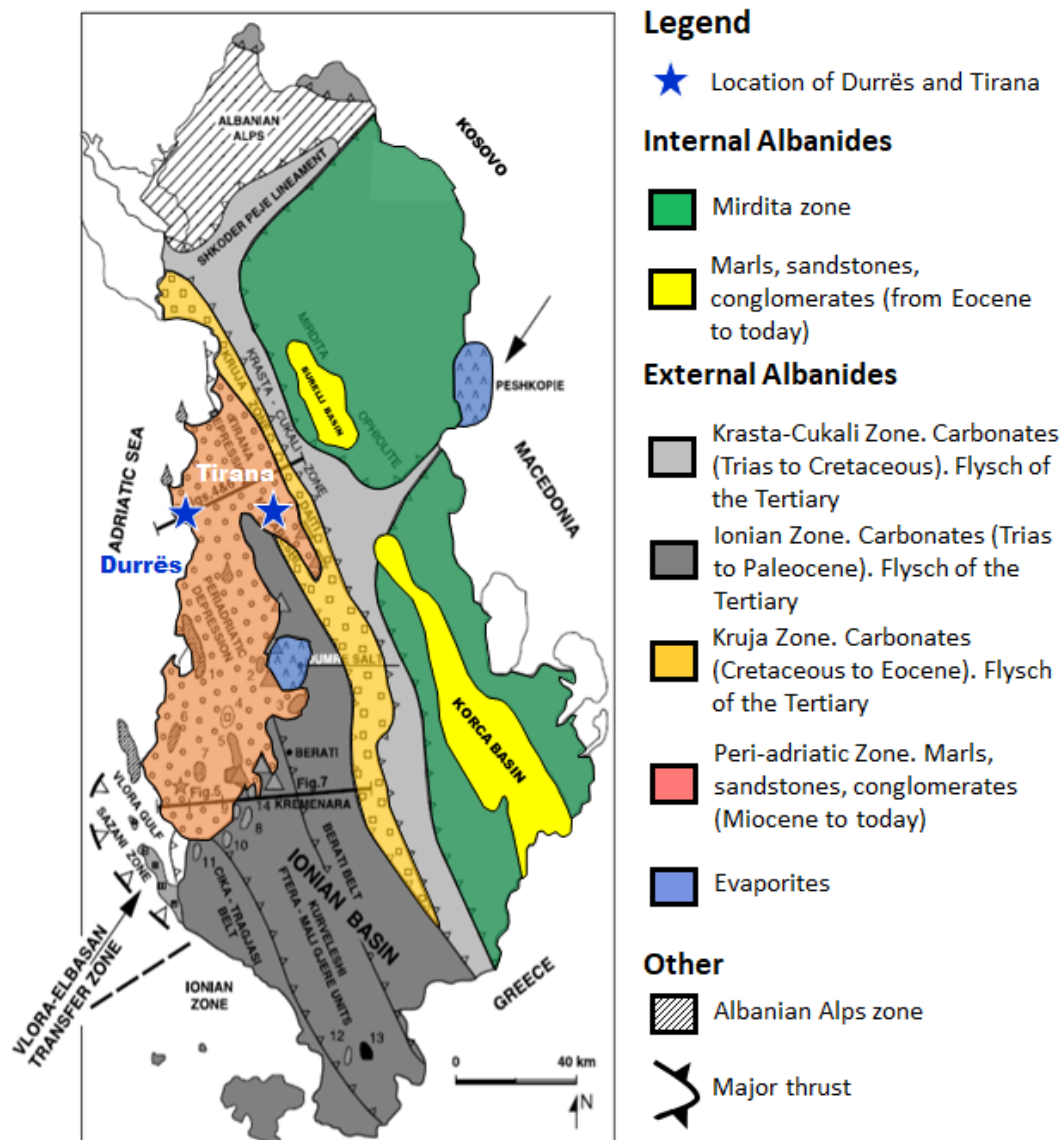


Figure 34. Simplified geological map with the main tectonic units of Albania). Geological time scale: Triassic (-251 to -200 mega annum (Ma)), Cretaceous (-145 to -65 Ma), Paleocene (-65 to -56 Ma), Eocene (-56 to -34 Ma), and Miocene (-23 to -5 Ma) (source: Roure et al., 2004; Berthelon, 2015).^{32,33}

The western part of the Durrës hills is composed of Miocene molassic formations comprising clay, siltstone, sandstone, and gypsum, whereas its central and eastern parts comprise Pliocene sandstones and conglomerates. In contrast, the Durrës plain is filled up with Pliocene and Quaternary deposits. The Pliocene deposits constitute the basement of the Quaternary ones and include sandstones and conglomerates that also occur in the central and eastern parts of the Durrës hills. The Quaternary deposits in the Durrës plain include alluvial, lagoonal, marshy, and marine deposits with a total thickness of 130 m.

The marshy Holocene deposits (composed of clay, clayey loam, sand, and organic material) played a role on the behavior of the buildings and the distribution of the earthquake-induced building damage in the city of Durrës. A large part of the city is founded on these marshy deposits, which have their maximum thickness at the central part of the swamp. The geological structure and related lithologies of this area are also revealed by its name ("Kënetë" in the Albanian language means "marshes").

In the eastern part of the earthquake-affected area, the Tirana syncline corresponds to the Tirana Depression (Aliaj et al., 2001; Skrami, 2001).^{34,35} The eastern earthquake-affected towns of Laç, Thumanë, Fushë-Krujë, Kamëz, and the city of Tirana are located along the eastern margin of the Tirana Depression. The alpine basement of the eastern margin is composed of Oligocene flysch and Upper Cretaceous limestone, while Miocene formations overlying alpine basement.

The Miocene formations dip westward and southwestward. More specifically, they dip 15° to the W in Thumanë, 15° to 30° to the SW in Fushë-Krujë, 5° to 15° to the SW in Kamëz and 10° to 15° to the SW in the Tirana area. Pliocene, Pleistocene, and Holocene deposits are overlying Miocene formations.

The most affected towns along the eastern margin of the Tirana Depression are founded mainly on recent deposits. More specifically, the towns of Laç and Thumanë are situated on Holocene marshy deposits with sand, gravels, and peat, Holocene alluvial deposits with sand and gravels, and Pliocene clays. The towns of Fushë-Krujë and Kamëz have a geological setting similar to Thumanë. They are founded on Holocene deposits of mainly sand on Pleistocene and Holocene alluvial deposits and Pliocene sandstones, clays, and conglomerates.

The aforementioned synclines and anticlines in the western and eastern earthquake-affected areas are bounded by active tectonic structures comprising thrust and strike-slip faults. These active structures belong to seismogenic zones responsible for the high historical and recent seismicity of the study area (Aliaj, 1988; Aliaj et al., 1996b).^{36,37} Furthermore, based on the tectonic structure of the earthquake-affected area and fault plane solutions of the November 26, 2019, Durrës earthquake, there is consistency between fault plane solutions and field geological data.

2.2 Site Effects

The Durrës alluvial basin has the geometrical and mechanical characteristics to induce ground motion amplification at the surface during earthquakes (e.g., soft soils filling a deep U-shaped valley). In February 2020, the L'Association Française du Génie Parasismique (AFPS) post-seismic mission carried out a number of seismic noise measurements (30 minutes of recording at each site) using a 3-component velocimeter (Tromino instrument) to measure the ground resonance fundamental frequency, f_0 , using the HVSr method (Nakamura, 1989).³⁸ The results are presented in the figures below (Figures 35 and 36).

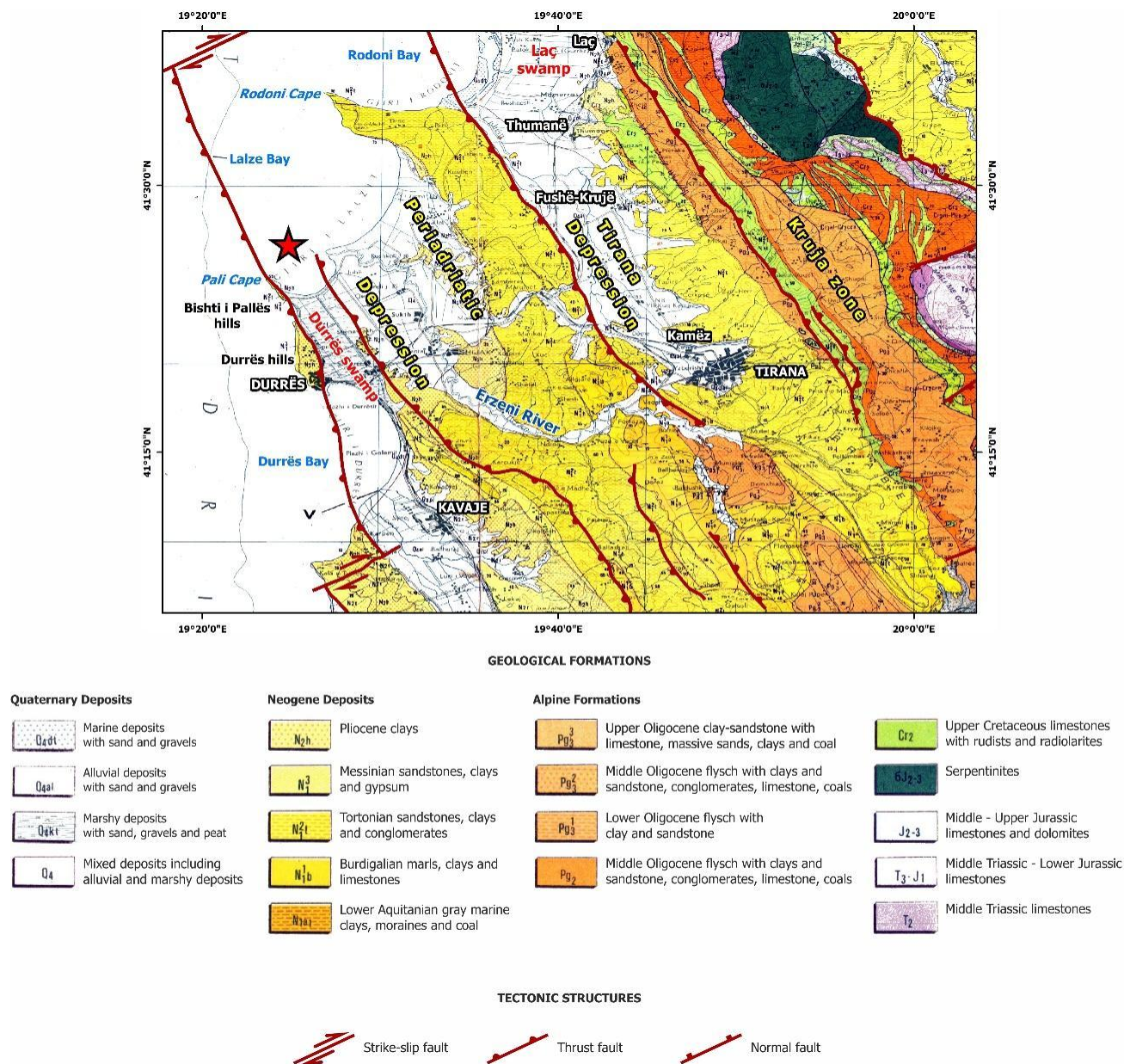


Figure 35. The geological map of the area affected by the Mw 6.4 Durrës (Albania) earthquake of November 26, 2019. It is mainly composed of Quaternary and Neogene deposits over the alpine basement. The Quaternary deposits are observed in the flat lowlands, whereas the Neogene deposits occur in the hilly areas. The alpine basement outcrops along the eastern margin of the Tirana Depression and comprise formations of the Kruza zone (source: MMKS, 1983; modified by Lekkas et al., 2019a, 2019b).³⁹

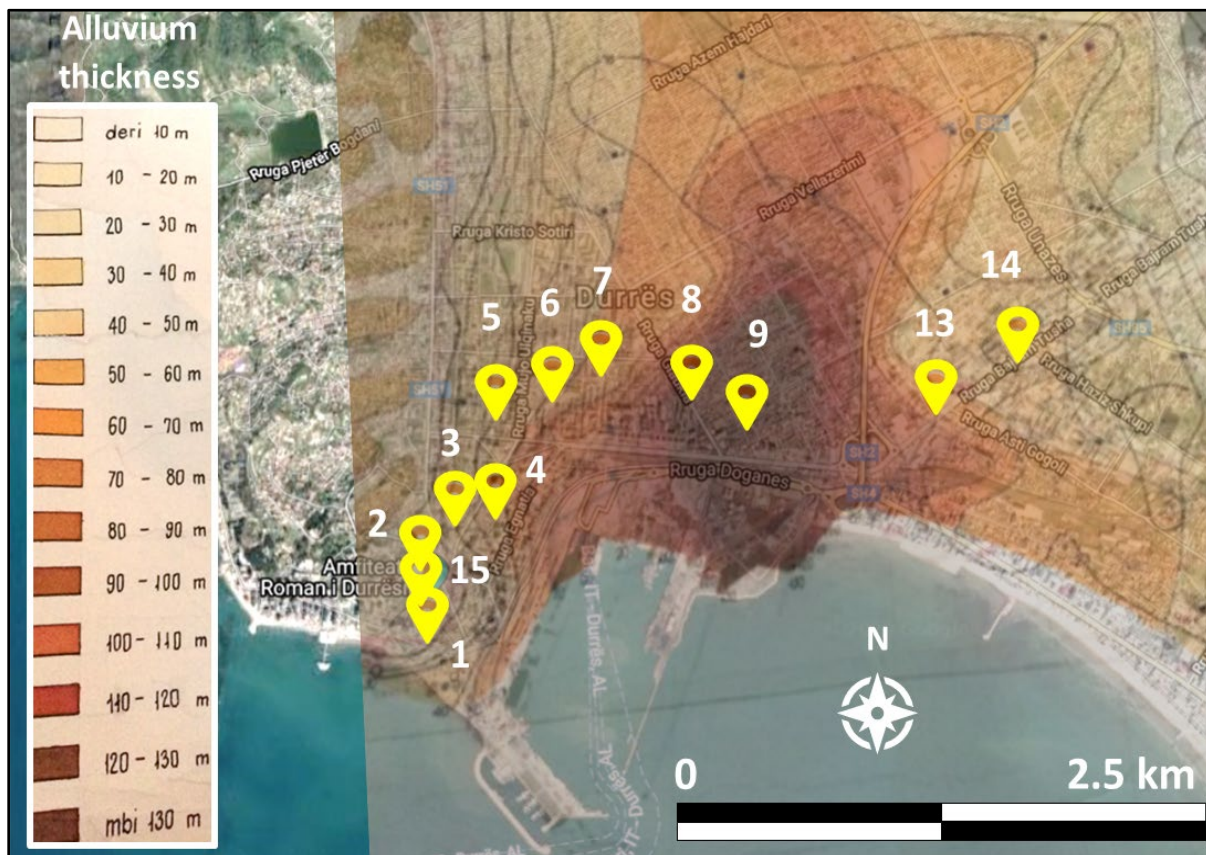


Figure 36. Synthesis of HVSR measure points and alluvium thickness in Durrës (source: AFPS, 2020).⁴⁰

2.3 Soil-structure Interaction

The code KTP-N2-89 does not require characterization of the foundations with respect to the soil-structure interaction. Except for losses of soil-bearing capacity in the liquefaction zone of Durrës, no severe visible disorders of foundations were reported.

However, the Durrës basin could generate severe and contrasting kinematic effects on deep foundations, as represented in Figure 37 with the shape of the ground displacement for the fundamental mode of vibration. Basically, on the western edge of the basin, multi-story buildings can be founded on piles anchored to the bedrock for maximum depths of 20 to 30 m. In the deepest part of the basin, deep foundations are floating piles, which are less affected by the strain generated by the kinematic effect.

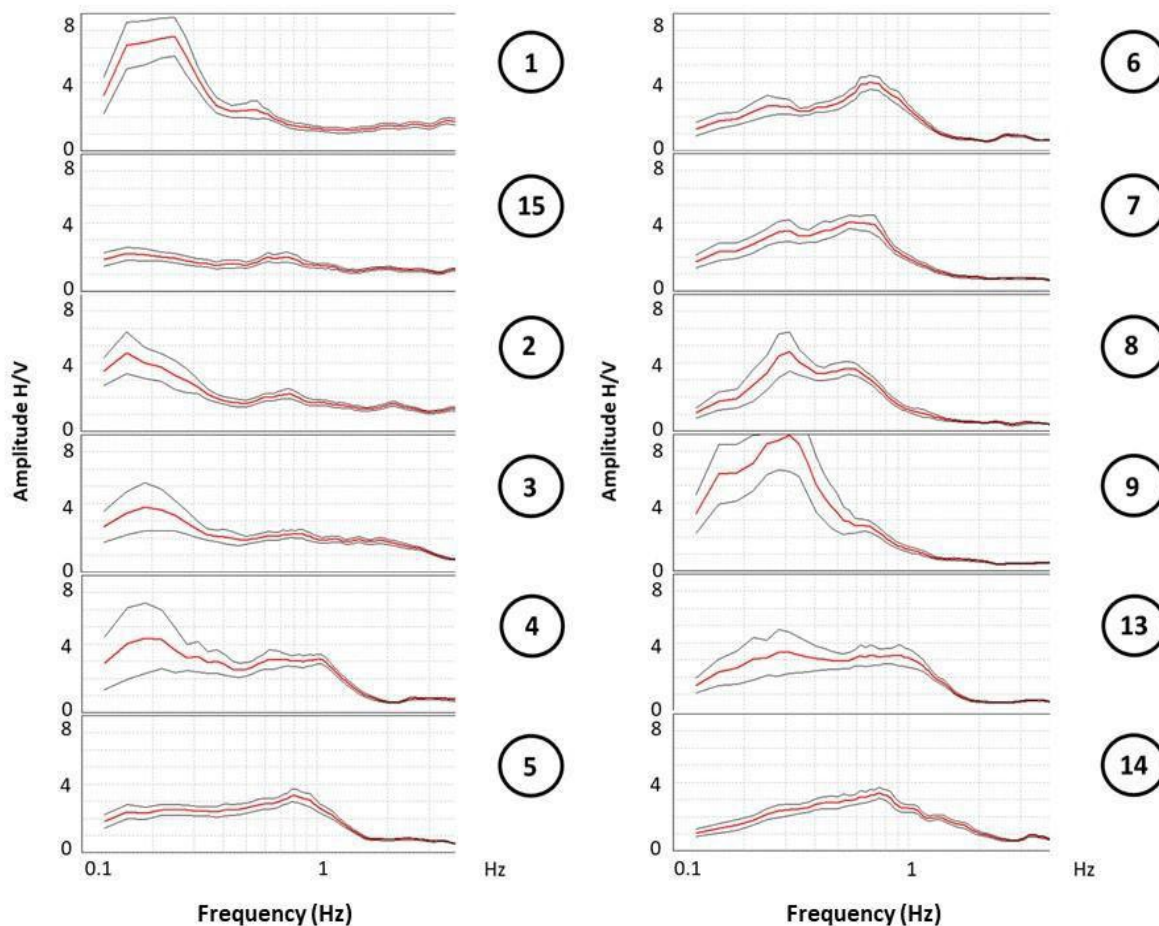


Figure 37. Synthesis of HVSR measurements in Durrës (source: AFPS, 2020).

We observe a relation between the depth of the basin and the distribution of damages. In fact, on the map established by McKenney in 2019, few characteristic areas could be identified (Figure 38). In the axial part of the valley (Zone 2), where the alluvium is thickest, there was little damage (Figure 38). Aleksander Moisiu University, located further north of this figure and not shown here, shows no damage (Brûlé et al., 2020).⁴¹ The distribution of damage is rather concentrated in two lateral zones (Zones 1 and 3), where the bedrock shallows (Figure 38).

In Zone 1, a band-shaped distribution of damage corresponding to a thickness of 5 to 20 m of alluvium (Zone 1.1 in Figure 38) can be distinguished. Some damaged structures are located in an intermediate zone (Zone 1.2 in Figure 38), corresponding to a 20 to 40-m thickness of soil. Finally, a higher density of damaged structures is concentrated in Zone 1.3 (Figure 38), corresponding to alluvial thicknesses up to 40 m. Zone 3 is located along a narrow strip of the shoreline, where the bedrock has a dip of around 10% with a sedimentary thicknesses of 40 to 70 m. This area is also affected by liquefaction (see section 2.4).

The map provided in Koçiu et al. (1985) reports tectonic contact (red barbed line) along Zone 1.1 (Figure 38) that is linked to the presence of a deep fault, reputed to have been active since the Pleistocene, around -2.6 Ma (Aliaj et al., 2004).⁴² Wave trapping phenomena in a waveguide formed by the fault gouge (e.g., Rovelli et al., 2002)⁴³ or seismic wave diffraction phenomena at the interface between geological units with different stiffnesses (Zone 1 and Zone 1.2; e.g., Kawase, 1996; Riga et al., 2016; Stambouli et al., 2018)^{44, 45, 46} may explain the spatial distribution of damage observed in Zones 1.1, 1.2, and 1.3 (Figure 38).

2.4 Liquefaction

2.4.1 Liquefaction history of the 2019 earthquake-affected area

Liquefaction triggered by earthquakes has been observed in western Albania, mainly in the Periadriatic Depression, during strong earthquakes of the 20th century (Petrovski and Paskalov, 1980; Koçiaj and Sulstarova, 1980; Shehu and

Dhima, 1983; Dibra 1983; Koçiu, 2004; Aliaj et al., 2010, and references therein; Figure 39).^{47,48,49,50,51} The main types of the observed liquefaction from 1905 to 1979 are the following (Figure 39):

- lateral spreading and ground settlements,
- ejection of liquefied material from ground cracks and formation of sand boils,
- failure of riverbanks.

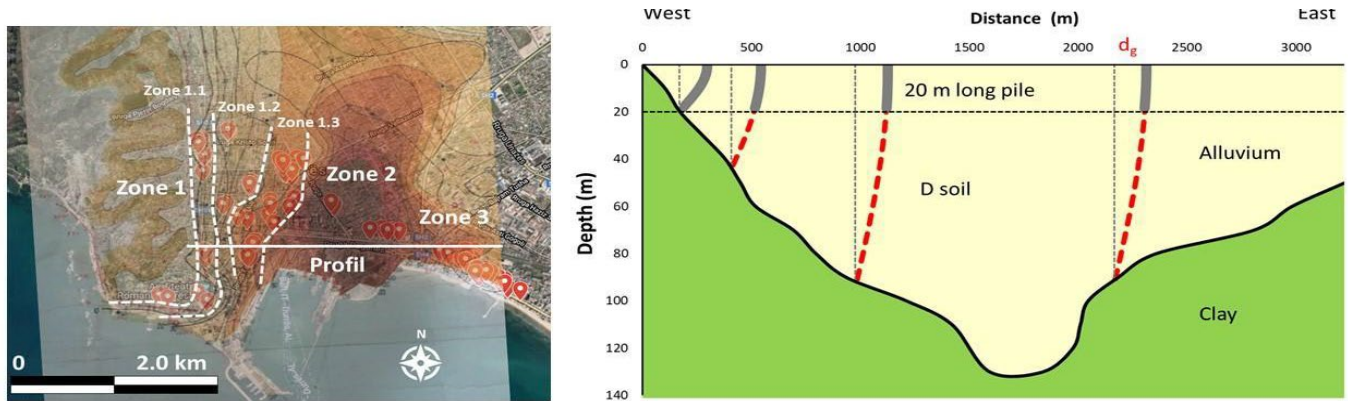


Figure 38. Principle of kinematic effects according to Eurocode 8 for 20 m long piles. The maximum surface displacement is d_g . On the left is the location of the profile (map of damages from McKenney, 2019). On the right is the kinematic effect on 20 m piles for variable D soil (source: AFPS, 2020).

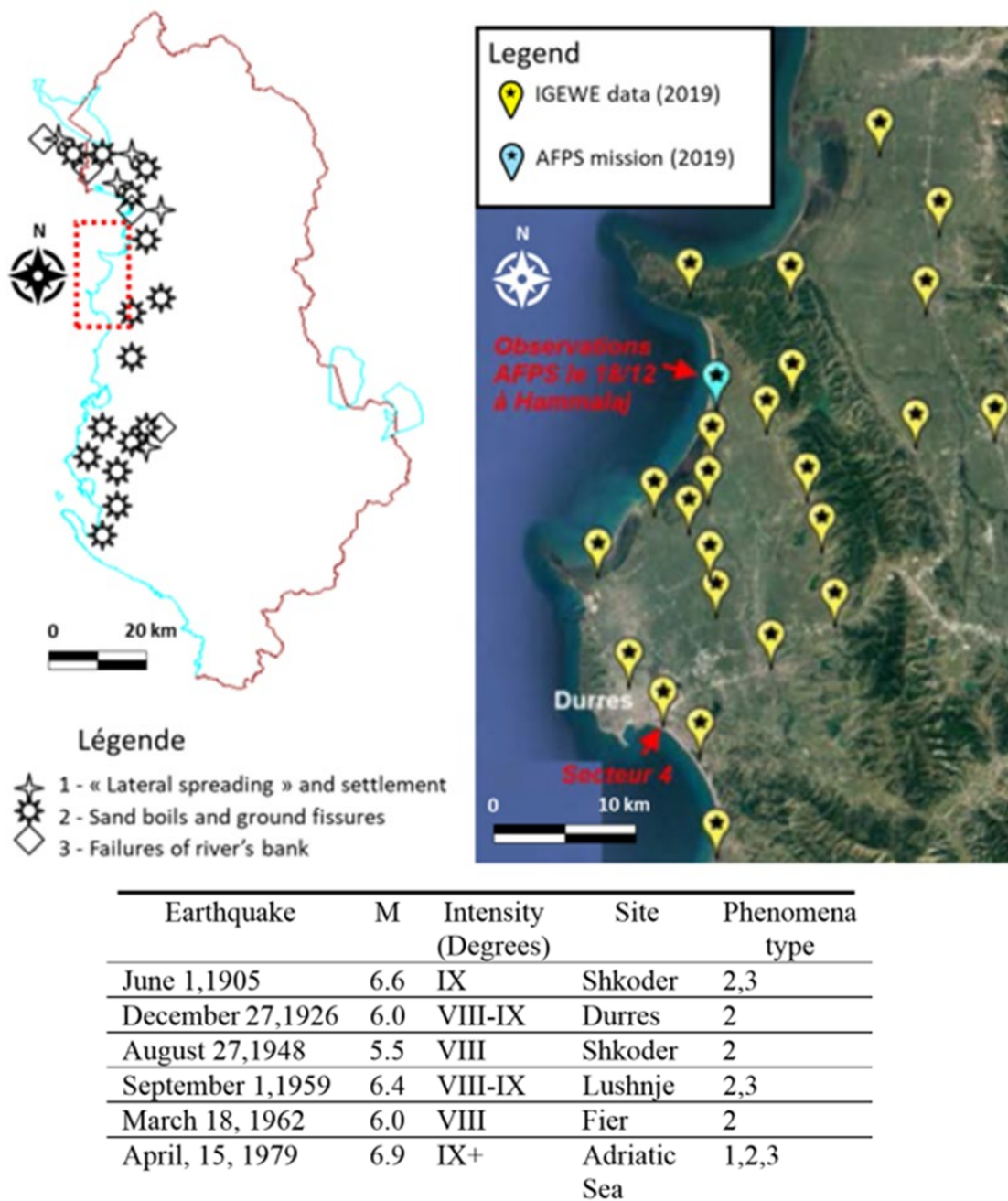


Figure 39. Soil liquefaction phenomena observed from 1905 to 1979 in the western part of Albania (top left), and mapping of the indices observed after the earthquake of 26 November 2019 (IGEWE and AFPS emergency mission, 2019) (top right). Data of historical earthquakes that induced soil liquefaction included (bottom) (source: Kociu, 2004; Kociu, 2014).

A synthesis of soil liquefaction phenomena (sand boils and induced settlements), lateral spreading, and riverbank failure during historical earthquakes in Albania was produced by Kociu (2004) over the period 1905 to 1979. The magnitudes of the earthquakes associated with these liquefaction phenomena were greater than or equal to M5.5.

2.4.2 Liquefaction potential of Durrës city

Based on the microzonation map of the city Durrës (Aliaj et al., 2010), it is concluded that the damaged area in Durrës is an area where big deformations on the free surface are expected in the event of an earthquake including liquefaction phenomena. Moreover, three smaller areas within the city of Durrës are also observed with different predominant periods and expected seismic intensities and are described as follows in reference to Figure 40:

A: Areas of big deformation on the free surface with predominant periods larger than 0.5-0.6 sec and seismic intensities larger than IX_{MSK64},

B: Areas with predominant periods equal to 0.4 to 0.5 sec and seismic intensities ranging from VIII $\frac{1}{2}$ to IX_{MSK64},

C: Steep slopes more than 15°.

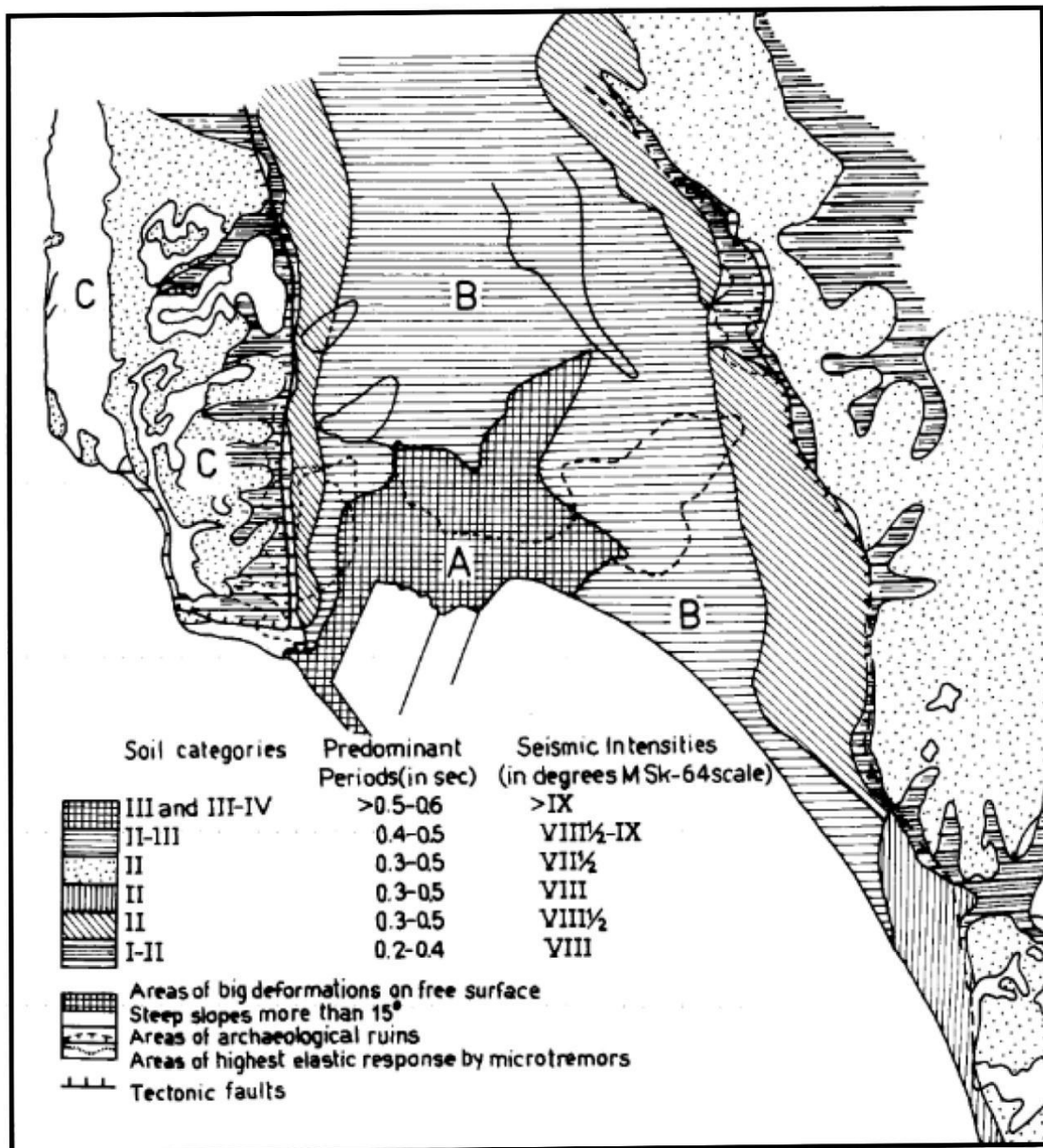


Figure 40. Microzonation map of the city of Durrës expressed in MSK-64 seismic intensities. The maximum expected MSK-64 intensities are larger than IX (source: Kociu, 2004; Aliaj et al., 2010).

Three areas with different potentials for liquefaction can be distinguished in the city (Koçi 2004; Figure 41). The highly susceptible area is the metropolitan area of Durrës comprising the port and the surrounding areas, which is composed of Holocene marshy deposits. The area with moderate susceptibility to liquefaction consists of Holocene alluvial deposits, whereas the area with low susceptibility to liquefaction comprises Pliocene deposits with clays and conglomerates (MMKS, 1983).

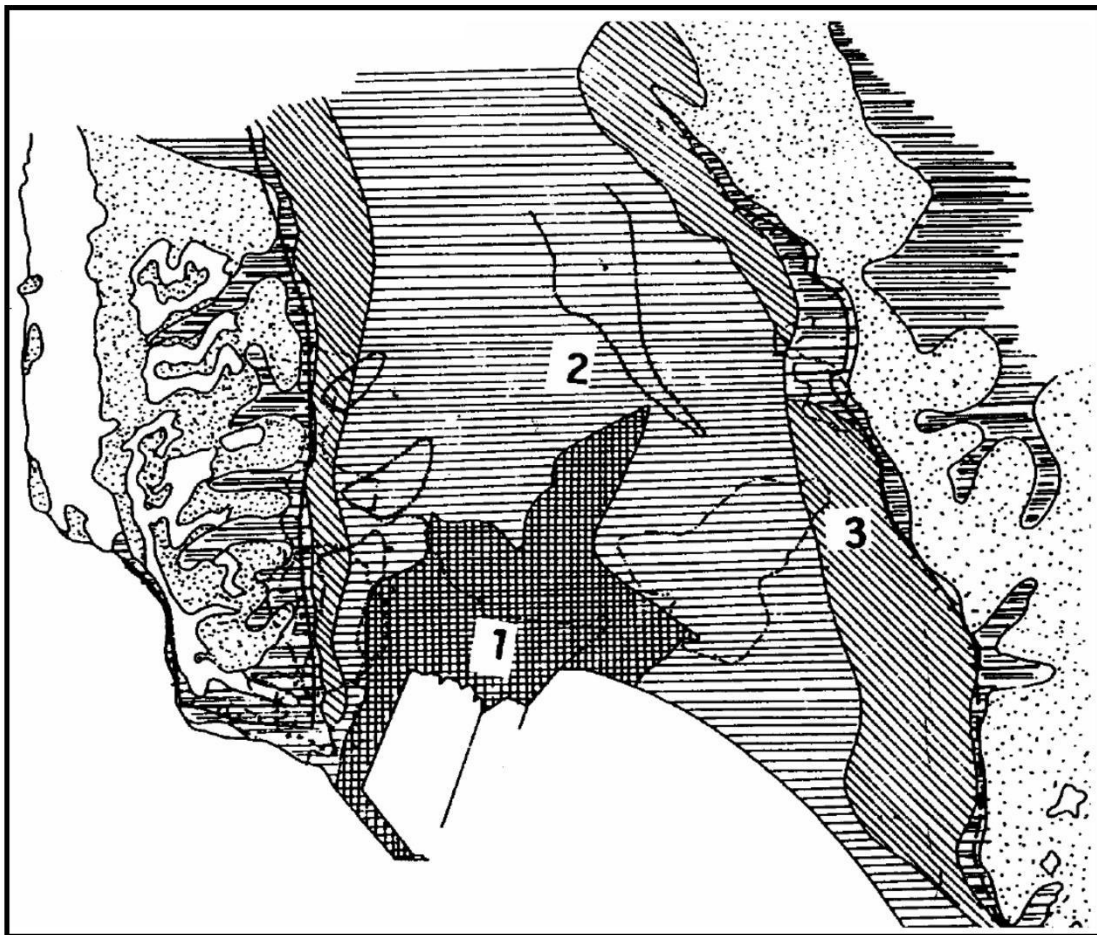


Figure 41. Map of liquefaction potential for Durrës city: (1) Areas highly susceptible to liquefaction, (2) areas moderately susceptible to liquefaction, and (3) areas where the liquefaction is less susceptible (source: Kociu, 2004).

The November 26, 2019 Durrës earthquake-triggered liquefaction phenomena were observed in several sites, including the coastal part of southern Durrës, the central part of the Rinia-Flakë Lagoon, the Erzen River estuary, and the Thumanë area (Figure 42).



Figure 42. Location of sites affected by liquefaction phenomena (highlighted with yellow symbols and location names), slope movements (highlighted with red symbols and location names), and ground cracks (highlighted with green symbols and location names) triggered by the earthquake of November 26. (Source: Mavroulis et al., 2019)⁵²

2.4.3 Liquefaction phenomena in the earthquake of November 26, 2019

Liquefaction phenomena were generated in the areas affected by the Mw 6.4 Durrës (Albania) earthquake on November 26, 2019 (Figure 42). They were initially recorded during a field reconnaissance conducted shortly after the earthquake (November 26, 2019, to November 28, 2019) in the frame of a scientific mission composed of members of the National and Kapodistrian University of Athens (Greece; Lekkas et al., 2019b). More details were acquired during a field reconnaissance conducted from December 14, 2019, to December 16, 2019, in the frame of a new scientific mission composed of members of the National and Kapodistrian University of Athens (Greece), the Earthquake Planning and Protection Organization (Greece), the Hellenic Association for Earthquake Engineering from Greece, the University Network of Seismic Engineering Laboratories of Italy, and the University of Bristol (United Kingdom; Sextos et al., 2020).⁵³

2.4.3.1 Liquefaction phenomena in the coastal part of southern Durrës

Liquefaction phenomena were triggered in the southern coastal part of Durrës at a distance of 2 km east of the port and almost 16 km south of the epicenter (Figure 42). They were observed west of the coastal road named SH4 leading from Durrës to Shkëmbi i Kavajës. Effects included the ejection of liquefied material comprising sand, silt, and water from ground cracks generated on the pavement (Figure 43). This material formed sand boils with a diameter of about 20 cm, and pavement were covered with sand and silt (Figure 43). The prevailing lithologies at this site are sands and silts, and the groundwater level is shallow.



Figure 43. *Liquefaction phenomena in the coastal part of southern Durrës. They included sand boils, ejection of liquefied material from ground cracks and pavements covered with sand and silt. This liquefaction site in southern Durrës was observed close to the collapsed Mira Mare Hotel. (source: Spyridon Mavroulis, Efthymios Lekkas, and Panayotis Carydis; Lekkas et al., 2019b).*

The liquefaction site was located in an area where structures with reinforced concrete frame and infill brick walls exhibited heavy structural damage, collapse, and tilting. However, the adjacent buildings suffered only nonstructural damage or no damage at all. These heavily damaged structures were the Villa Verde, Mira Mare, and Lubjana hotels (Figure 44). The Mira Mare Hotel, located 30 m from the liquefaction site, entirely collapsed. The Villa Verde hotel, located 100 m from the liquefaction site, suffered partial collapse. The Lubjana hotel, located about 75 m from the liquefaction site, presented tilting due to the failure of the ground floor columns in the backside of the building. All buildings were demolished a few days after the completion of the search and rescue operations, and the rubble was completely removed.



Figure 44. The liquefaction site in the southern part of Durrës was close to three hotels that suffered very heavy structural damage: the totally collapsed Mira Mare Hotel, the partially collapsed Vila Verde hotel, and the tilted Lubjana hotel (source: Spyridon Mavroulis, Efthymios Lekkas, and Panayotis Carydis; Lekkas et al., 2019b).

Light liquefaction phenomena were observed in this coastal area after the M_w 5.6 foreshock on September 21, 2019, and comprised small scale subsidence detected along sections of pavement close to the seashore (Lekkas et al., 2019a). There was no observed impact on the built environment.

2.4.3.2 Liquefaction phenomena in Rinia – Fllakë Lagoon

Liquefaction phenomena were triggered in the central part of the Rinia-Fllakë Lagoon located along the southwestern part of the Lalze Bay. The Rinia-Fllakë Lagoon is very shallow and extends from the east of Pali Cape to the west of the Erzen River delta. It is separated from the sea by a narrow sandy beach on its western side and from the adjacent agricultural fields by a wide line of pine trees. The town of Rinia is located at its southern part.

The liquefaction was observed at three sites (*Figure 45*) and is composed of:

- Individual sand boils were formed by the ejection of liquefied material comprising mainly sand and water on the surface (*Figure 46*, *Figure 47*).
- The alignment of sand boils were observed with elongated/aligned multiple sand boils in the central part along almost N-S trending ground cracks (*Figure 48*, *Figure 49*).
- Water and sand fountains were observed by locals in still waters.

The observed liquefaction phenomena did not cause structural damage due to the fact there are no buildings because of the lagoon. They caused only slight damage to infrastructure, including tilting to electrical pillars (*Figure 46*).



Figure 45. Liquefaction phenomena were generated in three sites in the central part of the Rinia-Fllakë Lagoon (source: Spyridon Mavroulis, Efthymios Lekkas, and Panayotis Carydis).



Figure 46. Liquefaction phenomena in the first site of the central part of the Rinia-Fllakë Lagoon. Individual sand boils were formed by the ejection of liquefied material. They resulted in tilting of electric pillars (source: Spyridon Mavroulis, Efthymios Lekkas, and Panayotis Carydis).



Figure 47. Liquefaction phenomena in the second site of the central part of the Rinia-Fllakë Lagoon. Sand boils were observed close to an adjacent canal of the lagoon (source: Spyridon Mavroutis, Efthymios Lekkas, and Panayotis Carydis).

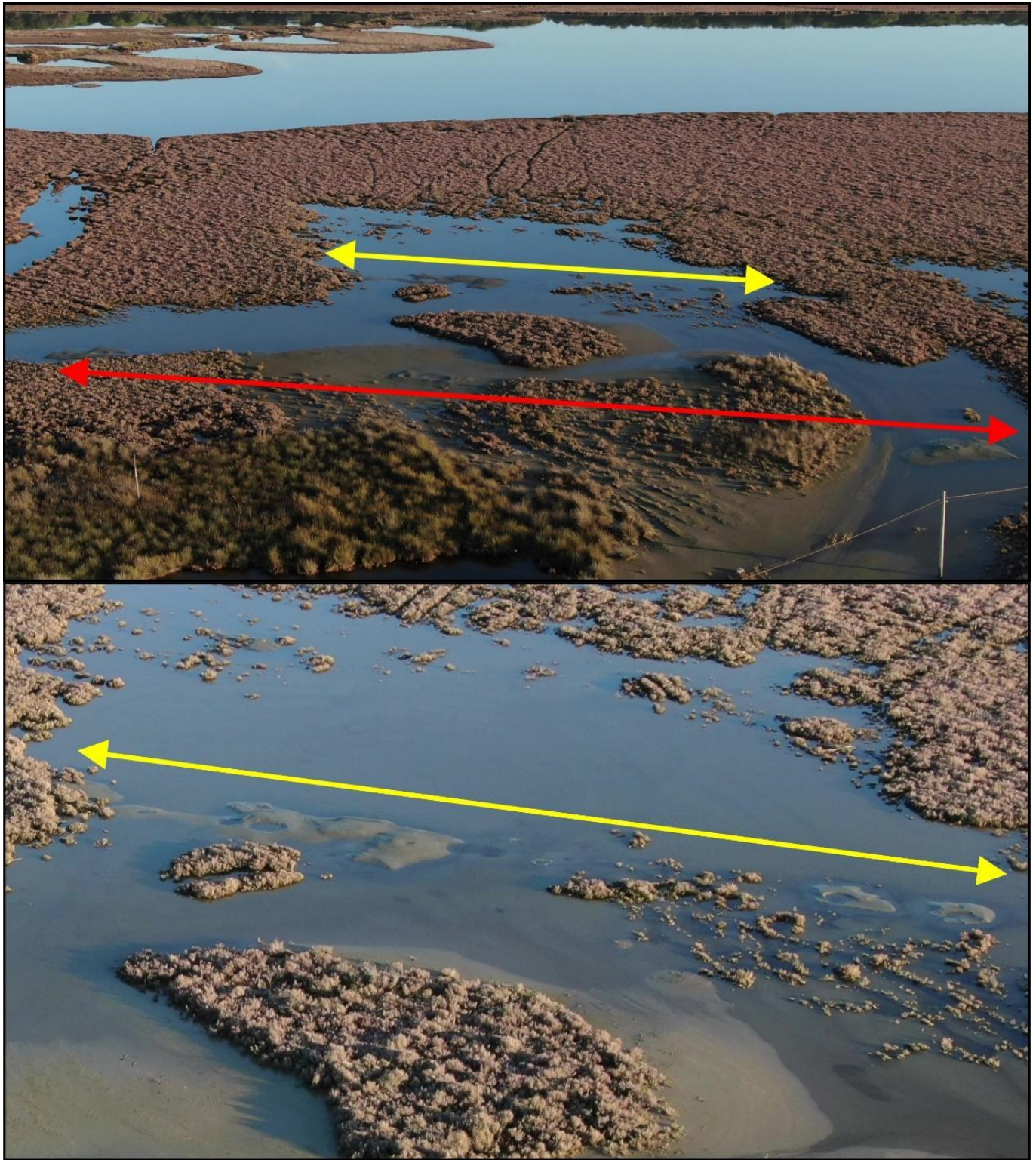


Figure 48. Liquefaction phenomena in the third site of the central part of the Rinia-Flakë Lagoon. The elongated/aligned multiple sand boils were observed along almost N-S trending ground cracks. Yellow and red arrows indicate the N-S direction of ground cracks (source: Spyridon Mavroulis, Efthymios Lekkas, and Panayotis Carydis).



Figure 49. Typical forms of liquefaction phenomena in the third site of the central part of the Rinia-Fllakë Lagoon. They consisted of sand boils generated not only in dry but also in shallow parts of the lagoon (source: Spyridon Mavroulis, Efthymios Lekkas, and Panayotis Carydis).

2.4.3.3 Liquefaction phenomena in the Erzen River estuary

The Erzen River estuary is located at the northeastern end of the Rinia-Fllakë Lagoon. It is composed of sediments supplied from the Erzen River, which along with its main tributaries drain the northern part of NW-SE trending Durrës plain (Figure 50).



Figure 50. Ejection of liquefied material was generated along ENE-WSW trending ground cracks in fields of the Erzen River mouth. (Source: Mavroulis et al., 2019)

Liquefaction phenomena were triggered along the Erzen River banks, especially close to the mouth of the Erzen River estuary. Ejection of liquefied material along ground cracks was observed (Figure 50).

2.4.3.4 Liquefaction phenomena close to the Mati River estuary

Liquefaction phenomena were also triggered close to the Mari River estuary, which is located in the eastern part of the area affected by the 2019 earthquake. This area is locally characterized by conditions suitable for the formation of swampy and lagoonal areas, such as the Patok Lagoon. These areas are very susceptible to liquefaction.

Liquefaction phenomena observed close to the Mari River estuary included the ejection of liquefied material and formation of sand boils along ground cracks in fields. They were observed close to residential buildings but did not cause observed damage.

2.5 Lateral Spreading

Lateral spreading was observed close to the Erzen River estuary along the southern riverbanks with gentle slopes (Pavlidis et al., 2020; Vittori et al., 2021; Figure 51).^{54,55} Ground cracks were generated along and parallel to the riverbanks, whereas lateral movement was directed towards the riverbed. These phenomena were attributed to local failures due to the earthquake ground shaking.



Figure 51: Lateral spreading close to the Erzen River mouth. They were observed along its southern banks (source: Pavlides et al., 2020).

2.6 Slope Failures

In Albania, many areas are prone to slope failures because of geological features, diverse terrain topography, high mountains, steep valley slopes, high-intensity spring and autumn rainfall, deep weathering associated with the humid climate, and man-modified slopes (Jaupaj et al., 2017).⁵⁶ Based on the compilation of the landslide inventory map of Albania (Figure 52), the following conclusions can be drawn from historical data:

- The landslides observed in Albania are mostly rotational, and they are spread over almost all of the country.
- Landslides are typically small or moderate.
- Landslides occur mostly on slopes between 15° and 25°.
- The affected slopes are composed of clay and flysch formations.
- Urban areas are more prone to landslides compared to other kinds of land usage because human activities and modification of the landscape play an important role in triggering landslides.
- Almost 75% of landslides in Albania are triggered by heavy rainfalls.

- More specifically, in the region of Durrës and Kavaja, three major types of slope failures have been identified (Kuliçi et al., 2017)⁵⁷:
 - a. rotational landslides, which occur principally in Quaternary deposits,
 - b. translational landslides, which occur in the Rogozhina formations and in Tortonian molasses, and
 - c. earth flows, which are usually associated with heavy rains and affect the Helmasi formation and the Serravalian formations.

Moreover:

- Slopes from 10° to 25° are prone to slope failures. It is a fact that fewer slope failures occur on mild and steep slope angles.
- Southwest and south-facing slopes are more susceptible to the generation of slope failures compared to other slope aspects.
- Urban areas and nonforested areas are more prone to slope failures compared to other land use because of human activities and intervention.

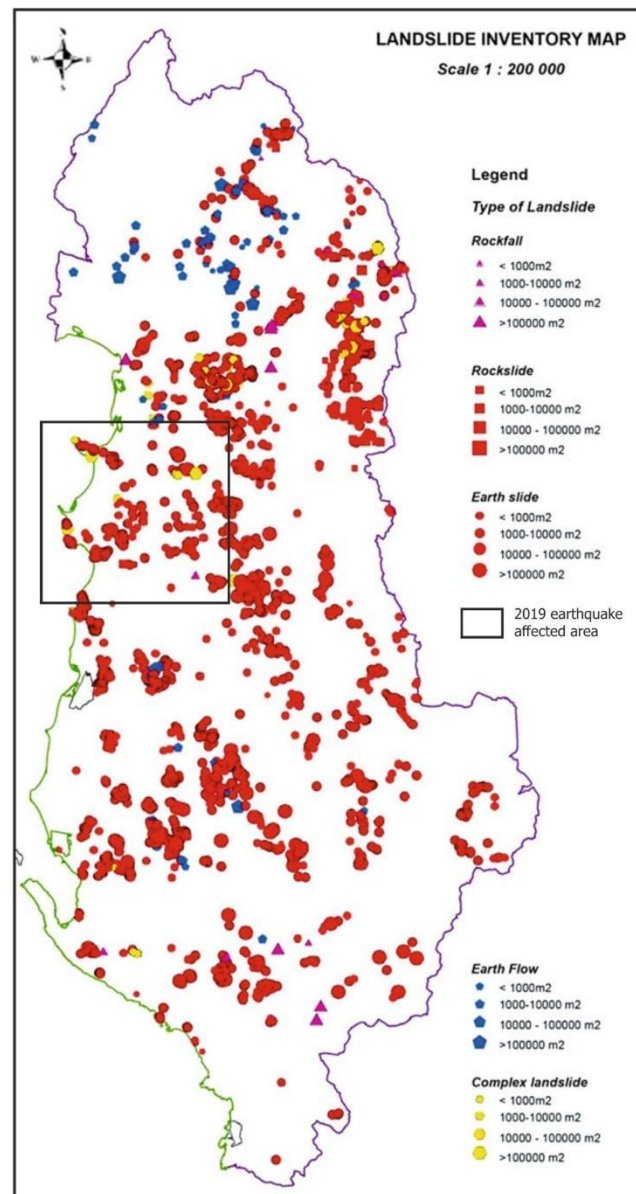


Figure 52. The landslide inventory map of Albania compiled by Jaupaj et al. The landslides observed in Albania are mostly rotational, and they are spread over almost all of the country. The 2019 earthquake-affected area in the black frame is characterized by the generation of earth slides, rockslides, and complex landslides (source: Jaupaj et al., 2017)

Considering the spatial distribution of slope failures in the 2019 earthquake-affected area (Figure 53), it is likely that the area has previously experienced earth slides, earth flows, and complex landslides. However, based on the Landslide Hazard Distribution Map of Albania (WHO, 2010; Figure 54), the landslide hazard is evaluated as very low (0-1) to low (2) in the western and the central parts of the affected area and medium (3) to high (4) in its eastern parts along the eastern margin of the Tirana Depression.

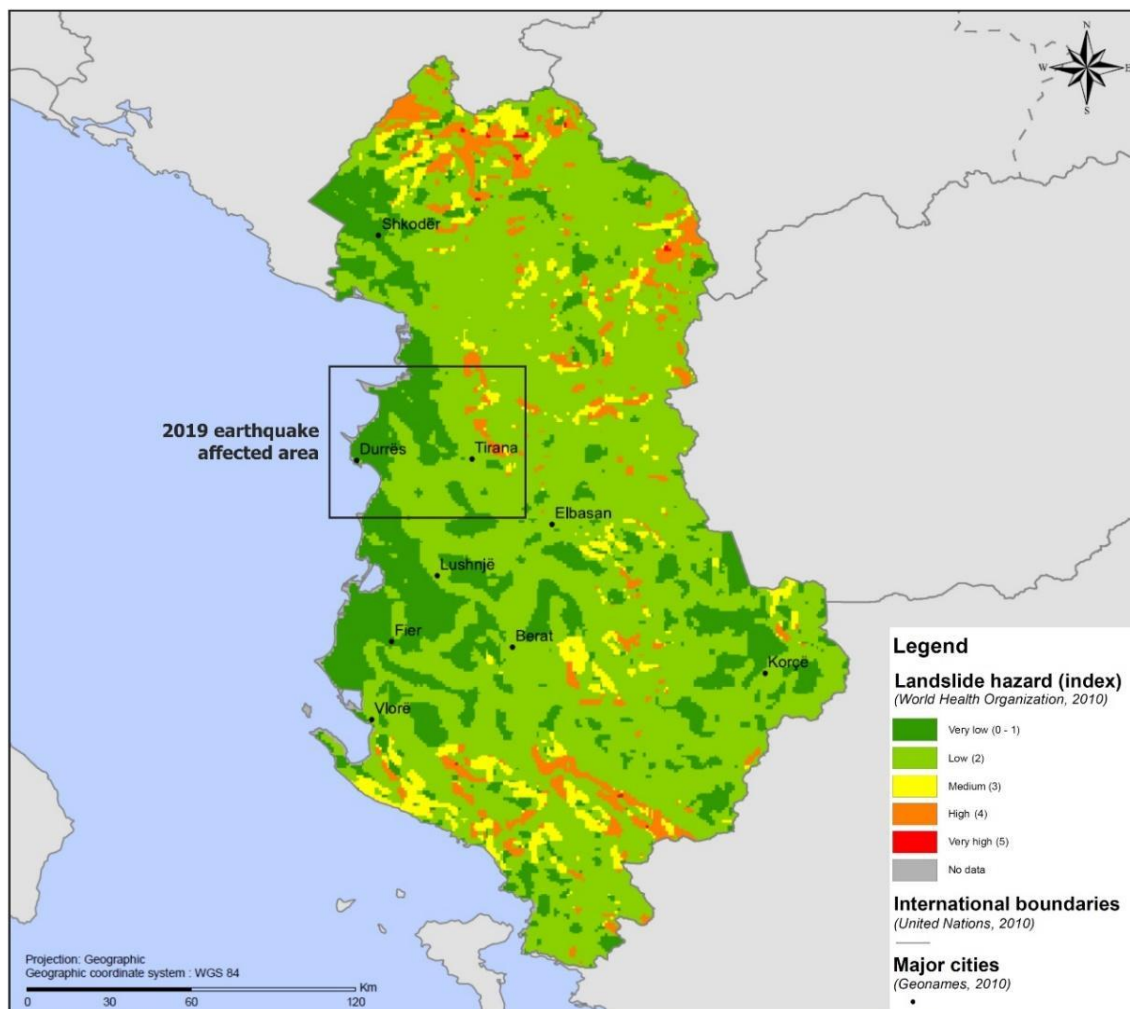


Figure 53. The Landslide Hazard Distribution Map of Albania compiled by WHO. The landslide hazard is evaluated as very low (0-1) to low (2) in the western and the central parts of the 2019 earthquake-affected area and as medium (3) to high (4) in its eastern parts along the eastern margin of the Tirana Depression (source: WHO, 2010).⁵⁸

This implies that the western area has rainfall patterns, terrain slope, geology, soil, land cover, and earthquakes that make localized landslides a rare hazard phenomenon. However, slope failures were triggered not only by the M_w 5.6 Durrës foreshock on September 21, 2019 (Lekkas et al., 2019a; Figure 53), but also by the November mainshock in the earthquake-affected area (Lekkas et al., 2019b; Vittori et al., 2021; Figure 41).

More specifically, landslides were induced by the September foreshock at slopes along the road leading from Durrës to Kavajë (Shkëmbi i Kavajës), located southeast of Durrës (Figure 54). The affected slopes are composed of Pliocene clays, which are intensively faulted (Figure 55). The slope and geological beds dip toward the road, resulting in instability conditions that can generate earthquake-induced slope failures. The mobilized material resulted in temporary traffic disruption without significant effects on the road asphalt surface, vehicles, and drivers. Landslides were also triggered by the November mainshock along the coastal area north of the Shkëmbi i Kavajës area. The mobilized material resulted in destruction of the coastal road and reached the adjacent flat lowland (Figure 56). The affected area is composed of clays along the affected slope and sands along the beach. The generation of the landslide can be attributed to the synergy of the earthquake ground motion with the existing unstable conditions formed by human processes (e.g., the construction of the coastal road) and by natural processes (e.g., the erosive action of the sea waves and winds).



Figure 54. Slopes were induced by the Mw=5.6 foreshock on September 21, 2019, along the road leading from Durrës to Kavajë, located southeast of Durrës (source: Lekkas et al., 2019a).

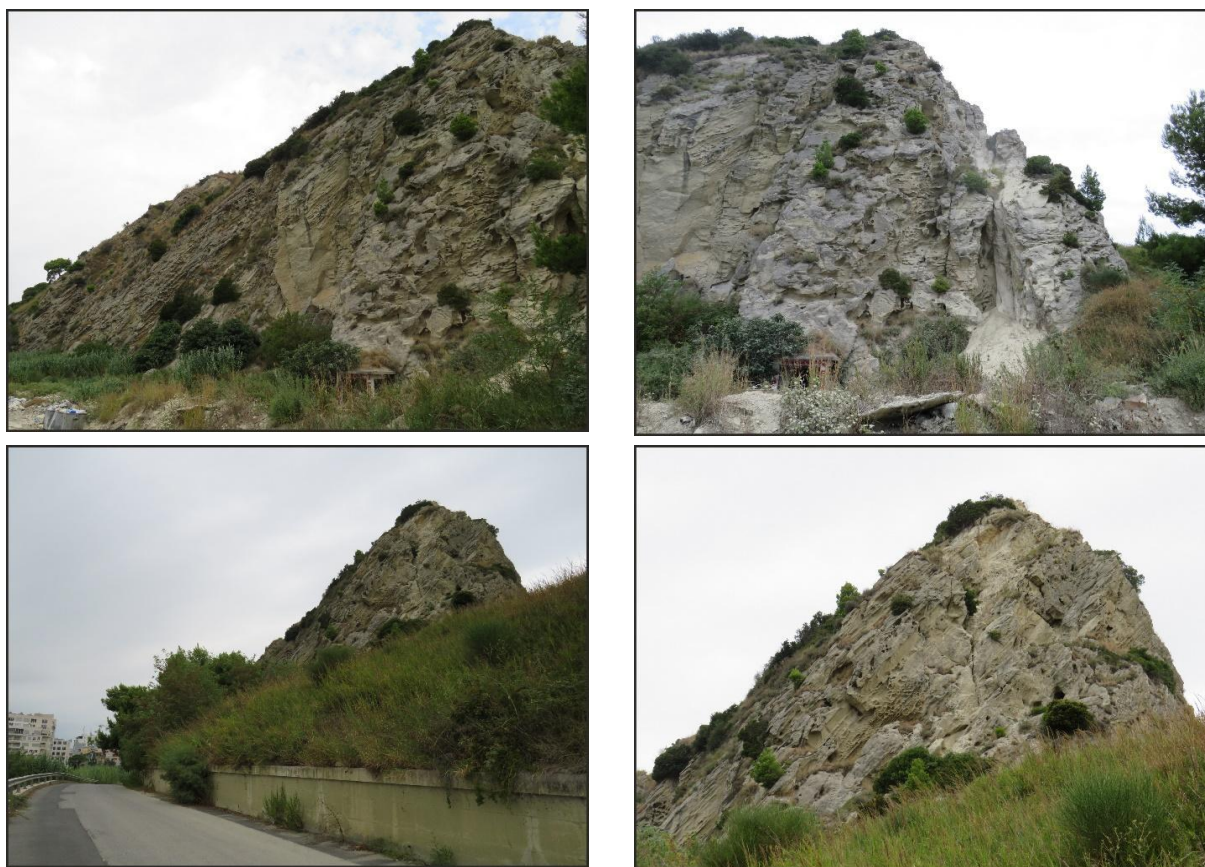


Figure 55. The Shkëmbi i Kavajës (Rock of Kavajë) was affected by the Mw 5.6 foreshock on September 21, 2019. The steep slopes are composed of Pliocene clays, which are faulted (source: Spyridon Mavroulis, Efthymios Lekkas, and Panayotis Carydis).



Figure 56. Slope movements were also triggered by the Mw 6.4 earthquake on November 26, 2019. A characteristic example is this coastal site located north of the Shkëmbi i Kavajës (Rock of Kavajë) area, which can be seen in the background (source: Pavlides et al., 2020, modified).

Slope failures were also generated by the November mainshock in the northern part of the Durrës hills and along the eastern margin of the Tirana Depression, east of the Thumanë area (Figure 41). North of Durrës, a small slide affected a steep instable clayey slope, shifting an old bunker several meters downward. The last evidence has been detected in the hilly area east of Thumanë along a slope subject to surficial movements, where a reactivation occurred near the local outcrop of the thrust front of the Albanides mountain range on the Tirana valley.

2.7 Ground Fissures

Seismic shaking also caused several typical ground fissures. Vittori et al. (2021) observed cracks along the rim of the southwestern side of Cape Bishtpalla and in the joints of limestones cropping out on the slopes of the Kruja mountainous area located east of Thumanë, a 30 m long and 2 to 10 cm wide arched fracture cutting the road in front of the water pumping station of Hamallaj (Figure 57) and several cracks cutting across the road near the water pumping station of Thumanë.



Figure 57. Ground cracks near the water pumping station of Hamallaj (source: Vittori et al., 2021).

2.8 Conclusions

The area of central-western Albania, which was affected by the M6.4 Durrës earthquake on November 26, 2019, is highly susceptible to ground failure, including liquefaction phenomena and slope movements. This susceptibility was assessed by relevant studies on the landslide and liquefaction susceptibility and history of the Periadriatic Depression, and it was verified by the generation of slope movements and liquefaction phenomena after not only the M6.4 Durrës earthquake on November 26, 2019, but also by its M5.6 foreshock that struck a couple months prior on September 21.

Liquefaction phenomena were triggered by the November mainshock in several sites of the earthquake-affected area. They were observed in the coastal part of southern Durrës, in the Rinia-Fllakë Lagoon, in the Erzen River estuary, and close to the Mati River estuary. The main characteristic of these liquefaction-affected sites is the existence of recent Holocene deposits, including marshy deposits of the Durrës swamp, lagoonal deposits in the Rinia-Fllakë Lagoon, and river deposits in the Erzen and Mati riverbanks and estuaries.

The main types of phenomena observed in the liquefaction-affected sites consisted of individual sand boils, ejection of liquefied material from ground cracks, arrangement of sand boils along ground cracks, and water and sand fountains in still waters.

The observed liquefaction phenomena were observed not only in uninhabited rural areas but also in urban residential areas. In the case of the coastal areas of Durrës, they were observed close to totally or partially collapsed hotels. In the case of the Rinia-Fllakë Lagoon, they caused slight damage to the electric power supply system. It is obvious that these phenomena are characterized by a high potential for causing heavy structural damage to buildings, infrastructures, and lifelines in the urban and rural areas along the coastal central-western region of Albania. For this reason, the need for a detailed and accurate liquefaction hazard and risk assessment is imperative.

Slope failures were triggered not only by the November mainshock but also by the September foreshock. They were generated in the Shkëmbi i Kavajës area by the September foreshock and in the Shkëmbi i Kavajës area, in the northern part of the Durrës hills and east of Thumanë area, by the November mainshock. They affected temporarily or permanently the adjacent road network. They included landslides and rockfalls.

REFERENCES

- ¹ Mihaljevic, J., Zupancic, P., Kuka N., Kaluderovic, N., Koçi, R., Markusic, S., Salic, R., Dushi, E., Begu, E., Duni, L., Zivcic, E., Kovacevic, S., Ivancic, I., Kovacevic, V., Milutinovic, Z., Vakilinezhad, M., Fiket, T., and Gulerce, Z., 2017. BSHAP Seismic Source Characterization Models for the Western Balkan Region. *Bulletin of Earthquake Engineering*, 15(2017), 3963–3985, (DOI: 10.1007/s10518-017-0143-5).
- ² Jouanne, F., Mugnier, J. L., Koci, R., Bushati, S., Matev, K., Kuka, N., Shinko, I., Kociu, S., and Duni, L., 2012. GPS Constrains on Current Tectonic of Albania, *Tectonophysics*, 554–557(2012), 50–62.
- ³ Aliaj, S., Melo, V., Hyseni, A., Skrami, J., Mehilla, L. L., Muço, B., Sulstarova, E., Prifti, K., Pasko, P., and Prillo, S., 1996a. *Neotectonic structure of Albania (in Albanian)*. Final report, Archive of Seismological Institute of Academy of Sciences, Tirana.
- ⁴ Dushi, E., Koçi, R., Begu, E., and Dushi, I., 2016. Seismically Induced Delayed-Landslide in Synej-Bagoje (Albania), March 2009. *Online International Interdisciplinary Research Journal*, Vol. 6, November 2016 Special Issue (1), ISSN 2249-9598.
- ⁵ Aliaj, S., Sulstarova, E., Muço, B., and Koçi, S., 2000. *Seismotectonic Map of Albania, Scale 1:500.000*. Seismological Institute, Tirana.
- ⁶ Sulstarova, E. and Koçiaj, S., 1975. *The Catalogue of the Albanian Earthquakes*. Seismological Center, Academy of Sciences, Tirana, Albania.
- ⁷ United Nations Development Programme (UNDP) Albania, 2003. *Risk Assessment-Albania, Disaster Management and Emergency Preparedness Project Executive Summary*, p. 82.
- ⁸ Papazachos, B. C., Savvaidis, A. S., Papazachos, C. B., Papaioannou, Ch. A., Kiratzi, A. A., Muco, B., Kociu, S., and Sulstarova E., 2001. *Atlas of Isoseismal Maps for Shallow Earthquakes in Albania and Surrounding Area (1851-1990)*. Aristotle University of Thessaloniki, Geophysical Laboratory publication number 10, 2001.

- ⁹ Moshou, A., Dushi, E., and Argyrakis, P., 2019. *A Preliminary Report on the 26 November 2019, Mw=6.4 Durrës, Albania Earthquake*, available at https://www.emsc-csem.org/Files/news/Earthquakes_reports/Preliminary_Report_Albania_26112019.pdf.
- ¹⁰ Delvaux, D. and Sperner, B., 2003. *Stress Tensor Inversion From Fault Kinematic Indicators and Focal Mechanism Data: The TENSOR Program*. In: Nieuwland, D. (Ed.). *New Insights into Structural Interpretation and Modelling*. Geological Society, London, Special Publication 212, 75–100.
- ¹¹ Basili, R., Kastelic, V., Demircioglu, M. B., Garcia Moreno, D., Nemser, E. S., Petricca, P., Sboras, S. P., Besana-Ostman, G. M., Cabral, J., Camelbeeck, T., Caputo, R., Danciu, L., Domac, H., Fonseca, J., García-Mayordomo, J., Giardini, D., Glavatovic, B., Gulen, L., Ince, Y., Pavlides, S., Sesetyan, K., Tarabusi, G., Tiberti, M. M., Utkucu, M., Valensise, G., Vanneste, K., Vilanova, S., and Wössner, J., 2013. *The European Database of Seismogenic Faults (EDSF) Compiled in the Framework of the Project SHARE*, available at <http://diss.rm.ingv.it/share-edsf/>. doi:10.6092/INGV.IT-SHARE-EDSF.
- ¹² Schurr, B., Duni, L., Dushi, E., Rohnacher, A., Gjuzi, O., and Kosari E., 2019. *Albania Aftershock Campaign (AlbACa)*. GFZ Potsdam, Institute of Geosciences, Energy, Water and Environment, Tirane, Albania.
- ¹³ Wiemer, S., 2001. A Software Package to Analyze Seismicity: ZMAP. *Seismological Research Letters*, 72(3), 373–382, (DOI: 10.1785/gssrl.72.3.373).
- ¹⁴ Government of Albania, European Union, United Nations agencies, and World Bank, 2020. *Albania Post-Disaster Needs Assessment, Volume A Report*. Tirana, Albania, available at https://ec.europa.eu/neighbourhood-enlargement/sites/near/files/albania_post-disaster_recovery_a_v9.0.pdf.
- ¹⁵ Morelli, C., 1941. La Sismicità dell' Albania. *Bollettino della Società Sismologica Italiana*, 39(1–2), 1–22.
- ¹⁶ Sulstarova, E., Kociu, S., and Aliaj, Sh., 1980. *Seismic Zonation of Albania*. Publication of Academy of Sciences of Albania and Seismological Centre of Albania, Tirana, p. 297.
- ¹⁷ Duni, L. and Kuka, N., 2004. Seismic Hazard Assessment and Site-Dependent Response Spectra Parameters of the Current Seismic Design Code in Albania. *Acta Geodaetica et Geophysica Hungarica*, 39(2–3), 161–176.
- ¹⁸ Kuka, N., Sulstarova, E., Duni, L., and Aliaj, S., 2003. *The Use of Spatial Seismicity Approach for the Evaluation of Seismic Hazard of Albania*. In: Book of Abstracts, Skopje Earthquake 40 Years of European Earthquake Engineering, Skopje-Ohrid, Macedonia, August 26–28, 2003, p. 8.
- ¹⁹ Boore, D. M., Joyner, W. B., and Fumal, T. E., 1997. Equations for Estimating Horizontal Response Spectra and Peak Ground Acceleration From Western North American Earthquakes: A Summary of Recent Work. *Seismological Research Letters*, 68(1), 128–153.
- ²⁰ Kuka, N. and Duni, L., 2007. *Probabilistic Assessment of Seismic Hazard of Albania*. Internal report, Institute of Geosciences, Energy, Water and Environment, Tirane, Albania, p. 41.
- ²¹ Duni, L., 2019. Acceleration Time Histories Recorded by the Albanian Strong Motion Network, processed by ART software, available at <https://www.geo.edu.al/newweb/?fq=november>.
- ²² Skarlatoudis, A., Papazachos, C., Margaritis, B., Theodoulidis, N., Papaioannou, Ch., Kalogeras, I., Scordilis, E., and Karakostas, V., 2003. Empirical Peak Ground Motion Predictive Relations for Shallow Earthquakes in Greece. *Bulletin of the Seismological Society of America*, 93(6), 2591–2603.
- ²³ Duni, L. and Theodoulidis, N., 2019. *Short Note on the November 26, 2019, Durrës (Albania) M6.4 Earthquake: Strong Ground Motion with Emphasis in Durrës City*, available at https://www.emsc-csem.org/Files/news/Earthquakes_reports/Short-Note_EMSC_31122019.pdf.
- ²⁴ Shehu, R., Shallo, M., Kodra, A., Vranaj, A., Gjata, K., Gjata, Th., Melo, V., Yzeiri, D., Bakiaj, H., Xhomo, A., Aliaj, Sh., Pirdeni, A., and Pashko, P., 1983. Geological Map of Albania in Scale 1:200.000, Hamit Shijaku Publishing-House, Tirana, Albania.
- ²⁵ Kociu, S., 2004. *Induced Seismic Impacts Observed in Coastal Area of Albania: Case Studies*. Proceedings of Fifth International Conference on Case Histories in Geotechnical Engineering, New York, NY, April 13–17, 2004, Paper number 3.17.
- ²⁶ Koçi, S., Sulstarova, E., Aliaj, S., Duni, L., Peçi, V., Konomi, N., Dakoli, H., Fuga, I., Goga, K., Zeqo, A., Kapllani, L., Kozmaj, S., and Lika, M., 1985. *Seismic Microzonation of Durres Town* (in Albanian). Internal report, Institute of Geosciences, Energy, Water and Environment, Tirane, Albania.
- ²⁷ Duni, L., Kuka, N., Koçi, R., Dushi, E., and Gjuzi, O., 2020. *Shear Waves Velocity Using the MASW Method in Durrës City*. Internal report, Institute of Geosciences, Energy, Water and Environment, Tirane, Albania.

- ²⁸ Theodoulidis, N., Grendas, I., Duni, L., Dushi, E., Kuka, N., Koci, R., Rrezart, B., and Gjuzi, O., 2020. *Report on Ambient Noise Measurements and Data Analyses in Durrës City, Albania*. Thessaloniki-Tirana, p. 29.
- ²⁹ Haghshenas, E., Bard, P.Y., and Theodulidis, N., 2008. Empirical Evaluation of Microtremor H/V Spectral Ratio. *Bulletin of Earthquake Engineering*, 6(2008), 75–108.
- ³⁰ Lekkas, E., Mavroulis, S., Papa, D., and Carydis, P., 2019b. The November 26, 2019 Mw 6.4 Durrës (Albania) Earthquake. *Newsletter of Environmental, Disaster and Crises Management Strategies*, 15, ISSN 2653-9454, available at https://edcm.edu.gr/images/docs/newsletters/Newsletter_15_2019_Albania_EQ.pdf.
- ³¹ Mjete Mësimore, Kulture e Sportive (Albania) (MMKS), 1983. *Harta gjeologjike e RPS të Shqipërisë : shkalla 1:200 000 / shtypur ne ndërmarrjen e Mjeteve Mësimore, Kulture e Sportive "Hamid Shijaku"*, available at <https://lccn.loc.gov/2013589105>.
- ³² Roure, F., Nazaj, S., Muska, K., Fili, I., Cadet, J.P., and Bonneau, M., 2004. *Kinematic Evolution and Petroleum Systems—An Appraisal of the Outer Albanides*. In: McClay, K. (Ed.), *Thrust Tectonics and Hydrocarbon Systems*, Vol. 82. American Association of Petroleum Geologists, Tulsa, Oklahoma, pp. 474–493, (DOI: 10.1306/M82813C25).
- ³³ Berthelon, J., 2015. *Etude Mécanique des Déformations des Chaînes Plissées d'Avant-Pays et Rôle des Argiles Roches-Mères Durant Leur Maturation*. Thesis, Université Pierre et Marie Curie.
- ³⁴ Aliaj, S., Baldassarre, G., and Shkupi, D., 2001. Quaternary Subsidence Zones in Albania: Some Case Studies. *Bulletin of Engineering Geology and the Environment*, 59(2001), 313–318, (DOI 10.1007/s100640000063).
- ³⁵ Skrami, J., 2001. Structural and Neotectonic Features of the Periadriatic Depression (Albania) Detected by Seismic Interpretation. *Bulletin of the Greek Geological Society*, 34(4), 1601–1609, (DOI: 10.12681/bgsg.17269).
- ³⁶ Aliaj, S., 1988. *Neotektonika dhe Sizmotektonika e Shqipërisë*. DSc thesis, Archive of Seismological Institute, Tirana.
- ³⁷ Aliaj, S., Melo, V., Hyseni, A., Skrami, J., Mehilla, L., Muco, B., Sulstarova, E., Prifti, K., Pashko, P., and Prillo, S., 1996b. *The Neotectonics Map of Albania on the Scale 1:200 000*. Archive of the Institute of Energy, Water and Environment, Polytechnic University of Tirana, Tirana, Albania.
- ³⁸ Nakamura, Y., 1989. A Method for Dynamic Characteristics Estimation of Subsurface Using Microtremor on the Ground Surface. *Quarterly Report of the Railway Technical Research Institute*, 30(1), 25–30.
- ³⁹ Lekkas, E., Mavroulis, S., Filis, C., and Carydis, P., 2019a. The September 21, 2019 Mw 5.6 Albania Earthquake. *Newsletter of Environmental, Disaster and Crises Management Strategies*, 13, ISSN 2653-9454, available at https://edcm.edu.gr/images/docs/newsletters/Newsletter_13_2019_Albania_EQ.pdf.
- ⁴⁰ L'Association Française du Génie Parasismique (AFPS), 2020. *Report of the post-earthquake mission on the earthquake in Albania*.
- ⁴¹ Brûlé, S., Seranaj, A., and Piquani A., 2020. Seismic Behavior of a Building Founded on Loose Soil Improved by Stone Columns. International Symposium on Durrës Earthquakes and Eurocodes, Tirana, Albania.
- ⁴² Aliaj, S., Adams, J., Halchuk, S., Sulstarova, E., Peci, V., and Muco, B., 2004. *Probabilistic Seismic Hazard Maps for Albania*. 13th World Conference on Earthquake Engineering, Vancouver, Canada, August 1–6, 2004, Paper number 2469.
- ⁴³ Rovelli, A., Caserta, A., Marra, F., and Ruggiero, V., 2002. Can Seismic Waves be Trapped Inside an Inactive Fault Zone? The Case Study of Nocera Umbra, Central Italy. *Bulletin of the Seismological Society of America*, 92(6), 2217–2232, (DOI: 10.1785/0120010288).
- ⁴⁴ Kawase, H., 1996. The Cause of the Damage Belt in Kobe: "The Basin-Edge Effect," Constructive Interference of the Direct S-Wave with the Basin-Induced Diffracted/Rayleigh Waves. *Seismological Research Letters*, 67(5), 25–34, (DOI: 10.1785/gssrl.67.5.25).
- ⁴⁵ Riga, E., Makra, K., and Pitilakis, K., 2016. Aggravation Factors for Seismic Response of Sedimentary Basins: A Code-Oriented Parametric Study. *Soil Dynamics and Earthquake Engineering*, 91(2016), 116–132, (DOI: 10.1016/j.soildyn.2016.09.048).
- ⁴⁶ Stambouli, A., Bard, P. Y., Chaljub, E., Moczo, P., Kristek, J., Stripajova, S., Durand, C., Zendagui, D., and Derras, B., 2018. *2D/1D Aggravation Factors: From a Comprehensive Study to Estimation with a Neural Network*. 16th European Conference of Earthquake Engineering, June 2018, Thessaloniki, Greece.
- ⁴⁷ Petrovski, J. and Paskalov, T., 1980. *The Earthquake of Montenegro-Yugoslavia of April 15, 1979*. Publication of the Institute of Earthquake Engineering and Engineering Seismology, 65, Kiril and Metodij University, Skopje, Yugoslavia.

- ⁴⁸ Koçiaj, S. and Sulstarova, E., 1980. The Earthquake of June 1, 1905, Shkodra, Albania; Intensity Distribution and Macroseismic Epicentre. *Tectonophysics*, 67(3–4), 319–332, (DOI: 10.1016/0040-1951(80)90272-3).
- ⁴⁹ Shehu, V. and Dhima, N., 1983. *The Influence of Engineering–Geological Conditions on the Intensity Distribution of the April 15, 1979 Earthquake in Shkodra-Lezha Region*. In: The Earthquake of April 15, 1979. 8 Nëntori, Tirana, Albania, pp. 387–404.
- ⁵⁰ Dibra, Z. [1983] “Disa dukuri te lengezimit te truallit nga termeti i 15 prillit 1979 “ (Some phenomena of the soil liquefaction of the April 15, 1979 earthquake) (In Albanian and English) In : “Termeti I 15 prillit 1979 “ P.H 8 Nentori ,Tirane, pp.404- 413.
- ⁵¹ Aliaj, S., Koçi, S., Muço, B., and Sulstarova E., 2010. *Seismicity, Seismotectonics and Seismic Hazard Assessment in Albania*. Academy of Sciences of Albania, Tirana.
- ⁵² Mavroulis S, Lekkas E, Carydis P. Liquefaction Phenomena Induced by the 26 November 2019, Mw = 6.4 Durrës (Albania) Earthquake and Liquefaction Susceptibility Assessment in the Affected Area. *Geosciences*. 2021; 11(5):215, (DOI: 10.3390/geosciences11050215).
- ⁵³ Sextos, A., Lekkas, E., Stefanidou, S., Baltzopoulos, G., Fragkiadakis, M., Giarlelis, C., Lombardi, L., Markogiannaki, O., Mavroulis, S., Plaka, A., Pnevmatikos, N., Skoulidou, D., Tsiatas, G., and Tsopelas, P., 2020. *Albania Earthquake of 26 November 2019. Report on Structural and Geotechnical Damage*. Hellenic Association of Earthquake Engineering, Athens, Greece, p. 47. (DOI: 10.13140/RG.2.2.16153.24167).
- ⁵⁴ Pavlides, S., Chatzipetros, A., Georgiadis, G., Lazos, I., Beqiraj, A., Muceku, Y., and Reçi, H., 2020. *Preliminary Report on the Ground Effects of the November 26, 2019, Albania Earthquake*. Earthquake Geology Research Team, Department of Geology, Aristotle University of Thessaloniki.
- ⁵⁵ Vittori, E., Blumetti, A. M., Commerci, V., Di Manna, P., Piccardi, L., Gega, D., and Hoxha, I., 2021. Geological Effects and Tectonic Environment of the 26 November 2019, Mw 6.4 Durres earthquake (Albania). *Geophysical Journal International*, 225(2), 1174–1191, (DOI: 10.1093/gji/ggaa582).
- ⁵⁶ Jaupaj, O., Lamaj, M., Kulici, H., Jusufati, M., Plaku, E., and Gjeta, I., 2017. *Landslide Inventory Map of Albania*. In: Mikos, M., Tiwari, B., Yin, Y., and Sassa, K. (Eds.). *Advancing Culture of Living with Landslides*, Vol. 2. Springer, Cham, Switzerland, (DOI: 10.1007/978-3-319-53498-5_5).
- ⁵⁷ Kuliçi, H., Jaupaj, O., and Lamaj, M., 2017. Landslide Susceptibility Map of Durrës and Kavaja Region, Albania. In: Dang K. and Sassa, K. (Eds.). 2017 International Programme on Landslides Symposium On Landslides, The International Consortium on Landslides, available at <https://iplhq.org/icl/wp-content/uploads/2017/12/2017-IPL-Symposium-Proceedings.pdf>.
- ⁵⁸ World Health Organization (WHO), 2010. *Albania: Landslide hazard distribution map*. In: The WHO E-Atlas of Disaster Risk for the European Region. Volume 1. Exposure to natural hazards Version 2.0, available at <http://eatlas.emro.who.int/europe/countries/albania/albania-landslide-map.html>.

ADDITIONAL REFERENCES

- Aristotle University of Thessaloniki Seismological Network, 1981. Aristotle University of Thessaloniki Seismological Network. International Federation of Digital Seismograph Networks, (DOI: 10.7914/SN/HT).
- Bard, P. Y. and Bouchon, M., 1985. The Two-Dimensional Resonance of Sediment-Filled Valleys. *Bulletin of the Seismological Society of America*, 75(2), 519–541.
- Carydis, P. and Lekkas, E., 2011. The Haiti Earthquake Mw = 7.0 of January 12th 2010: Structural and Geotechnical Engineering Field Observations, Near-Field Ground Motion Estimation and Interpretation of the Damage to Buildings and Infrastructure in the Port-au-Prince area. *International Journal of Earthquake Engineering*, 28(3), 24–42.
- Cornou, C. and Bard, P.-Y., 2003. Site-to-Bedrock Over 1D Transfer Function Ratio: An Indicator of the Proportion of Edge-Generated Surface Waves? *Geophysical Research Letters*, 30(9), 1453, (DOI: 10.1029/2002GL016593).
- Duni, L., 2013. *MASW Measurements for the Characterization of the Albanian Seismological Network Stations*. Internal report, Institute of Geosciences, Energy, Water and Environment, Tirane, Albania.
- Gulerce, Z. and Salic, R., 2015. *Improvements in the Harmonized Seismic Hazard Maps for the Western Balkan Countries*. Final report, SfP project number 984374, p. 61.

- Institute of Geosciences, Energy, Water and Environment (IGEWE), 2002. Albanian Seismological Network [Data set]. International Federation of Digital Seismograph Networks, (DOI: 10.7914/SN/AC).
- Istituto Nazionale di Geofisica e Vulcanologia (INGV) Seismological Data Centre, 2006. *Rete Sismica Nazionale*. Istituto Nazionale di Geofisica e Vulcanologia, Italy, (DOI:10.13127/SD/X0FXNH7QFY).
- International Seismological Centre (2021), ISC-GEM Earthquake Catalogue, (DOI: 10.31905/d808b825).
- Koci, R., 2013. *Geological Characterization of the Albanian Seismological Network Stations*. Internal report, Institute of Geosciences, Energy, Water and Environment, Tirane, Albania
- Koci, R., Duni, L., Kuka, N., and Dushi, E., 2019. Preliminary Seismological Data of the November 2019 (Mw6.4), Durrës Earthquake. Internal technical report, Department of Seismology, Institute of Geosciences, Energy, Water and Environment, Polytechnic University of Tirana.
- Le Roux, O., Cornou, C., Jongmans, D., and Schwartz, S., 2012. 1-D and 2-D resonances in an Alpine Valley Identified From Ambient Noise Measurements and 3-D modelling. *Geophysical Journal International*, 191(2), 579–590, (DOI: 10.1111/j.1365-246X.2012.05635.x).
- Mediterranean Very Broadband Seismographic Network (MedNet) Project Partner Institutions, 1990. *Mediterranean Very Broadband Seismographic Network*. Istituto Nazionale di Geofisica e Vulcanologia, (DOI: 10.13127/SD/FBBBTDTD6Q).
- Theodoulidis, N., Cultrera, G., Cornou, C., Bard, P. Y., Boxberger, T., DiGiulio, G., Imtiaz, A., Kementzetzidou, D., and Makra, K., and The Argostoli NERA Team, 2018. Basin Effects on Ground Motion: The Case of a High-Resolution Experiment in Cephalonia (Greece). *Bulletin of Earthquake Engineering*, 16(2), 529–560, (DOI: 10.1007/s10518-017-0225-4).
- Uebayashi, H., 2003. Extrapolation of Irregular Subsurface Structures Using the Horizontal-to-Vertical Spectral Ratio of Long-Period Microtremors. *Bulletin of the Seismological Society of America*, 93(2), 570–582, (DOI: 10.1785/0120020137).
- Wells, D. and Coppersmith, K., 1994. New Empirical Relationships Among Magnitude, Rupture Length, Rupture Width, Rupture Area and Surface Displacement. *Bulletin of the Seismological Society America*, 84(4), 974–1002.



[Photo: Jitendra Bothara]

EERI Earthquake Reconnaissance Report:
M6.4 Albania Earthquake on November
26, 2019



Volume 3: Resilience and Recovery

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PREFACE

This Earthquake Engineering Research Institute (EERI) Earthquake Reconnaissance Report for the M6.4 Albania earthquake on November 26, 2019, is divided into four volumes. Volume 1 is the Executive Summary, which provides a brief overview of the key observations in all areas. The remaining volumes provide background and in-depth descriptions of these observations.

- Volume 2, “Seismology and Geotechnical Effects” describes seismological aspects of the earthquake and a summary of geotechnical impacts.
- Volume 3, “Response and Recovery” describes response and recovery, as well as the performance of lifelines and transportation infrastructure.
- Volume 4, “Building Performance” focuses on the performance of major construction types: residential masonry buildings, cast-in-place reinforced concrete buildings, and prefabricated reinforced concrete buildings. The performance of special use buildings, including schools, hospitals, and heritage and religious structures, is also described. An overview of Albanian building codes and construction practices is also provided in this volume, along with damage assessment data collected by several of the reconnaissance teams.

1 LIFELINES, TRANSPORTATION AND RESPONSE

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1.1 Introduction

As described in Volume 2, the earthquake on November 26 caused geotechnical damage, such as liquefaction and soil spreading in localized areas; however, the major cause of damage was ground shaking. Although most observed damage was to building structures (Volume 4), the earthquake also caused limited damage to infrastructure. Overall, the damage to bridges, railways, airports, the power sector, telecommunication, water supply, and irrigation systems was limited. Services provided by these systems were restored shortly after the earthquake.

Healthcare facilities suffered damage ranging from minor to major, and a few healthcare buildings were later demolished. Critical healthcare functions were restored shortly after the earthquake with minimum disruption to daily life. The performance of healthcare facilities is described in detail in Volume 4.

The damage and destruction triggered an emergency response immediately after the earthquake that is described in Section 1.3.

1.2 Distributed Infrastructure

1.2.1 Community infrastructure

Community infrastructure, including town and rural roads and services, community buildings, places of worship, and river protection systems, suffered earthquake damage. The earthquake caused limited damage to local roads (Figure 1), river embankments (Figure 2) and some river protection structures, and street lighting. Minor to severe damage to 42 municipality-owned buildings (Figure 3) and, similarly, religious buildings was also reported; however, none of these buildings suffered partial or total collapse.



Figure 1. Damage to the road in front of the drainage pumping station in Hamallaj (41.486820, 19.517701), Durrës. The photographs show the same damage from each side of road (source: Altin Sula).



Figure 2. Damage to a water canal in Hamallaj (41.488834, 19.511943), Durrës (source: Markel Baballëku).



Figure 3. Damage suffered by a municipal building (source: Jitendra Bothara).

1.2.2 Energy

All components of the electrical power system (e.g., production, transmission, or distribution) escaped major earthquake damage, even in the hard-hit areas. The earthquake caused mostly moderate damage to the transmission and distribution system, such as destruction of unreinforced masonry substation structures, overturning of unanchored transformers, and

damage to electrical distribution poles, bus bars, insulators, and switches; however, a few of these also suffered severe damage (Figure 4). The earthquake did not affect electrical power generation plants, as these are in the far northeast and northwest of Albania in areas that were not affected by the earthquake. Some 91,642 households lost power supply in the hard-hit areas, out of which approximately 60% were in the Durrës area; however, 80% of the connections were restored within a day utilizing back-up equipment and parts.



Figure 4. Severely damaged electrical substation (source: B. Skenderi, 2019).¹

1.2.3 Communication

The communication sector suffered minor to moderate damage and limited downtime due to the disruption of services. The telecommunication system suffered damage to buildings, equipment, cables, cabins, and antennas. Two buildings that have three telecommunication antennas installed on them suffered destruction; however, the television broadcaster and cable television buildings did not suffer damage. Five post offices suffered severe damage, and another eight suffered small to moderate damage. Most of the damage to the communication system was concentrated in the Durrës area. Because of damage to telecom infrastructure, service recipients lost connection temporarily, and the network experienced congestion; however, service was restored quickly with minimal disturbance to their users (Government of Albania et al., 2020).²

1.2.4 Transportation (roads, rails, air, and water)

A transportation network in the earthquake-affected areas suffered limited damage and disruption. The road network only suffered minor damage from pavement cracking (Figure 5), damage to secondary elements of the two overpass bridges

near Durrës (Figure 6), and damage to bridge deck seating (Figure 7). Similarly, in Durrës, a wagon repair workshop, one railway station, and one railway bridge suffered moderate to severe damage. Albanian civil aviation, including air transport operations, did not report any damage (Government of Albania et al., 2020).



Figure 5. Cracking damage to pavement of Durrës-Tirana highway in Marikaj. The crack was likely caused by ground displacement because of a nearby ditch. Note the extension of the crack to the adjoining building (source: Hysain Bilgin and Altin Bidaj).



Figure 6. Damage to highway overpass near Durrës (41.324108, 19.483383) (source: Jitendra Bothara).



Figure 7. Minor damage to seating of bridge deck for the Dajlani Overpass (41.317032, 19.470297) (source: Markel Baballëku).

1.2.5 Water, sanitation and hygiene

Post-earthquake observations show that the water, sanitation, and solid waste management structures or systems suffered minimal damage and pipeline breakage, though there were extensive networks of water and sewer systems in the area. The earthquake caused damage to a sewage treatment plant and water supply pipes near Durrës (Figure 8) and one pumping station in Lezha (Figure 9). The damage to the pipeline was fixed within a day. Four water depots also suffered damage in Tirana (Government of Albania et al., 2020).



Location of damaged water supply pipeline



Close view of pipeline



Damaged pipeline under repair

Figure 8. Damage to water supply pipeline near Ishem, Durrës County (41.541943, 19.612233) (source: Markel Baballëku).



Figure 9. Damage to a pumping station, Laç, Kurbin (41.644272, 19.682648) (source: Markel Baballëku).

1.2.6 Infrastructure resiliency

The Albanian earthquake in 2019 caused limited damage to the infrastructure in the regions of strongest ground shaking. Most of the services were restored immediately after the disaster, such as the broken water supply pipeline, and 80% of the electricity distribution connections were restored within a day (Government of Albania et al., 2020). This showed the capability of mobilizing manpower, materials, and equipment to cope with the limited impacts of the disaster; however, considering the overall limited impact of the earthquake on the infrastructure in the affected areas, it is difficult to gauge the resiliency of infrastructure and infrastructure management systems if a larger earthquake were to occur in the future.

1.3 Emergency Response and Recovery

1.3.1 Rescue operations and emergency shelter

The Government of Albania declared a state of emergency on November 27 for Durrës and Tirana. The Committee of Civil Emergency was formed to plan the immediate response and initiate life-saving operations. Rescue operations involving 8,500 responders started immediately after the earthquake, out of which around 10% came from abroad. In total, 48 occupants were saved from damaged and collapsed buildings (Government of Albania et al., 2020). Rescue operations were finished on November 29, 2019, three days after the earthquake.

Between 14,000 to 17,000 people needed temporary shelter (World Bank GPURL D-RAS Team, 2019).³ Less than a day after the event, tents and emergency supplies were provided to the displaced population. Apart from tents, hotels, public

buildings, and sport halls were used as temporary shelters. Later, the majority of the displaced population was moved from tents to hotels and private housing. The event occurred during a low tourist season; therefore, most of the hotel capacities were not occupied and were able to take in the displaced population.

An estimated 9.2% of households moved out of their homes in the affected areas. By the end of December 2019, approximately a month after the earthquake, two-thirds of the displaced households had returned to their homes.

1.3.2 Building inspections and building damage classification

Building inspections started immediately after the event on November 26. Apart from local engineers, over 100 engineers from Greece, Italy, France, and Switzerland participated in building inspections. Based on discussions with the local authorities, the authors of this section estimate that approximately 500 engineers were involved in post-earthquake building inspections. Buildings were assigned green (i.e., safe), yellow (i.e., needs further inspection), or red (i.e., unsafe) tags. In the first two weeks following the event, the priority of the inspection and damage classifications were schools, hospitals and severely damaged buildings in the epicentral region. Because of a lack of a centralized organization, engineers used different methodologies to classify damaged buildings, which led to inconsistent results. Certain buildings were examined several times. On December 8, 2019, a unique building damage classification methodology and an official Rapid Damage Assessment (RDA) form was adopted by the Albanian government. The efforts became better organized, and the building inspections and damage classification continued until mid-January. After mid-January, the post processing of data collected in the field started, and damage assessment efforts were then focused on buildings with severe damage to decide whether the buildings should be demolished and rebuilt or repaired and retrofitted. The RDA form used after December 8 consisted of three parts. The first part of the RDA form contained questions regarding the building's age, who constructed it (e.g., self-built, government, private contractor), and whether additional floors were later added to it. The second part consisted of questions regarding building materials for various structural and nonstructural building elements (e.g., walls, columns, beams, roof, floors, etc.). The third part of the RDA form dealt with building damage. The observed damage was classified into six damage states that ranged from "No damage" (D0) to "complete destruction" (DS5).

According to the report published by the World Bank, by December 11, 2019, the inspection of approximately 14,000 buildings was completed. Table 1 presents building inspection data from the three most affected municipalities completed by December 10, 2019 (World Bank GPURL D-RAS Team, 2019). Data indicate 46 heavily damaged buildings were demolished in these three municipalities by this date. The table indicates more buildings were recommended for demolition in Shijak than in Durrës, which indicates an inconsistency in data. The inconsistency may have occurred because more experienced engineers were deployed in Durrës, which suffered more damage than Shijak, resulting in more accurate assessments of buildings in Durrës. Furthermore, as a result of the panic that occurred in the first few days following the event and a lack of training in building damage assessment, it is possible that building damage assessments were too conservative, misclassifying moderate damage as severe. The different levels of damage that occurred in different parts of the earthquake-affected areas may be attributed to varying maintenance levels for the buildings. Buildings in Durrës were generally more maintained because it is a tourist city. It has also been reported that the buildings damaged in the earthquake of September 2019 were not repaired and may have suffered more damage during the earthquake of November 2019.

Table 1: Building damage statistics from the Office of Natural Disaster Management Operations in three municipalities in the epicentral region (as of December 10, 2019) (source: World Bank GPURL D-RAS Team, 2019).

	Durrës M.	Kruja M.	Shijak M.	Combined
Inspected	2112	2499	1670	6281
Safe	1368	1533	346	3247
Uninhabitable	651	921	900	2472
Demolition	93	45	424	562
Demolished	34	12	0	46

Note: Inspected = total number of inspected buildings; Safe = good enough to occupy; Uninhabitable = needs further inspection; Demolition = recommended for demolition.

More than 95,000 housing units were damaged, which was 18% of the total number of housing units in 11 affected municipalities. A total of 11,490 housing units suffered severe damage and should be demolished, whereas 83,745 housing units suffered minor to moderate damage and can be repaired (Government of Albania et al., 2020).

Several GIS-based tools were developed after the event to help with response and recovery efforts. These tools were used to create a map of critical facilities in Durrës to enable tenants to report building damage using their mobile phones and to enable engineers to add building damage classification data to the online GIS database (AFPS, 2020; ESRI, 2020).^{4,5} A centralized GIS database enabled an overview of the spatial distribution of building damage and was used as a tool to prioritize needs and resources in the aftermath of the event. A map showing data reported until February 2021 is presented in Figure 10. The figure is based on a total of 2,447 reports; that is, it does not contain all damaged buildings. It does show, however, a large concentration of severely damaged buildings in Durrës city center and beach area.

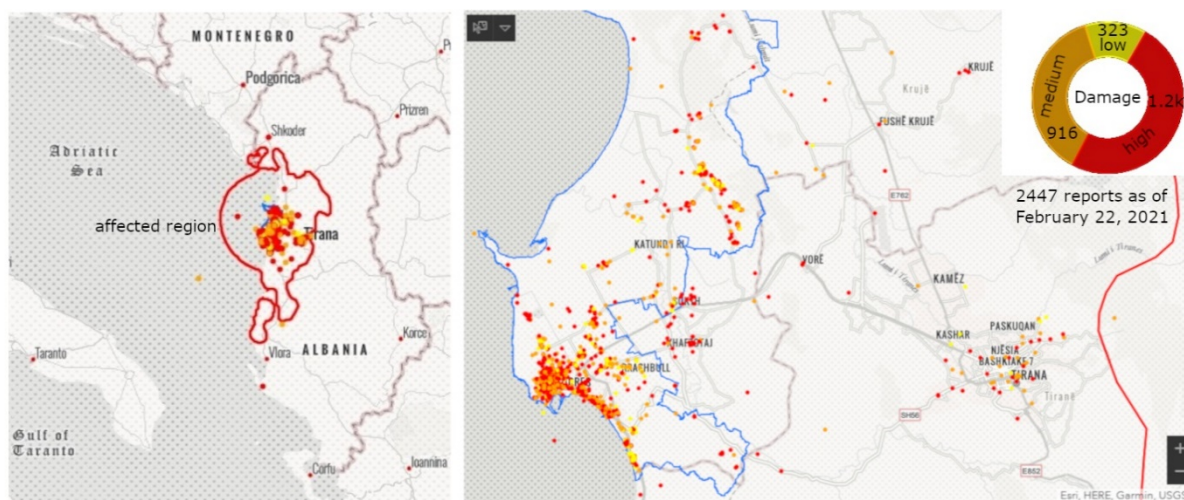


Figure 10. Spatial distribution of building damage according to data gathered using a GIS-based tool (source: information retrieved from <https://gdi-online.maps.arcgis.com/apps/opsdashboard/index.html#/1cac80e89b524f0e932a302425f25602> on February 22, 2021).⁶

1.3.3 Post-earthquake building functionality

The safety and functionality of stairs and elevators enable evacuation from damaged buildings; hence, these nonstructural building elements are of great importance immediately after earthquakes. Stairs of several severely damaged buildings were blocked by fallen masonry infill walls (Figure 11). This was typical in multi-story buildings with structural systems consisting of reinforced concrete frames with masonry infill walls, where the masonry infill was separated from the reinforced concrete frames because of large reinforced concrete frame deformations or a weak bond between the reinforced concrete frame and the infill walls; however, several buildings in Durrës and Fushë-Krujë had functioning elevators, despite significant damage to the masonry infill walls (Figure 12). The performance of masonry infill is discussed in further detail in Volume 4. Additional photos of building damage are shown in Figures 13, 14, and 15.



Figure 11. Masonry infill debris blocking stairs (source: McKenney, 2019; Nikolić-Brzev et al., 2020).^{7,8}



Figure 12. Functional elevators in a building with severe infill damage in Fushë-Krujë (photo: Nikolić-Brzev et al., 2020).



Figure 13. Masonry infill debris damaged the building's electrical and piping infrastructure (source: Nikolić-Brzev et al., 2020).



Figure 14. Damage to cladding in lower levels in Durrës (left) (41.3234, 19.4546); damage in Fushë-Krujë (right) (41.4785, 19.7266) (source: Jitendra Bothara).



Figure 15. Damage to the masonry infill in lower floors in Durrës (source: Nikolić-Brzev et al., 2020).

Business interruption due to masonry infill damage was observed in Durrës. In most cases, damage to masonry infill walls at the ground levels of buildings was the primary cause of business interruption (Figure 16). Observed businesses were

operational immediately after the earthquake in those buildings without wall damage (McKenney, 2019). Losses due to business interruption are estimated to be 5.46 million Euros (Government of Albania et al., 2020).



Figure 16. Business interruption due to masonry infill damage (source: McKenney, 2019).

1.3.4 Recovery efforts

Following the earthquake, on December 6, the Government of Albania initiated the process for the Post-Disaster Needs Assessment (PDNA) (Government of Albania et al., 2020), which was completed with support from the European Union, the United Nations, and the World Bank. The PDNA process started on December 16, twenty days after the event, and the assessment was completed on January 30, 2020, approximately 2 months after the earthquake. The PDNA proposed the Build Back Better approach and estimated a need of 1,076.15 million Euros for recovery and reconstruction. Out of the estimated recovery cost, 803 million Euros were estimated to be required for reconstruction and recovery of the Housing sector alone. On February 17, 2020, an International Donors Conference was organized, where 1.15 billion Euros were pledged to help Albania, surpassing the estimated amount needed for recovery.

Government has access to the funds pledged by donors. By July 2020, 8 months after the event, the design of many buildings damaged in the earthquake was almost completed, and large-scale construction work, organized and supervised by the government, was expected to start soon. As of April 2021, it was observed that the recovery of public health and educational facilities was faster compared to the housing sector. In the areas of Thumanë, Kurbin, and partially Tirana, there is progress in the housing sector recovery with small interruptions; however, this process is delayed in the Durrës area. Causes for this delay might be the larger extent of damage to the housing sector in this area and the difficulties in setting up adequate administrative procedures for reconstruction and monitoring. For the buildings whose repair costs exceed 70% of the rebuilding costs, it was decided that they will be demolished and rebuilt (AFPS, 2020). The construction work on several school buildings that were demolished after the earthquake has begun as of July 2020 (Figure 17, Figure 18, Figure 19). In the case of the “Ramazan Subashi” school in Vorë, Tirana, reconstruction started just 3 months after the earthquake and was finished by December 2020 (Figure 20).



Figure 17. Damaged “Ramazan Subashi” school in Vorë, Tirana (source: Markel Baballeku).



Figure 18. Rebuilding the “Ramazan Subashi” school in Vorë, Tirana, as of July 2020 (source: Markel Baballeku).



Figure 19. Rebuilding the “Ramazan Subashi” school in Vorë, Tirana, as of July 2020 (source: Markel Baballëku).



Figure 20. Finished construction on the “Ramazan Subashi” school in Vorë, Tirana, as of December 2020 (source: Markel Baballëku).

Reconstruction activities were allowed to proceed, despite the COVID-19 pandemic, because special permits were issued to construction companies. Reconstruction delays may have been caused because of difficulties regarding the import of

construction materials and goods that were caused by the pandemic. It is estimated that the recovery efforts for ordinary buildings (e.g., multi-family residential buildings) were delayed approximately 2 months because of the ongoing COVID-19 pandemic. The Albanian government is transferring financial assistance to the owners of apartments in lightly damaged (DS1, DS2) single- and multi-family buildings to help repair the damage. The situation is more complex in multi-family moderately (DS3) to severely (DS4) damaged buildings because it is unclear how to finance the repair of the shared building elements, such as elevators, stairs, or building infrastructure. An additional issue is the uneven distribution of damage (i.e., usually lower floors suffered more damage than higher floors); therefore, the same financial assistance to all apartment owners in multi-family buildings is problematic.

Some owners started repairing their houses a few days after the event, whereas others were still waiting for financial support from the government, construction permits, or retrofit designs as of July 2020. There is a shortage of engineers, construction workers, and construction companies to design and repair damaged buildings. An additional issue is that construction companies prefer to work on the construction of new buildings rather than repairing damaged ones. As of mid-January 2020, the Albanian government adopted Eurocode 8 Part 3 as mandatory for the assessment and retrofit of damaged buildings; however, the current Albanian building code is still mandatory for rebuilding demolished buildings and constructing new buildings.

Due to a lack of experience of engineers in charge of the structural retrofitting of buildings, difficulties are present in following the assessment and retrofitting standards adopted for this purpose. In some cases, especially for unreinforced masonry buildings, decisions have been made to demolish, even when the buildings suffered slight damage from the earthquake. These decisions may have been affected by the deteriorated condition of the buildings due to their long lifespan.

The Albanian Development Fund has initiated a call to all affected municipalities to submit proposals and preliminary designs for non-residential buildings to be rebuilt or retrofitted; the Albanian Development Fund will then fund the selected projects.

The Albanian government is providing scholarships for children and pensions for the surviving adults of the families with deceased members. Families that are in temporary shelter are also financially supported by the government.

1.3.5 Loss estimation and Post-Disaster Needs Assessment

According to the estimates published by the PDNA report, estimated total losses are 985.1 million Euros, or 7.5% of Albania's gross domestic product, for 2018 (Government of Albania et al., 2020). It is estimated that direct losses are 843.9 million Euros, and indirect losses are 141.2 million Euros. The PDNA has categorized losses into eight sectors (Table 2). The Housing sector suffered 78.5% of direct losses, or 662 million Euros. Indirect losses are dominated by the expected losses in the productive sector: an estimated loss of 73 million Euros due to an expected decline in tourist visits in the next 3 years. The spatial distribution of losses indicates that 62% of losses are in Tirana and Durrës, which is equally distributed among the two largest cities. Similar findings can be found in the report presented by the World Bank, where the direct losses are also represented relative to the total exposure value (World Bank GPURL D-RAS Team, 2019).

Table 2: Direct and indirect losses categorized into sectors (source: Government of Albania et al., 2020).

Sectors	Direct losses [million EUR]	Indirect losses [million EUR]	Total [million EUR]
Education	63.59	8.76	72.35
Housing	662.30	34.00	696.30
Productive	70.82	79.66	150.48
Infrastructure	30.41	3.01	33.42
Social Protection	—	0.62	0.62
Civil Protection and DRR	8.75	13.22	21.97
Health Care	8.02	1.91	9.94
Total	843.89	141.18	985.07

The insurance of assets and business is very low in Albania—only 2% of the properties are estimated to be insured against earthquakes (OECD, 2018).⁹ Therefore, the majority of losses and recovery costs must be borne by business owners, building owners, and government. The direct losses to private property and loss of employment have serious financial consequences to the population. It is estimated that around 10,000 employees temporarily lost their jobs in the Durrës region. It is expected that most of the affected families cannot financially recover without government support (IFRC, 2019).¹⁰ The families that were affected the most are those in which most family members were employed in a single business that was interrupted by the earthquake.

1.4 Conclusions

Distributed infrastructure:

- The 2019 Albanian earthquake caused limited damage to the distributed infrastructure in the hard-hit earthquake-affected areas.
- Most of the services were restored within 24 hours after the earthquake showing the capability of local authorities in mobilizing manpower, materials, and equipment to cope with the impacts of the disaster in a moderate earthquake.
- The earthquake shaking was not strong enough to test the resilience of the distributed infrastructure and infrastructure management systems in response to extreme shaking. Hence, Albanian infrastructure authorities should consider evaluating their resilience capabilities to respond to larger scenario earthquakes more effectively.

Emergency Response and Recovery:

- 9.2% of households in the affected areas moved out of their damaged dwellings immediately after the earthquake.
- It is important to prepare post-earthquake building assessment forms and to train engineers on how to perform assessments before an earthquake occurs. More consistency and training would expedite and increase the quality of building damage assessments immediately after earthquakes. In the case of this earthquake, the lack of organization in the first 2 weeks prolonged the total time needed for building inspections and damage assessments, leading to a suboptimal use of available human and material resources.
- GIS-based tools were used to help with the response and recovery efforts. A centralized organization of building inspection and damage classification is important. Using centralized GIS databases can be helpful, as they enable better-informed decision-making because of the availability of up-to-date visualization of inspected

building damage; better cooperation between the affected population and the engineers on the field using mobile apps and easily accessible statistics on the recovery progress provides a useful tool to monitor and guide recovery operations. The same equally applies to infrastructure.

- Building components were damaged due to damage of masonry infill walls. This reduced the building's functionality.
- Masonry infill wall failure and nonstructural damage reduced access to the stairs, hindering the evacuation of tenants.
- A total of 18% of housing units in the affected areas suffered damage, and another 2% were severely damaged.
- Infill wall damage was dominant in the lower floors of multi-story buildings, causing business interruption.
- After the earthquake, Eurocode 8 Part 3 was adopted as mandatory for building retrofits, whereas the current Albanian building code is still being used for rebuilding demolished buildings and building new ones. It is important to regulate building retrofitting using the latest building codes and to train engineers on how to use them before an earthquake occurs. Without clear guidelines or regulations regarding building retrofitting, the quality of the retrofit is more uncertain. Furthermore, the discrepancy between building codes used for retrofitting and rebuilding should be avoided.
- Total losses are estimated at 985.1 million Euros, or 7.5% of Albania's gross domestic product, for 2018. The estimated cost of recovery is around 1 billion Euros, out of which around 80% is needed for the Housing sector alone.

REFERENCES

- ¹ Skenderi, B., 2019. FOTOT: Dëmtimet e kabinave elektrike nga tërmeti, OSHEE tregon zonat që kanë mbetur pa drita, available at <http://www.gazetatema.net/2019/11/26/fotot-demtmet-e-kabinave-elektrike-nga-termeti-oshee-tregon-zonat-qe-kane-mbetur-pa-drita/#img=7>.
- ² Government of Albania, European Union, United Nations agencies, and World Bank, 2020. *Albania Post-Disaster Needs Assessment, Volume A Report*. Tirana, Albania, available at https://reliefweb.int/sites/reliefweb.int/files/resources/albania_post-disaster_recovery_a_v9.0.pdf.
- ³ World Bank GPURL D-RAS Team, 2019. *M6.4 Albania Earthquake Global Rapid Post Disaster Damage Estimation (Grade) Report*, available at https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/assessments/2019-12-16_grade_alb_eq_nov2019_final.pdf (accessed November 17, 2021).
- ⁴ Esri, 2020. *Real-Time GIS Apps Quicken Response to Earthquake in Albania*, available at <https://www.esri.com/about/newsroom/arcnews/real-time-gis-apps-quicken-response-to-earthquake-in-albania/> (accessed February 1, 2021).
- ⁵ French Association for Earthquake Engineering (AFPS), 2020. *Report of the Post-Earthquake Mission on the Earthquake in Albania (Unofficial English Translation)*.
- ⁶ Esri, GDi, 2020. Raportimi i Demeve te Termetit, available at <https://gdi-online.maps.arcgis.com/apps/opsdashboard/index.html#/1cac80e89b524f0e932a302425f25602> (accessed February 22, 2021).
- ⁷ McKenney, C., 2019. *Reconnaissance Observation Report: Albania M6.4 Earthquake on November 26, 2019*.
- ⁸ Nikolić-Brzev, S., Marinković, M., Milićević, I., and Blagojević, N., 2020. *Posledice zemljotresa u Albaniji od 26.11.2019. na objekte i infrastrukturu [Consequences of the November 26, 2019 Albania earthquake on buildings and infrastructure]*, Serbian Association for Earthquake Engineering, Belgrade, Serbia (in Serbian), pp. 1–80.
- ⁹ Organisation for Economic Co-operation and Development (OECD), 2018. *Financial Management of Earthquake Risk*, available at <http://www.oecd.org/finance/insurance/Financial-management-of-earthquake-risk.pdf> (accessed November 17, 2021).
- ¹⁰ International Federation of Red Cross and Red Crescent Societies (IFRC), 2019. *Emergency Appeal, Albania: Earthquake n° MDRAL008*, available at <https://reliefweb.int/report/albania/emergency-appeal-albania-earthquake-n-mdral008> (accessed December 1, 2021).



EERI Earthquake Reconnaissance Report:

**M6.4 Albania Earthquake on November
26, 2019**



Volume 4: Building Performance

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PREFACE

This EERI Earthquake Reconnaissance Report for the M6.4 Albania earthquake on November 26, 2019, is divided into four volumes. Volume 1 is the Executive Summary, which provides a brief overview of the key observations in all areas. The remaining volumes provide background and in-depth descriptions of these observations.

- Volume 2, "Seismology and Geotechnical Effects," describes seismological aspects of the earthquake and a summary of geotechnical impacts.
- Volume 3, "Response and Recovery," describes response and recovery, as well as the performance of lifelines and transportation infrastructure.
- Volume 4, "Building Performance," focuses on the performance of major building types: residential masonry buildings, cast-in-place reinforced concrete buildings, and prefabricated reinforced concrete buildings. Performance of special use buildings, including schools, hospitals, and heritage and religious structures, are also described. An overview of Albanian building codes and construction practices is also provided in this volume, along with damage assessment data collected by a few reconnaissance teams.

1 OVERVIEW OF BUILDING CODES AND PRACTICES

1.1 Building Codes

The development and the level of enforcement of building codes in practice and the construction typologies in Albania are strongly related to the political and economic development of the country throughout different time periods. Figure 1 shows a timeline of design codes, major seismic events, and construction typologies characteristic for different time periods.

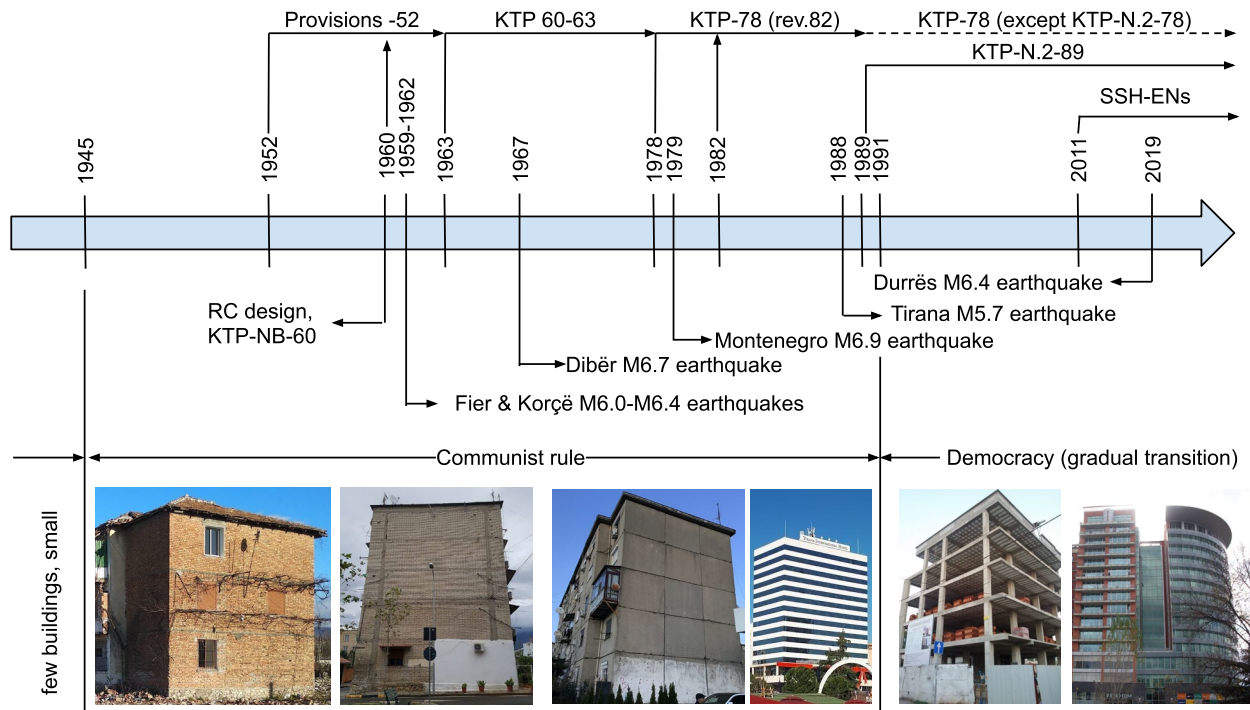


Figure 1. Timeline of design codes, major seismic events, and construction typologies (photos: Brisid Isufi).

Until the end of World War II, Albania's population inhabited predominantly rural areas and lived in low-rise brick masonry or adobe dwellings. During the communist period (1945-1991), the construction industry advanced significantly, and the development of design codes became necessary. The first seismic design provisions in Albania, published in 1952, were titled, "Provisions for earthquake-resistant constructions" (Council of Ministers, 1952).¹ The 1952 document included a seismic zonation map that identified Durrës and the southwestern part of Albania as the regions with the highest hazard (intensity VIII). In the period from 1960 to 1963, these provisions evolved into design code KTP-SN 60 (technical design

code for the design of building structures), code KTP-NB 60, which covered the design of reinforced concrete structures for the first time, and the seismic design code of 1963 (KTP-63) following a series of strong earthquakes from 1952 to 1962 that affected the southeast and southwest regions of Albania.

The next edition of the code was published in 1978, and it contained substantial revisions of both seismic and non-seismic design of masonry, concrete, and steel buildings. The Montenegro earthquake in 1979 motivated further improvements of the code provisions and resulted in an amendment published in 1982, which specifically addressed the seismic design part of the code. Most notably, the amendment in 1982 introduced more stringent requirements for masonry buildings and favored the confined masonry construction technology. The most recent edition of the code, KTP-N.2-89, was published in 1989, and it contained only provisions related to the seismic design of structures (Academy of Sciences and Ministry for Construction, 1989).² At the time of the earthquake on November 26, 2019, the effective codes were KTP-78 (covering material-specific design, loads, combinations of actions, etc.) and KTP-N.2-89 (covering the seismic design of structures). Further details about the historical development of design codes in Albania can be found in Baballëku and Myftaraga (2020).³

Before 1989, seismic design codes in Albania covered exclusively construction typologies that were common in Albania at the time of the respective publication. It is worth noting that the great majority of multi-story buildings in Albania were masonry buildings until the 1990s (Novikova et al., 2015).⁴ This was clearly reflected in the codes, which were mostly focused on masonry buildings. As the construction industry advanced, the codes were revised to cover modern construction typologies and the latest design concepts. In the 1989 revision, seismic design provisions for reinforced concrete buildings were introduced for the first time, including provisions dealing with masonry infills in reinforced concrete frames and seismic detailing rules for main structural members. The detailing requirements (see Figure 2 for an example) were prescribed depending on the seismic intensity at the construction site with more stringent requirements for sites located at higher seismic intensities. For example, the maximum allowed spacing of longitudinal bars enclosed by hoops (d_{st}) was 300 mm for a seismic intensity up to VIII and 200 mm for intensity IX in the MSK-1964 scale.

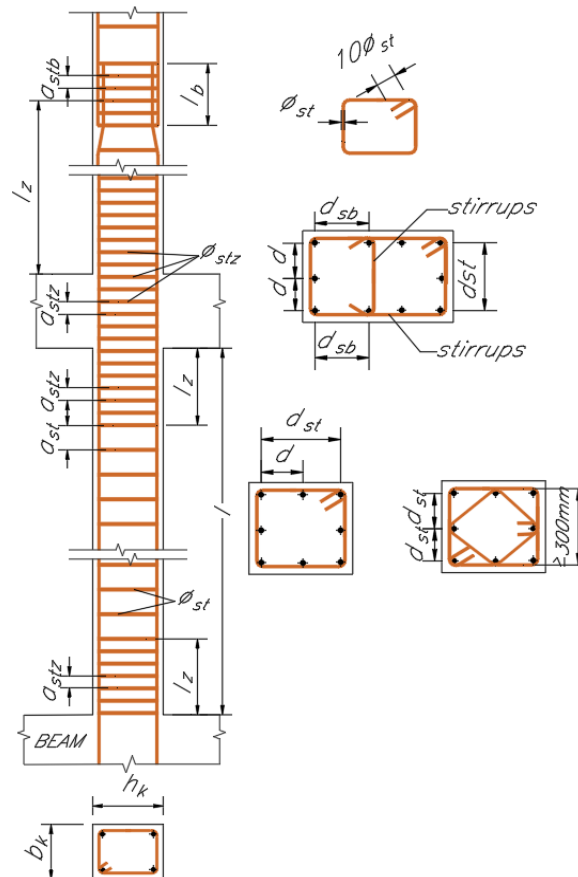


Figure 2. Rules for detailing of reinforced concrete columns according to KTP-N.2-89 (source: Enes Veliu, based on KTP N.2 89).

Seismic analysis methods prescribed by the Albanian seismic codes also evolved over the years. According to the 1978 seismic design code KTP-N.2-78 (1978),⁵ the seismic action was represented by a design response spectrum. The response spectrum analysis was a default analysis method prescribed by KTP-N.2-89, whereas dynamic time history analysis was permitted as a complementary analysis for important structures. Different response modification factors (behavior factors) were prescribed for different lateral load-resisting systems.

The seismic hazard level mandated by the code has also evolved through time. The Montenegro earthquake in 1979 (M6.9) was a major seismic event that significantly affected the northwestern region of Albania and motivated a revision of the seismic hazard map of Albania and an increase of seismic intensity in the northern part of the country. The seismic zonation map shown in Figure 3(a) has not been formally revised to date; however, several seismic hazard studies have been published in recent years (see Volume 2 for more details).

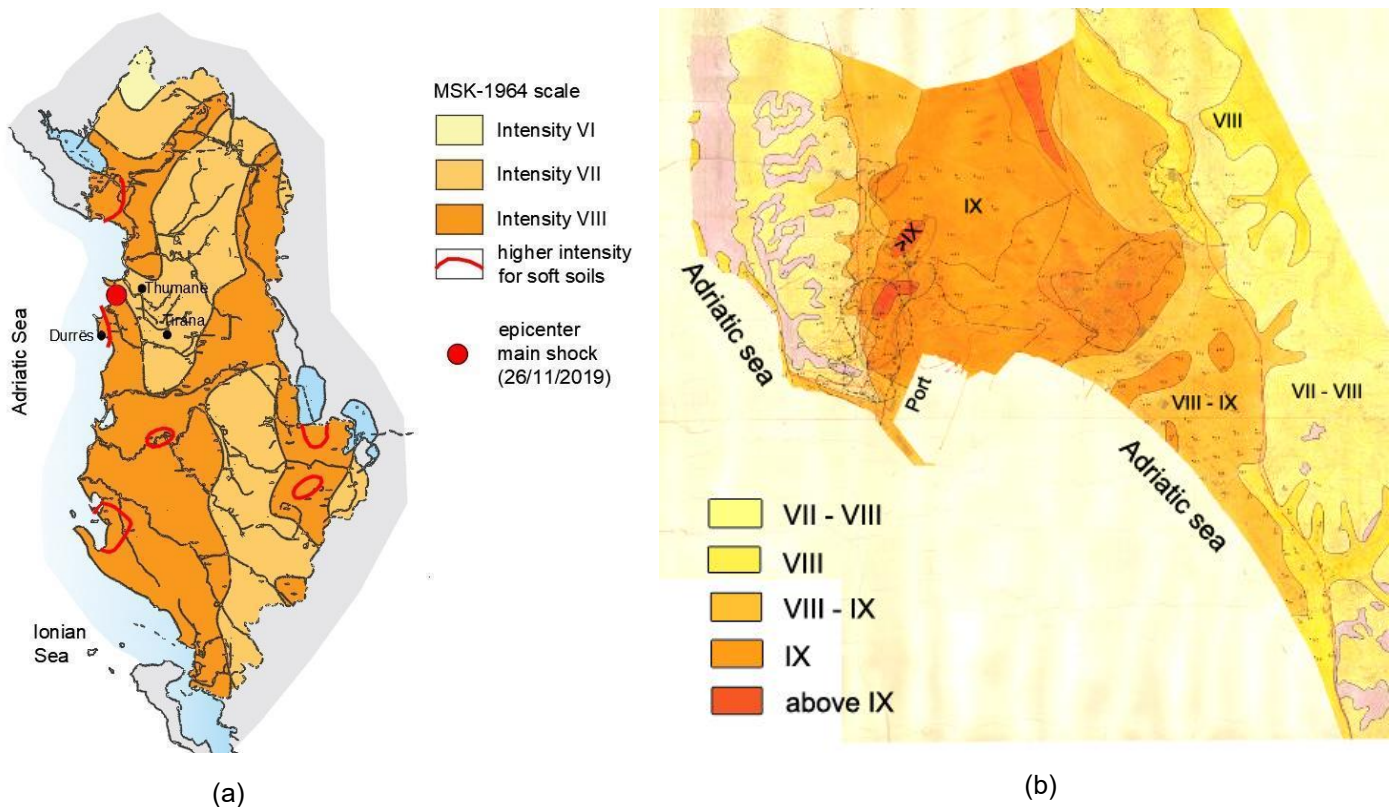


Figure 3. Seismic hazard maps: (a) a current seismic hazard map of Albania based on MSK-64 scale (source: Qendra Sizmologjike e Akademisë së Shkencave, 1979)⁶ and (b) a seismic microzonation map for Durrës (source: Koçiu et al., 1985).⁷

According to KTP-N.2-89, seismic microzonation maps (developed only for the largest cities) may overrule the seismic zonation map of Albania. According to these maps (see Figure 3(b) for Durrës), the seismic intensity is higher than IX in some areas of Durrës, whereas the maximum intensity VIII was assigned to certain areas of Tirana. For Durrës, the possibility for seismic shaking with an intensity of more than VIII was already acknowledged in the seismic hazard map of Albania (Figure 3(a)), which identifies Durrës as an area in which the prescribed seismic intensity can be increased due to soft soil conditions.

Although the KTP-N.2-89 code provisions are considered to be advanced for the time and there was a reasonable understanding of seismic hazard in the Durrës region, the code has several limitations (e.g., a lack of explicit treatment of damage limitation and serviceability criteria, as well as incomplete detailing provisions required to ensure ductile seismic behavior). On the other hand, major political and economic changes that occurred in Albania in the 1990s ultimately affected the construction industry and code enforcement. During that period, Albania reopened to the world, and technical expertise from neighboring countries started to influence the construction practice. The transition period after the fall of communism was characterized by informal construction due to limited code enforcement (Chryssy and Augustinius, 2010)⁸ associated with a lack of proper documentation and limited quality control of the design and construction. The level of enforcement of the KTP-N.2-89 code in the 1990s is unknown.

To meet the demand for the design and construction of modern structures, starting from the 1990s, structural designers resorted to the use of seismic design codes from other countries with an increasing use of Eurocodes after their publication in the 2000s. In 2011, Eurocodes (parts 0-3) were adopted as a national standard (Luka, 2018), whereas other parts were adopted in the following years. The status of “national standard” (SSH-ENs in Figure 1) allows for the application of the Eurocodes on a voluntary basis (or in agreement with the investor), but KTP-N.2-89 has remained the main seismic design code enforced by law as a minimum for all new structures. An eventual withdrawal of the KTP-N.2-89 code and a full adoption of Eurocodes is expected in the near future.

1.2 Construction Practice and Building Typologies

As mentioned in the previous section, until the end of World War II, the majority of the population of Albania lived in rural areas; hence, the building stock consisted mostly of low-rise buildings (usually one or two stories high). Masonry was the prevalent construction technology at the time, and construction was performed using low-strength burnt clay bricks and adobe (sun-dried mud) bricks or blocks. The communist period (1945-1990) was characterized by increased construction activity. The construction was funded and executed by the government agencies. In many cases, schools, hospitals, and residential buildings were constructed based on standardized designs (Fischer et al., 2019).⁹ The majority of urban buildings constructed during that period were low- to mid-rise apartment buildings (usually three to five stories high). Masonry remained the most prevalent construction technology during the communist period; however, the use of reinforced concrete technology started in the 1960s and was mostly in the form of mid-rise prefabricated large panel buildings (four to six stories high). Prefabricated elements were manufactured in government-owned plants and transported to construction sites. The quality of construction materials varied depending on economic constraints; in some cases, masonry units of substandard quality were used. Construction was usually performed by skilled artisans, but in some cases, other citizens were engaged as unskilled volunteers; as a result, the quality of construction was substandard in some instances.

After the end of the communist period in Albania, there was a transition to a democratic governance (starting from 1991). Building design and construction practice were no longer centralized. Designs were developed by private companies, and there were changes in the construction technology. Monolithic (cast-in-place) reinforced concrete construction emerged as the predominant construction practice for all types of buildings (low- and mid-rise), whereas prefabricated large panel construction and load-bearing masonry construction were gradually phased out. Most buildings were constructed using reinforced concrete frames and slab structural systems with a masonry exterior and interior partition walls. Masonry units were clay blocks. Buildings constructed during this period were of variable quality due to limited quality assurance at all levels (design, construction materials, and construction execution). During that period, informal construction practices were followed both in urban and rural areas. Vertical building extensions were observed in several instances (see Figure 4(a)), and in some cases, these buildings experienced significant damage during the recent earthquake. Horizontal extensions were also very common (see Figure 4(b)). Occasionally, horizontal extensions had structural systems that differed from the main buildings with different dynamic properties and seismic behavior (for example, a new reinforced concrete extension of an existing masonry building) and were often without appropriate construction joints. Widespread damage was present in buildings with horizontal extensions, ranging from severe structural damage to the cracking of mortar in the façade. Quality assurance related to the building design and construction process in Albania was gradually raised to a higher level in recent years.



(a)



(b)

Figure 4. Building extensions: (a) a vertical extension of a five-story unreinforced masonry building (top floor level) and (b) a horizontal extension of an unreinforced masonry building with a confined masonry addition (photos: Svetlana Brzev).

An overview of the Albanian building stock based on the census of 2011 shows that only a small fraction of existing buildings (about 7%) were constructed before 1960. A significant fraction of the building stock (24%) was constructed in the period from 1960 to 1990, but a majority of the buildings (more than 40%) were constructed after 1990 (see Figure 5(a)). In spite of the construction boom in the post-1990 period and the widespread construction of multi-story buildings, most buildings in Albania (on the order of 95%) are one or two stories high (see Figure 5(b)). Although the ratio of multi-story buildings is very low (5% of the total building stock), it is estimated that 2/3 of the population affected by the earthquake in November 2019 occupied multi-story apartment buildings; this can be explained by the fact that the earthquake-affected larger urban settlements, like Tirana and Durrës (the first and second largest cities in Albania, respectively), and smaller towns, like Krujë and Fushë-Krujë.

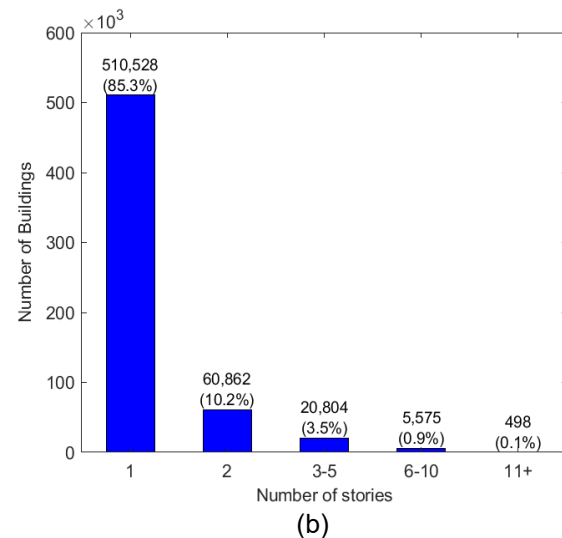
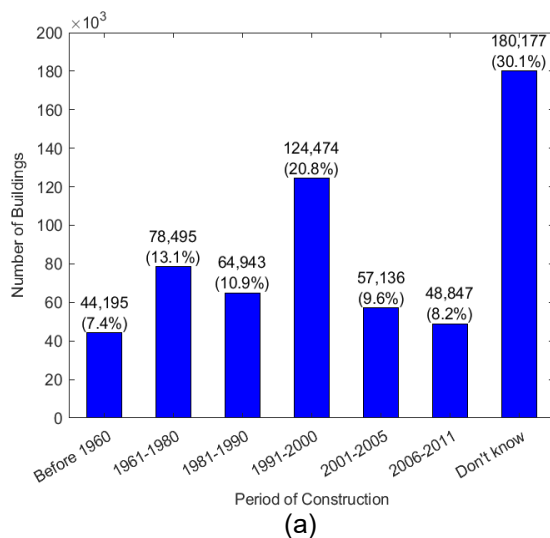


Figure 5. Albanian buildings: (a) a historic breakdown and (b) the number of stories (INSTAT, 2011).¹⁰

In terms of the construction materials, masonry has been the most prevalent construction technology. In 2011, more than 80% of all existing buildings in Albania were of masonry construction, which is in line with the fact that almost the entire building stock (85% of all buildings) comprises one-story buildings.

A summary of prevalent building typologies is presented in Table 1. A brief description of each common building typology is presented next. Masonry typologies will be presented first, followed by the reinforced concrete building typologies.

Table 1. Prevalent building typologies in Albania (1960-present).

Building height	Period	
	1960-1990	Post-1990
Low-rise	Unreinforced masonry Confined masonry	Reinforced concrete frame with masonry infills
Mid-rise	Unreinforced masonry Confined masonry Hybrid (confined masonry and reinforced concrete frame) Prefabricated large panel reinforced concrete buildings	Reinforced concrete frame with masonry infills
High-rise	Very rare. One example: Hotel Tirana International (15-story building with reinforced concrete walls and columns)	Reinforced concrete frame with masonry infills

Low-rise masonry buildings are mostly used for single-family housing both in rural and urban areas (see Figure 6). Before the 1990s, unreinforced masonry walls were usually built using solid clay bricks and, in some cases, clay blocks. Pre-1990 single-story masonry buildings typically have a lightweight ceiling and a roof. Older two- to three-story buildings have timber floors, whereas buildings of a more recent construction have monolithic (cast-in-place) reinforced concrete solid slabs, composite concrete and masonry floors, prefabricated hollow core slabs, or semi-prefabricated slabs with joists. Due to the climatic conditions, the majority of low-rise buildings have sloped roofs covered by clay tiles.



(a)



(b)

Figure 6. Low-rise masonry buildings: (a) unreinforced masonry buildings in a row in an urban area (Tirana) and (b) a rural, unreinforced masonry building (photos: Svetlana Brzev).

Following the reported good performance of confined masonry in the Montenegro earthquake in 1979, field applications of this technology started in Albania (note that Albania was also affected by the earthquake). The key features of confined masonry buildings are vertical reinforced concrete confining elements (tie-columns) at the building corners and wall intersections, but these elements were usually not provided at the openings. Horizontal reinforced concrete tie beams were also provided at the floor levels (integrated into reinforced concrete floor slabs). During that period, clay blocks were sometimes used for the wall construction. After the end of the communist period, reinforced concrete frame construction with masonry infills became the prevalent technology even for low-rise single-family housing construction.

Masonry was widely used for the construction of apartment buildings from 1960 to 1990 (see Figure 7). Unreinforced masonry walls (usually solid clay bricks) were used for buildings up to three or four stories high, whereas taller buildings (five stories high) had confined masonry walls with horizontal and vertical reinforced concrete confining elements, especially after the Montenegro earthquake and the amendment of the code published in 1982 (see section 2.1). Wall thickness was variable up the building height: A larger thickness (38 cm) was typically used for the lower two floors, and a reduced thickness (25 cm) was used for the upper floors. These buildings have either cast-in-place reinforced concrete

floor slabs or prefabricated hollow-core reinforced concrete slabs and sloped roofs (timber frame structure with clay tiles, usually in the older buildings) or flat reinforced concrete roofs.



(a)



(b)

Figure 7. *Masonry apartment buildings: (a) a 4-story unreinforced masonry building (solid clay bricks) with reinforced concrete floors in Durrës and (b) a five-story unreinforced masonry building (calcium silicate bricks) in Tirana (photos: Svetlana Brzev).*

Some buildings with multiple functions (e.g., a ground-floor parking garage or a store and upper floors residential) have a hybrid structural system with the features of both a reinforced concrete frame and confined masonry typologies. These buildings have reinforced concrete moment-resisting frames at the ground floor level to enable large open spaces and confined masonry walls at upper floors. This system was permitted by the 1989 Albanian seismic code KTP-N.2-89 with some restrictions regarding the area occupied by reinforced concrete frames, and it was practiced in Albania for a few years. Subsequently, multi-story buildings were constructed almost exclusively with reinforced concrete frame systems. Figure 8(a) shows a street in the Shkëmbi i Kavajës area near Durrës, Albania. The majority of buildings in this area had commercial use on the ground floor and residential use on the upper floors. An interior reinforced concrete column on the ground floor level can be seen in Figure 8(b).



(a)



(b)

Figure 8. *Buildings with a commercial ground floor: (a) an exterior view showing stores on the ground floor level and (b) an interior view of a building on the ground floor level showing a reinforced concrete column (photos: Google Maps).*

The reinforced concrete building construction practice in Albania started to gain popularity in the 1960s. There are two prevalent building typologies for multi-story reinforced concrete buildings: prefabricated large panel buildings in the period from 1960 to 1990 and cast-in-situ frame buildings with masonry infills after 1990. The construction of low-rise reinforced concrete buildings started after 1990. Like in eastern European countries with socialist or communist governments at that time, prefabricated construction in Albania was used to meet increased demands for urban housing. These are mid-rise buildings (five or six stories high) and are known as large panel buildings because the key structural components are wall and slab reinforced concrete panels joined by means of welded connections. The technology for prefabrication used in Albania was originally developed in China. Buildings of this type can be found in cities like Tirana and Durrës, and in many cases, they are in dilapidated condition due to inadequate maintenance and a lack of plaster or other façade overlay. Figure 9(a) shows a typical five-story large panel building (front) and an adjacent post-1990 reinforced concrete frame building in Durrës, whereas Figure 9(b) shows a large panel building in Vorë (close to Tirana) that has undergone a renovation.



Figure 9. Prefabricated large panel reinforced concrete buildings: (a) a typical five-story large panel building and an adjacent eight-story modern reinforced concrete building in Durrës and (b) a well-maintained large panel building in Vorë (photos: Svetlana Brzev and Markel Baballëku).

After the end of the communist period in 1991, cast-in-place reinforced concrete technology became prevalent for all types of buildings in Albania, ranging from low-rise single-family housing to high-rise buildings in urban areas. Most mid-rise buildings are 5 to 12 stories high. Many buildings of this type have an open ground floor for commercial use and residential use on upper floors. An example of a typical reinforced concrete building is shown in Figure 10(a). The main structural system is a reinforced concrete frame with masonry infills. A typical reinforced concrete frame consists of columns and wide, shallow beams, which are a part of a ribbed reinforced concrete slab with polystyrene or clay masonry infills (see Figure 10(b)). Because the beams have the same depth as floor slabs (typically from 250 to 300 mm), the structural system could be considered a column-slab system (as opposed to a moment-resisting frame). Reinforced concrete shear walls are usually provided in newer structures, but many buildings in the earthquake-affected area either did not have reinforced concrete shear walls at all or these walls were provided only at the elevator core. Buildings without walls that were designed to resist shear around the elevator are also common (see Figure 10(d) for an example). Masonry infills and partition walls are in the form of clay blocks with horizontally aligned holes (see Figure 10(c)) and are not isolated from the frame.



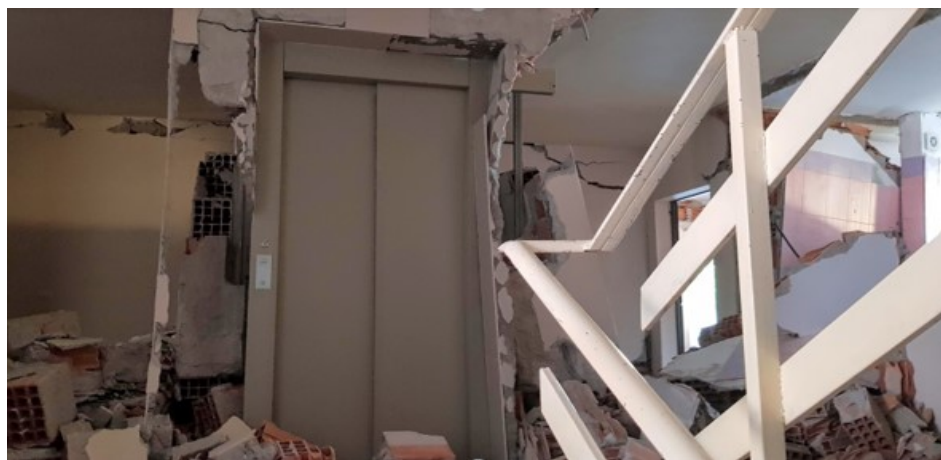
(a)



(b)



(c)



(d)

Figure 10. *Mid-rise reinforced concrete frame buildings with masonry infills: (a) a typical six-story building in Durrës, (b) a reinforced concrete floor structure consisting of wide beams within column grids and polystyrene infill, (c) a masonry construction practice using clay blocks with horizontally aligned holes (photos: Svetlana Brzev and Brisid Isufi), and (d) a building without a reinforced concrete shear wall core around the elevator (photo: Sextos et al., 2020).¹¹*

Cast-in-place reinforced concrete technology has been used for construction of low-rise buildings since 1990. These are usually smaller buildings (two to four stories high) and are used as single-family housings, restaurants, small hotels, etc. (see Figure 11(a)). In many cases, this is informal construction; that is, the buildings were designed without input from qualified engineers and architects and do not comply with the building code requirements. Reinforced concrete columns are usually of small size (300–400 mm section), and the beams are shallow (approximately 30 cm deep). Floor systems consist of composite masonry slabs with concrete topping (see Figure 11(c)), reinforced concrete joists with concrete topping, or solid reinforced concrete slabs. In most cases, the reinforced concrete frame is constructed first, followed by the masonry infills (see Figure 11(b)); however, in some cases, masonry walls are constructed at each floor level, and floor slab is constructed atop the walls. Roofs are either flat or sloped depending on the climatic conditions. It is common to have an open ground floor that is used as a garage.



(a)



(b)



(c)

Figure 11. Low-rise reinforced concrete frame buildings with masonry infills: (a) a completed building in Durrës. (b) a typical building under construction, and (c) a composite clay and concrete floor slab (photos: (a) Svetlana Brzev; (b) Charleson et al., 2020; (c) Lekkas, 2019).^{12,13}

2 RECONNAISSANCE TEAM OVERVIEW

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Roberto Gentile

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After the earthquake on November 26, 2019, teams from the United States, United Kingdom, Italy, and Greece participated in complementary reconnaissance activities in the field with the aim of collecting data related to the structural performance of different building typologies. An effort was made to use compatible and, wherever possible, identical tools and procedures for Rapid Visual Inspection. The data collection approach and selected results for the two teams (Earthquake Engineering Field Investigation Team (EEFIT) and Hellenic Association for Earthquake Engineering (HAEE)/University of Bristol) are summarized next. It should be noted that other teams that participated in development of this report have also collected building damage data; however, damage collection was not the primary focus of their activities and is not going to be discussed in this section.

2.1 Earthquake Engineering Field Investigation Team (EEFIT)

Shortly after the earthquake on November 26, 2019, the EEFIT management committee discussed the deployment of a field mission to observe the damage in Albania. The committee reached a consensus to deploy a team of five to six members for a four-day mission two to three weeks after the earthquake. Based on initial information from media and personal contacts, it was decided to limit the scope to the housing sector with the following objectives: i) to carry out observations on the characteristic damage patterns in the main structural typologies in the Albanian residential building stock and ii) to review the evolution of the Albanian seismic code and construction practice and assess possible links between the observed damage patterns with code and construction practice deficiencies.

EEFIT missions over time have demonstrated the singularity of each post-disaster scenario and the need for an ad hoc planning of each mission. The damage assessment of the structures affected by the earthquake in November 2019 was

undertaken by collecting the information provided in Table 2, which was tailored towards the specific needs of the mission, and included target building typologies, building locations, accessibility, and time availability. During the mission, the information was collected on mobile phones and stored directly in a Microsoft Excel document that was subsequently uploaded on a server at the end of each day. Moreover, the team decided to use two different damage assessment applications under the development at the time of the mission and provided feedback to the developers. The damage assessment applications were provided by EEFIT and the University of Bristol.

Table 2. Collected information by the EEFIT application.

Collected information	
Building identifier	Age of Construction
Person recording	Structural System
Hour of inspection	Façade
Date	Extension
Location	Date of Extension
Latitude	Typology of Roof
Longitude	Typology of Floor
Occupancy	EMS 98 damage grade
Access	Structural performance level (ASCE 41 scale)
Current occupation status	Failure mechanism
Number of floors	Comments
Basement	

The European Macroseismic Scale (EMS-98) (ESC, 1998) was adopted to estimate the damage state of the Albanian buildings. Five damage states (DS1 to DS5) are available for masonry and reinforced concrete buildings, in addition to the no damage state (DS0). In addition, the ASCE 41 scale (ASCE 41-17, 2017)¹⁴ was adopted, which is widely used in the engineering community to define the performance acceptance criteria for the seismic design and evaluation of buildings. There are five different performance levels in the scale (S-1 to S-5); however, the EEFIT team considered the following damage states: S-1, Immediate Occupancy; S-3, Life Safety; S-5, Collapse Prevention; and greater than S-5, Collapse. Discrete and well-separated performance levels facilitated the field data collection.

The team inspected 70 structures during the mission. Out of those, 26% of the buildings were accessed (exterior plus some spaces in the interior), whereas the remaining buildings were inspected from the outside only. Apart from the most affected urban areas, such as Durrës and Durrës Beach, the team also visited several other affected towns and villages, such as Bubq, Prezë, Laç, Lezhë, Krujë, and Thumanë.

Multiple building typologies were identified, but the majority were reinforced concrete frames (without a concrete core or with a small core) and load-bearing masonry buildings, which constitute approximately 65% and 30% of the inspected building portfolio, respectively. Other identified building typologies include prefabricated reinforced concrete large panel buildings and confined masonry buildings. A majority (70%) of the inspected buildings were residential buildings while a limited number of public buildings were also visited, such as schools, hospitals, and fire stations. The team also surveyed some cultural heritage sites, including several towers, religious buildings, and fortification walls. One bridge was also inspected as the only infrastructure assessed.

Further details about the EEFIT mission and observations made can be found in EEFIT (2020)¹⁵ and Freddi et al. (2021).¹⁶

2.2 Hellenic Association for Earthquake Engineering (HAEE) and the University of Bristol (UoB)

Two weeks after the earthquake on November 26, 2019, the HAEE in collaboration with the Earthquake Planning and Protection Organization of Greece (EPPO) organized a field mission to perform Rapid Visual Inspection in Albania. The team consisted of 14 experienced civil engineers, academics, and researchers. It included representatives from the University of Bristol and the Italian University Network for Earthquake Engineering (ReLUIIS, also known as Rete dei Laboratori Universitari di Ingegneria Sismica in Italian). The team was deployed for a two-day mission to perform structural and geotechnical damage inspections in Durrës and Thumanë. The scope of the mission was to evaluate the damage patterns and seismic performance of structures and, potentially, to transfer knowledge regarding the current code provisions for the design and retrofit of earthquake-resistant structures.

2.2.1 Post-quake Rapid Visual Inspection (RVI) Tool

Many methodologies are available worldwide for either pre- or post-earthquake Rapid Visual Screening (RVS) of buildings (e.g., ASCE 41-17, 2017; FEMA, 2000; FEMA, 2015).^{17,18} The New Zealand National Society for Earthquake Engineering, the Japan Building Disaster Prevention Association (Japan Building Disaster Prevention Association, 1990),¹⁹ and the Italian Group for the Defense against Earthquakes (GNDT, 1993)²⁰ also developed widely applied methodologies for RVS. Most RVS procedures require data collection based on exterior and interior visual observations of the buildings. Data typically include building identification information (i.e., usage, area, number of stories, etc.), photos, sketches, and documentation of pertinent data related to seismic performance.

2.2.2 RVI in Durrës and Thumanë

The HAEE/UoB/EPPO/RELUIIS team organized daily field missions at the city of Durrës (December 14) and the village of Thumanë (December 15). The RVI was performed for selected buildings using the Post-Quake RVI (SAFER) application (Figure 12, Table 3). The buildings were mainly inspected from the exterior and, in some cases, from the interior as well. Statistics of damaged buildings in Durrës and Thumanë are presented, along with damage classifications and preliminary conclusions based on field observations. It should be noted that the focus was on severely damaged buildings. As a result, the statistical distribution and conclusions reflect the particular building sample only and should not be extrapolated to the entire portfolio of the visited towns.



Post-Quake RVI (SAFER)

University of Bristol Εργαλείο

3 PEGI 3

⚠ Δεν έχετε καμία συσκευή.

➕ Προσθήκη στη λίστα επιθυμιών

Εγκατάσταση

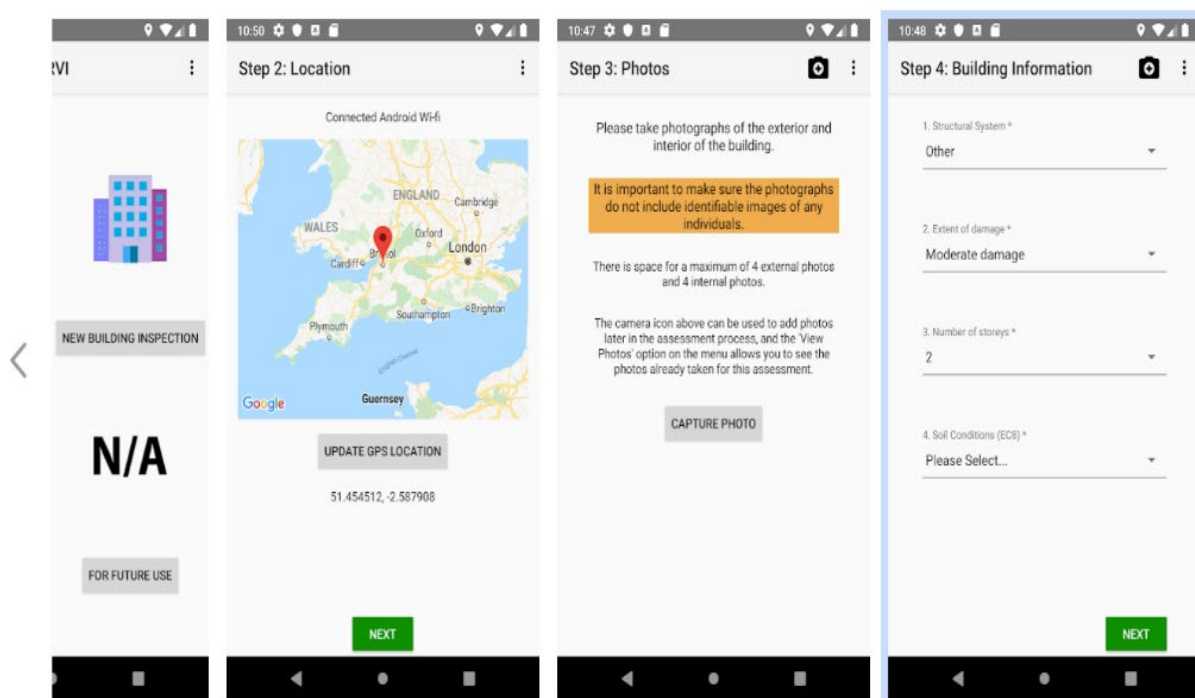


Figure 12. Post-Quake RVI (SAFER) application - University of Bristol (source: <https://play.google.com/store/apps/details?id=uk.ac.bristol.rit.safer2&hl=en>).

Table 3. List of collected data using Post-Quake RVI (SAFER).

Location	GPS latitude/longitude, country
Building Information	Structural system, extent of damage, number of stories, soil conditions, regularity in plan and elevation
Type of Damage	Settlement, in-plane infill panel cracking, out-of-plane infill panel cracking, beam flexure failure, beam flexure shear, column flexure failure, column flexure shear, shear wall failure flexure, shear wall failure shear, short column failure, joint failure, soft story, pounding
Other Information	Notes, date/time, username

The damage extent was classified as slight, moderate, major, and collapse based on FEMA 154 (2015), which roughly correspond to the four Structural Performance Levels identified by ASCE 41-17 (and used by the EEFIT team). This common assumption facilitated the migration of the data collected by both teams (EEFIT and HAEE), particularly given that both teams used the same application (Post-Quake RVI (SAFER)). Finally, because a number of parameters, such as the structural system and materials used, construction age, building height (number of stories), existence of irregularities in plan and elevation, construction stages, soil type, and more, strongly affect the structural performance, they are also commented on and related to the observed structural damage.

2.2.3 Post-quake RVI aggregated data and statistics

The field-collected data for both teams was combined and resulted in inspection surveys for 75 buildings that were mainly in Durrës and Thumanë. Figure 13 shows the locations and damage states for the inspected buildings in Durrës.

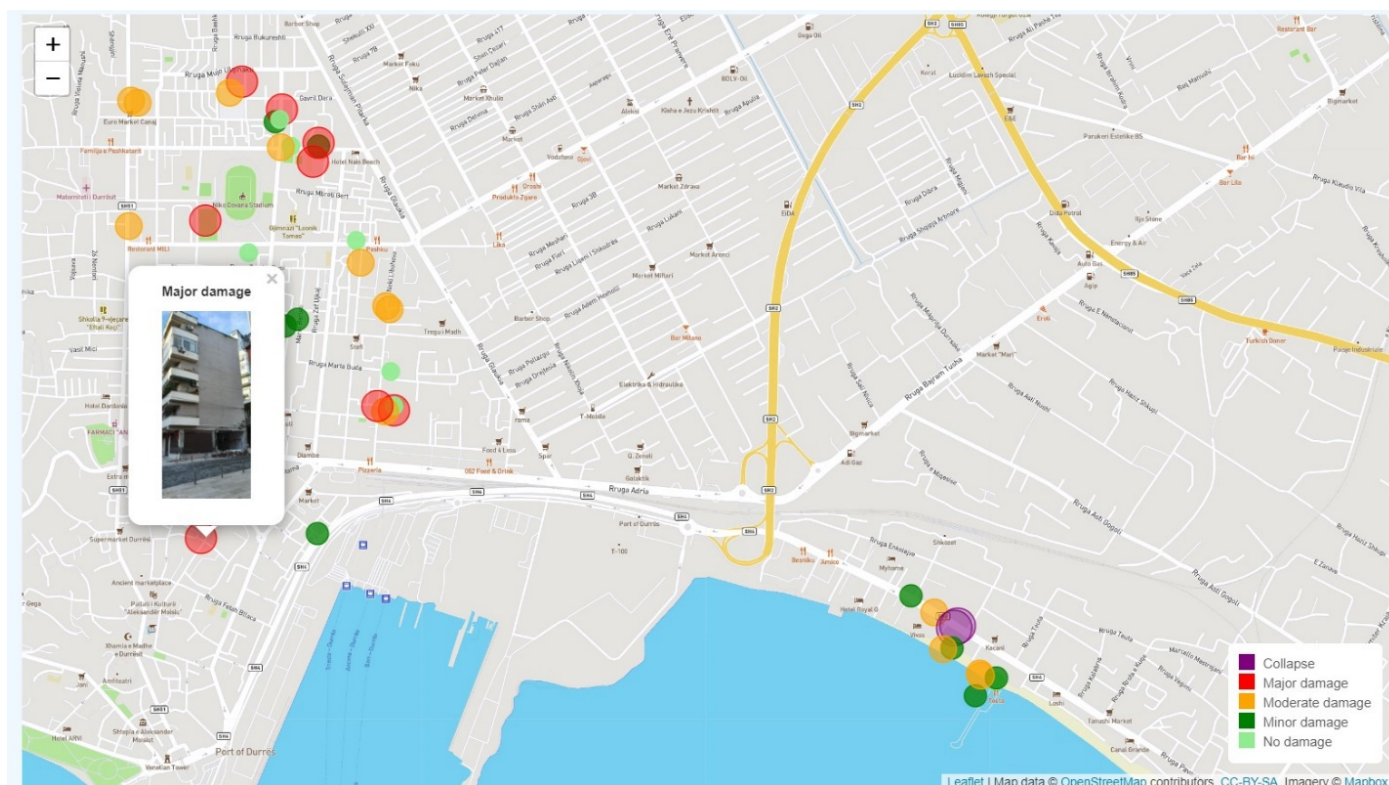
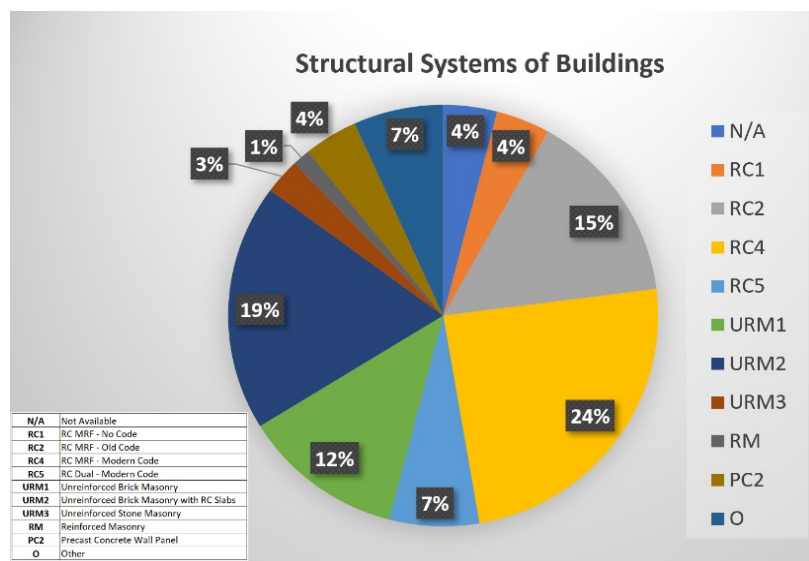


Figure 13. Map showing location and damage state of inspected buildings in Durrës (source: HAEE and EEFIT migrated data).

Structural systems were categorized in a similar way as prescribed in FEMA 154 (2015). The majority of inspected buildings were reinforced concrete buildings, and the most common structural systems were reinforced concrete moment-resisting frames designed to modern codes (RC4, 24%) and unreinforced masonry with reinforced concrete slabs (URM2, 19%). For buildings with less than five stories (low- to mid-rise buildings), the most common structural types were unreinforced brick masonry (URM1) buildings (29%) and URM2 buildings (23%), whereas, for buildings with more than (or equal to) five stories (mid- to high-rise buildings), the most common structural types were RC4 (38%) and reinforced concrete buildings designed to old codes (RC2, 19%) (see Figure 14).



Number of Stories < 5

Number of Stories ≥ 5

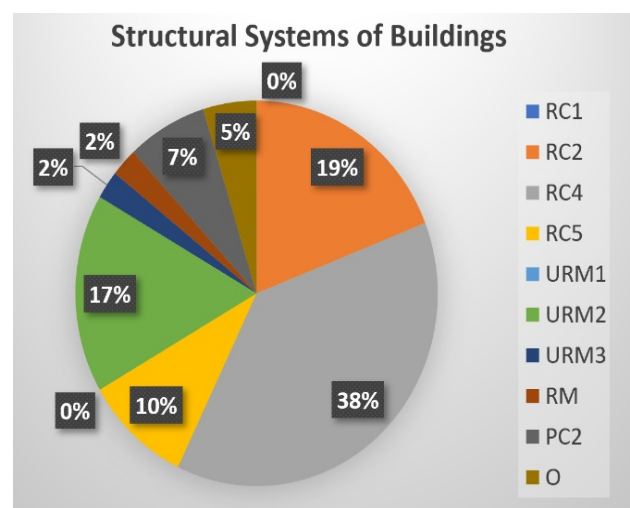
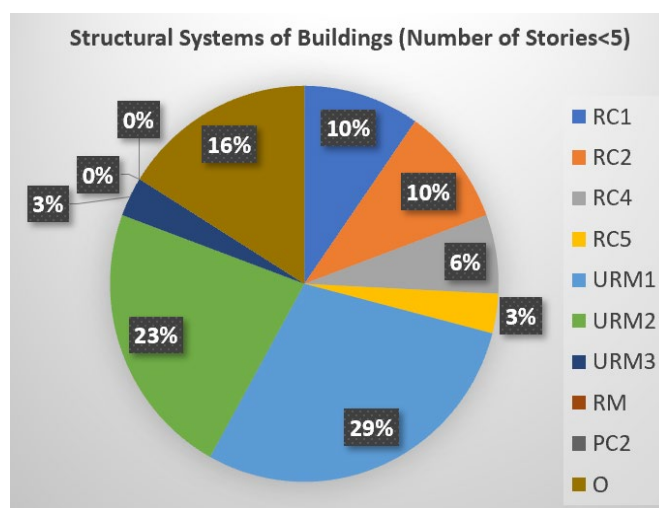


Figure 14. Structural systems for all inspected buildings based on the HAEE & EEFIT migrated data (source: Sextos et al., 2020).

The damage level related to the structural system is depicted in Figure 15. It should be noted that moderate to major damage was observed in the majority of inspected RC4 buildings and URM2 buildings, whereas major damage or collapse was more frequent in RC2s and URM1s. In terms of the damage level as related to the building height, it is obvious that the damage extent in low- to mid-rise buildings (number of stories <5) is higher for unreinforced masonry (URM) buildings; the majority of inspected URM1 and URM2 buildings experienced major damage or collapse. Furthermore, for the case of low- to mid-rise buildings, the majority of collapsed buildings were URM1 buildings and RC2 buildings, whereas RC4 buildings were less damaged. Out of all inspected mid- to high-rise buildings (number of stories ≥5), the majority of RC4 buildings exhibited only minor to moderate damage, whereas the majority of RC2 and URM2 buildings experienced moderate to major damage. It can be seen from Figure 15, Figure 16, and Figure 17 that the damage extent is higher for low-rise buildings (number of stories <5). This is in line with the acceleration response spectra corresponding to the recorded ground motion at Tirana (TIR) and Durrës (DURR) stations, which showed that the spectral accelerations are highest in the period range from 0.2 to 0.5 sec, corresponding to low- to mid-rise buildings (refer to Volumes 1 and 2 of this report).

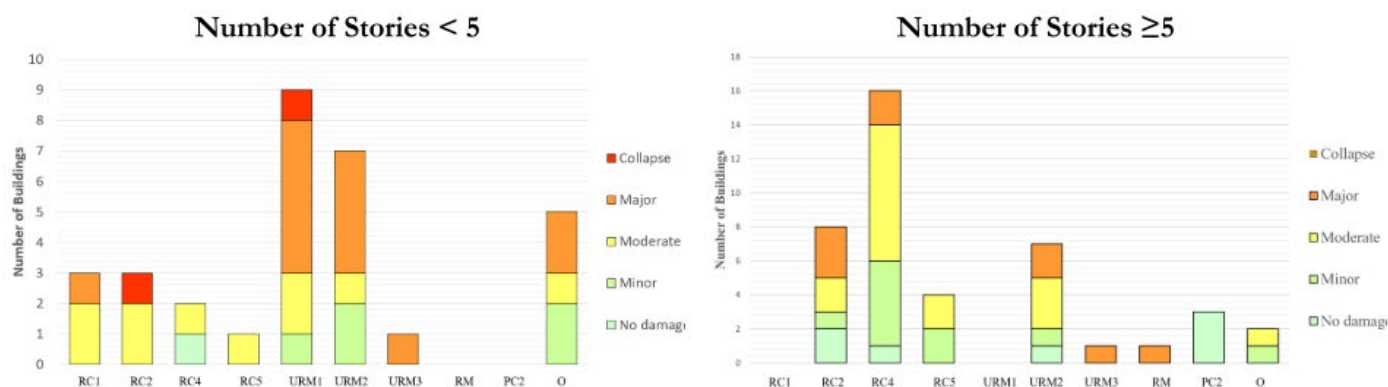


Figure 15. Structural systems of inspected buildings and the damage level (source: Sextos et al., 2020; HAEE and EEFIT migrated data).

Finally, it should be noted that the damage statistics for buildings in Tirana have been presented elsewhere (World Bank GPURL D-RAS Team, 2019)²¹ and the qualitative results are in good agreement because the majority of buildings with severe damage (red-labeled) were low-rise buildings designed to old codes.

The type of damage as related to the structural system is depicted in Figure 16. It can be noticed that the most frequent damage type for low- to mid-rise load-bearing URM buildings and mid- to high-rise reinforced concrete frame buildings is in-plane and out-of-plane wall failure (which is related to failure of masonry infills). Furthermore, beam and column damage (flexural and shear) is more frequent for buildings designed to old codes (RC2). Figure 17 shows the damage type as related to the building height. It is observed that both low- to mid-rise and mid- to high-rise reinforced concrete buildings developed in- and out-of-plane failures of infill panels, whereas in-plane failure was more frequent in low-rise buildings. Flexural failure of reinforced concrete columns is more common in mid- to high-rise buildings, whereas shear and short column failure were more frequent in low- to mid-rise buildings, as expected.

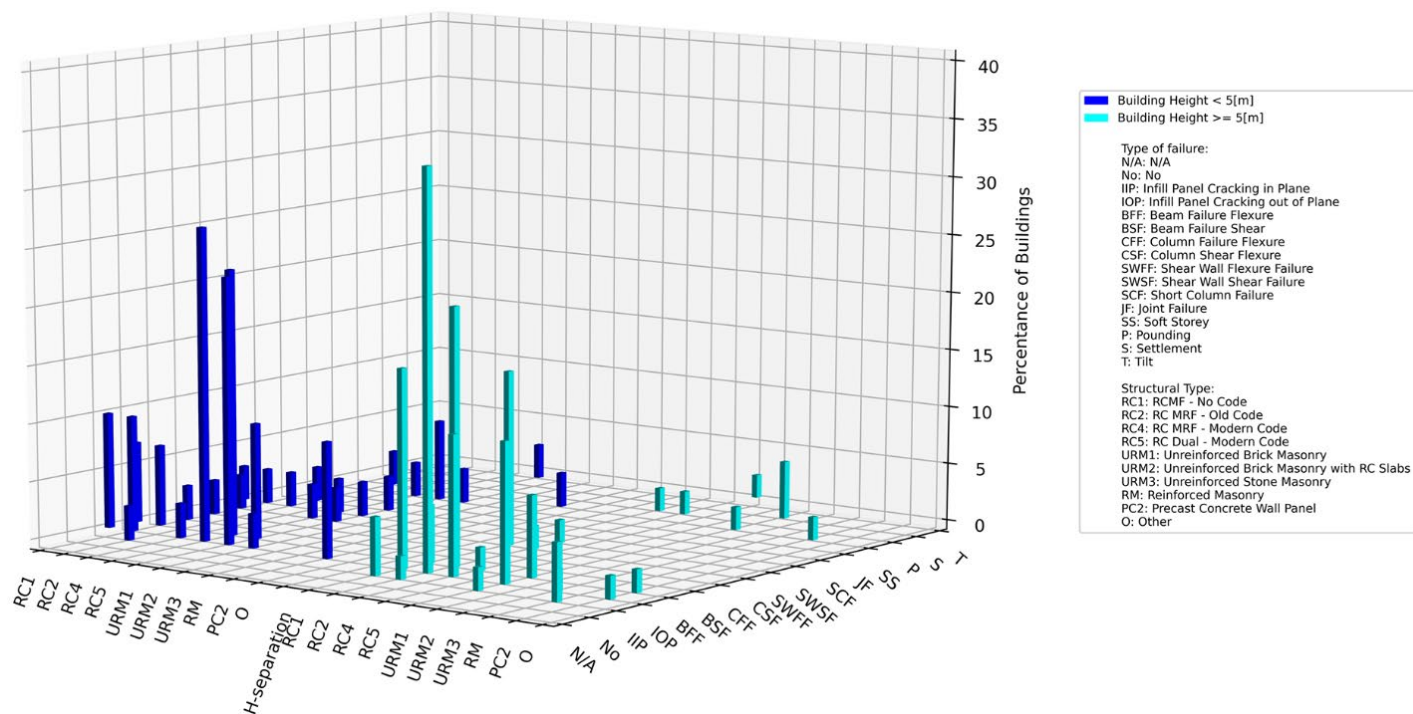


Figure 16. Structural systems of inspected buildings and the type of damage (source: Sextos et al., 2020; HAEE and EEFIT migrated data).

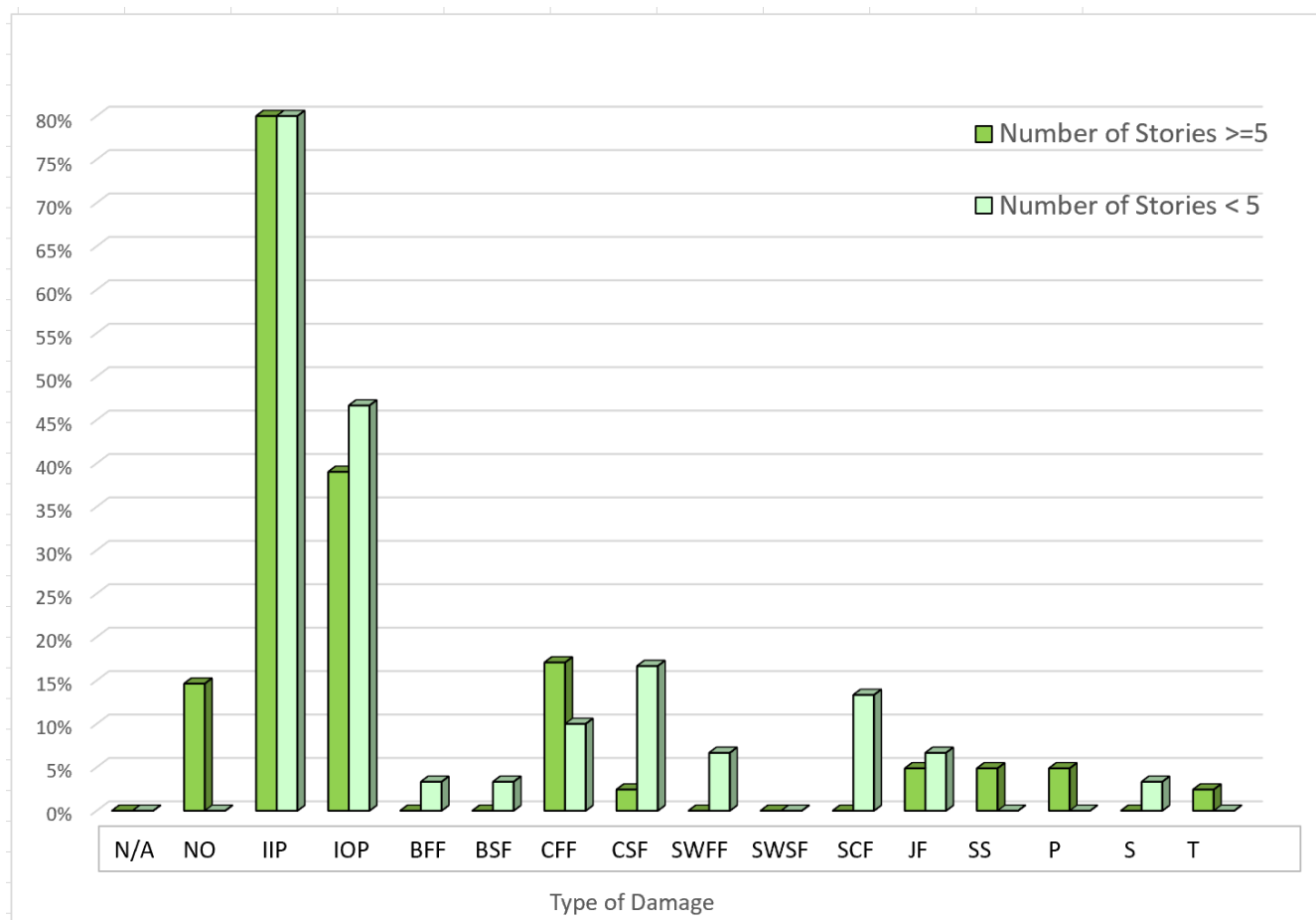


Figure 17. Building height and the type of damage (source: Sextos et al., 2020; HAEE and EEFIT migrated data).

3 PERFORMANCE OF RESIDENTIAL MASONRY BUILDINGS

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3.1 Introduction

Masonry has been a traditional housing construction practice in Albania for centuries. A large majority of masonry buildings constructed before 1990 are of unreinforced masonry construction (URM), whereas confined masonry technology has also been practiced since the 1980s. Examples of Albanian masonry buildings of different vintages are presented in Figure 18 (Guri, 2016).²² A detailed discussion regarding the typologies of masonry buildings in Albania is presented in section 2.2.



Figure 18. Evolution of masonry construction in Albania: (a) a low-rise URM building of the 1944 to 1963 vintage, (b) a mid-rise brick masonry URM building of the 1964 to 1978 vintage, (c) a mid-rise confined masonry building with silicate bricks of the 1979 to 1990 vintage, and (d) a low-rise confined masonry building with clay blocks of post-1990 construction (photos: Merita Guri).

Different masonry materials were used for building construction in Albania depending on the economic constraints and the development of the masonry manufacturing technology. Older masonry buildings were constructed using sun-dried bricks or stone, whereas either fired clay or silicate bricks are used in more recent construction. Figure 19 shows different masonry units that have been used in Albania, including solid clay bricks, silicate bricks, clay blocks (known as hollow clay tiles in North America), and concrete blocks. It is important to note that, before 1990, mostly solid masonry units (clay and silicate bricks) had been used, whereas after 1990, clay and concrete blocks had been used.



(a)



(b)



(c)



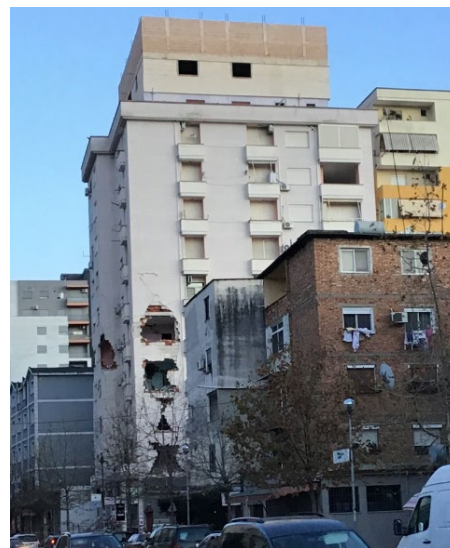
(d)

Figure 19. Types of masonry units used in Albania: (a) solid clay bricks, (b) clay blocks, (c) silicate bricks, and (d) hollow concrete blocks (photos: SUZI-SAE).

In general, masonry buildings performed well during the earthquake in November 2019. For example, many reinforced concrete buildings experienced damage or collapse, but the majority of mid-rise URM buildings from the 1960 to 1990 period remained undamaged. Many existing mid-rise URM buildings in Albanian centers were exposed to the November 2019 earthquake (Figure 20(a)). Figure 20(b) shows a high-rise reinforced concrete building with damaged masonry infills in Durrës and adjacent undamaged URM buildings. The good performance of mid-rise URM buildings can be explained by standardized building designs (templates) and regular plans and elevations. Because the construction was controlled by the government, there was a high-quality control of construction materials (e.g., use of solid clay bricks and cement mortar) and technical solutions (e.g., rigid reinforced concrete floors, good connections between structural elements, good interlocking between the walls).



(a)



(b)

Figure 20. URM apartment buildings: (a) a typical street in the center of Durrës showing URM apartment buildings from the 1960-1990 vintage and (b) an undamaged URM apartment building (front) and modern reinforced concrete frame building with damaged masonry infill (back) in Durrës (photos: SUZI-SAE).

3.2 Low-Rise Single-Family Buildings

The majority of low-rise single-family buildings with URM walls either remained undamaged or experienced minor damage in the epicentral area of the earthquake; however, a few buildings experienced severe damage or collapse. Poor seismic performance of these buildings was mostly due to inadequate design and construction performed by local artisans without input by qualified technicians (non-engineered construction). In most cases, these buildings are two stories high but were originally constructed as single-story buildings. Walls on the ground floor level were constructed with stone masonry, or using solid clay bricks, with a timber or reinforced concrete floor. The second floor was often constructed later (as a part of an extension) using different masonry units (e.g., clay or concrete blocks) and different floor systems (composite concrete and masonry floor) compared to the original building. The poor performance of these buildings can be attributed to the construction practice adopted in the building extensions as well as structural irregularities in plans and/or elevations. This section presents examples of damaged low-rise masonry buildings that illustrate typical damage patterns observed in the November 2019 earthquake. Most examples are related to URM buildings, but an example of a damaged confined masonry building is also included.

3.2.1 Unreinforced masonry buildings

Both SUZI-SAE and EEFIT teams surveyed several low-rise URM buildings in the Bubq village (Krujë municipality), in which many single-family houses experienced damage, but there were no casualties. According to the information gained from local engineers, some houses were initially damaged because of the September 2019 foreshock, but they experienced more severe damage or even collapse in the November 2019 earthquake. Figure 21 shows failure of a typical single-family brick masonry house in the Bubq village, with a portico at the ground floor level and an irregular L-shaped plan with a re-entrant corner. It should be noted that many single-family masonry buildings in the affected area had irregular plan shapes. It can be seen from the photo that the damage was concentrated at the ground floor level. The observed damage was triggered by torsion of the portico. Horizontal cracks were observed in the columns of the first floor (portico) (Figure 21(a)) at the top. Also, a transverse wall adjacent to the portico experienced severe out-of-plane damage and a separation from the floor slab (Figure 21(b)).



(a)



(b)

Figure 21. Single-family URM building in the Bubq village: (a) severe in-plane damage of the piers located on the ground floor and (b) out-of-plane failure of the rear wall (photos: EEFIT).

Figure 22 shows a front façade of another two-story building surveyed in Bubq village. This is an example of a building with both horizontal and vertical extensions. The original single-story building was constructed in stone masonry, whereas the extended portion (the second floor and a part of the ground floor) was constructed using solid clay bricks. The floor structure was a cast-in-situ reinforced concrete slab, and the roof was a timber truss with clay tile roofing. This building was located atop a small hill, and there was an adjacent, newer building of similar size, which was likely a reinforced concrete frame structure with masonry infills that remained undamaged (see Figure 22(a)). The damage in the masonry building was observed primarily at the top story level, in the form of diagonal cracks in the walls due to in-plane seismic effects (Figure 22(c)). The damage can be attributed to an irregular building elevation and a flexible roof structure. The absence of horizontal confining elements at the roof level was observed at the interior; a horizontal crack at the top of the wall indicates an inadequate roof-wall connection (Figure 22(d)). The roof covering (clay tiles) was noticeably displaced (Figure 22(c)).



(a)



(b)



(c)



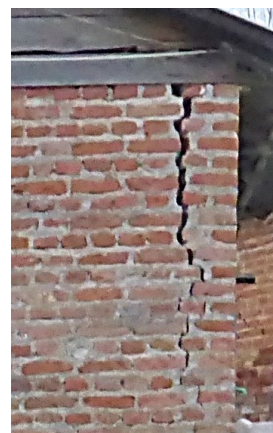
(d)

Figure 22. Damaged single-family URM house in the Bubq village: (a) the front façade of a damaged URM building (right) and an adjacent reinforced concrete frame building that remained undamaged (left), (b) a rear view of the house revealing building extensions, (c) a damaged exterior wall at the second floor (exterior view), and (d) an interior view of the same wall (photos: SUZI-SAE).

A two-story URM building with a timber roof in the Bubq village experienced severe damage in the form of vertical cracks at both ends of the gable wall (shown in Figure 23(a)), indicating the onset of an out-of-plane failure of the walls in the transverse direction. Note that the crack on the right end of the wall, which is extremely wide, extends over the entire floor height and indicates a risk of the transverse wall toppling outwards (Figure 23(b)). The observed damage can be attributed to the absence of horizontal confinement (ring beams) at the roof level, which could lead to the collapse of individual walls and roof and, ultimately, lead to a partial or complete collapse of the entire building.



(a)



(b)

Figure 23. URM building damaged due to out-of-plane failure mechanism in the Bubq village: (a) a view of the gable wall showing vertical cracks at both ends and (b) a detail of the vertical crack at the right end of the wall (photos: SUZI-SAE).

Four multi-family URM apartment buildings collapsed in Thumanë, and several single-family URM buildings were also damaged and surveyed during the visit. For example, a single-story URM building inspected by the HAEE team was severely damaged (Figure 24(a)). The building had 115 mm (one-wythe) thick brick masonry walls (Figure 24(b)) that experienced damage in the form of wide diagonal cracks (Figure 24(c)). The timber roof experienced a partial collapse, and clay tile roofing was dislocated (Figure 24(b) and 24(c)). Major damage of reinforced concrete slabs was observed in the form of cracking, permanent displacements, and corrosion of reinforcement.



(a)



(b)



(c)

Figure 24. Severely damaged single-story URM building in Thumanë: (a) Exterior view, (b) view of masonry brick wall, and (c) wide diagonal cracks in masonry brick wall (photos: HAEE).

Figure 25 shows another single-story URM building in Thumanë with hollow concrete block masonry walls and a reinforced concrete roof. The walls were severely damaged because of in-plane (red color in the picture) and out-of-plane seismic effects (blue color). The in-plane damage was in the form of stepped cracks along the mortar joints, which is typical for concrete block masonry walls. A horizontal crack at the wall-to-roof slab can be attributed to the sliding behavior. A vertical crack was also observed at the wall intersection, indicating a poor bond between the walls. Significant damage observed in this building can be attributed to high seismic demand, use of low-strength concrete blocks, and inadequate wall connections to the roof.



Figure 25. A single-story URM building with hollow concrete block masonry in Thumanë: in-plane damage (red outline) and out-of-plane damage (blue outline) (photos: SUZI-SAE).

The teams identified only one collapsed single-family masonry building, which was located in the Bubq village (Figure 26). This two-story URM building is a typical example of post-1990 masonry construction practice in Albania. The building was originally constructed in 1992 with the walls built using hollow concrete blocks bonded with cement mortar (Figure 26(b)) and a reinforced concrete slab (Figure 26(a)). In 1997, the second floor was constructed, as well as the portico (ground floor) and the veranda (second floor). A hollow core precast reinforced concrete floor slab at the second floor level supported a timber truss roof and clay tile roofing (Figure 26(a) and (c)). The EEFIT team observed that its floor structure lacked connections with the veranda of the second level (see Figure 26(a)). Also, the quality of concrete blocks was poor, and it contributed to the poor seismic performance of the damaged buildings.

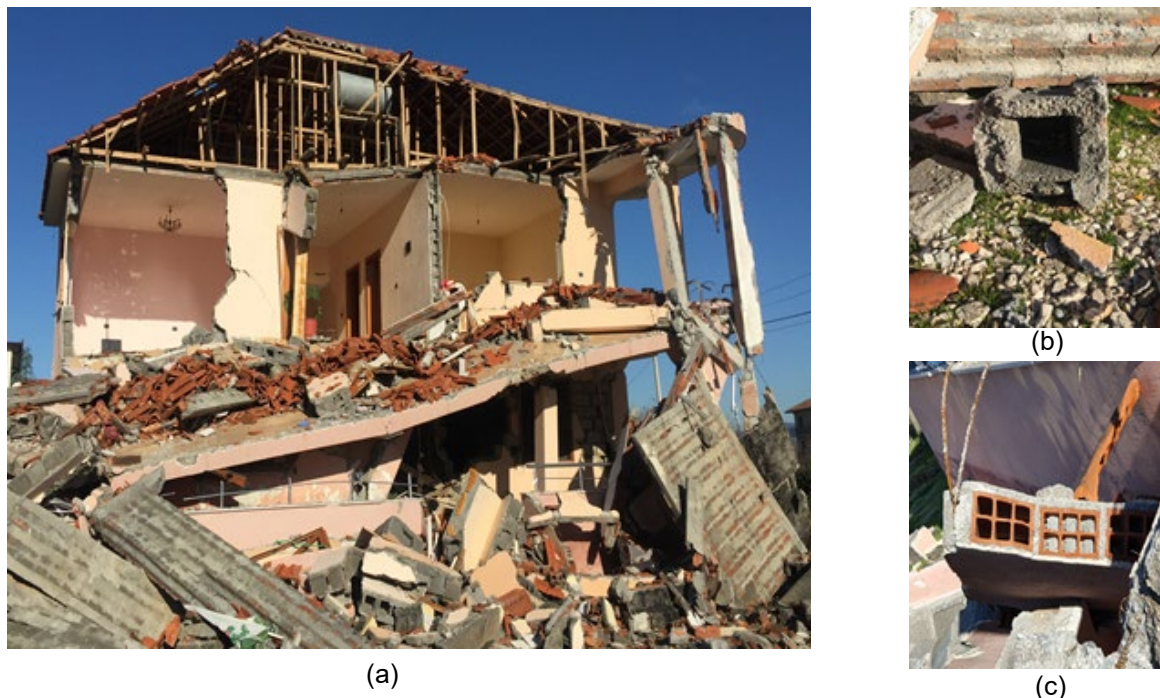


Figure 26. Single-family URM house in the Bubq village: (a) a collapse that occurred due to torsion of the portico on the ground floor, (b) URM walls with hollow concrete blocks, and (c) a cast-in-situ reinforced concrete slab at the ground floor level and reinforced concrete waffle slab with clay blocks at the second floor level (photos: EEFIT).

3.2.2 Confined masonry buildings

Very few examples of low-rise confined masonry buildings were observed in the epicentral area of the earthquake. A three-story confined masonry building in Thumanë with reinforced concrete slabs experienced severe damage (Figure 27(a)). The walls were 25 cm thick, which should be adequate for a building of this size, but masonry was of substandard quality. The walls were constructed using low-strength clay bricks (which appear to be partially fired or perhaps even unfired). The building had an irregular elevation, which also contributed to high seismic demand and the resulting damage. The damage was in the form of diagonal tension cracks in masonry walls and piers between the openings, both at the exterior (Figure 27(b) to (d)) and interior (Figure 27(g) to (h)) of the building. Damage due to the out-of-plane seismic effects was also observed (Figure 27(i)). Vertical reinforced concrete confining elements at the wall intersections also experienced damage, and it was observed that vertically aligned ladder-type wire reinforcement was used (instead of longitudinal and transverse reinforcing bars) (Figure 27(f)). The external staircase was detached from the building because of the earthquake, causing wide cracks and failure at the wall corners (Figure 27(d) and (e)). A partial collapse of the timber roof was also observed. Flexural cracks in reinforced concrete floor slabs were also observed. The concrete quality was poor; for example, rounded large-size aggregate was used for concrete construction, as observed during the reconnaissance.



Figure 27. Severely damaged three-story confined masonry building in Thumanë (photos: HAEE).

3.3 Mid-Rise Multi-Family Buildings

A large majority of mid-rise URM buildings were constructed in the period from 1960 to 1990. These were residential multi-family buildings constructed according to standardized designs that were approved by Albanian government agencies (Bilgin and Huta, 2018).²³ Two national codes were applied in the design of these buildings: KTP-9-78 (KTP 9-78, 1978)²⁴ for gravity loads and KTP-2-78 (KTP 2-78, 1978) for seismic loads. These buildings are still in use in Albania and account for a large fraction of the residential stock.

3.3.1 Unreinforced masonry buildings

Three- and five-story buildings are representative of this typology in terms of plan dimensions, wall layout, material types and properties, and structural features (Figure 28). It should be noted that some of these buildings had irregular (e.g., L-shaped) plans, as shown in Figure 28(a). It can be seen from a rectangular-shaped floor plan (Figure 28(a)) that

transverse walls are uniformly distributed at an approximate spacing of 3.6 m, whereas there are only two longitudinal walls (at the exterior). The typical floor height is 2.8 m, and the openings have regular layouts. The wall thickness is 38 cm on the bottom two stories and 25 cm on the remaining stories, whereas partition walls are 12 cm thick. Masonry walls are made of solid fired clay bricks with dimensions 250×125×60 mm or silicate bricks with dimensions 250×125×65 mm. Bricks are bonded using cement or silicate mortar. Two main floor systems have been used: cast-in-place reinforced concrete slabs and hollow core precast reinforced concrete slabs.

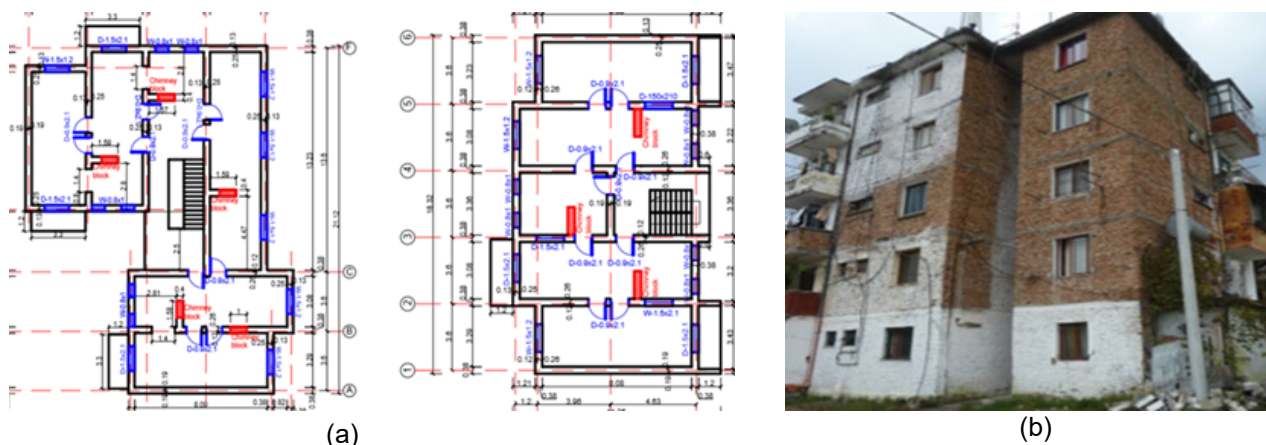


Figure 28. Mid-rise URM buildings: (a) standardized floor plans for five-story URM buildings (source: Bilgin and Korini, 2012)²⁵ and (b) a typical 5-story URM building in Thumanë, Albania (photo: EEFIT).

URM buildings with fired clay brick walls in cement mortar and cast-in-situ reinforced concrete slabs showed good seismic performance, which can be attributed to reinforced concrete cast-in-situ slabs that acted as diaphragms under seismic loads. Major deficiencies are related to irregularities in elevations due to unauthorized interventions (e.g., vertical extensions, closure, and creation of new openings). It was observed that different masonry units were used for renovations (see Figure 29) that were carried out by local residents. These interventions, compounded by a lack of maintenance and deteriorated construction materials, may contribute to damage and/or collapse of these buildings in future earthquakes.



Figure 29. Irregular elevations created by unauthorized interventions on URM buildings in Durrës (photos: EEFIT).

Figure 30 shows a five-story URM building in Fushë-Krujë that was damaged in the November 2019 earthquake. The damage pattern was in the form of diagonal cracks that developed because of in-plane seismic effects. These cracks were observed at the lower three floors, which were subjected to the highest seismic demand. This is an example of moderate damage that did not have a major impact on overall seismic safety. Additional damage patterns in mid-rise URM buildings are shown in Figure 31.



Figure 30. Moderate damage of a five-story URM building in Fushë-Krujë (photos: SUZI-SAE).

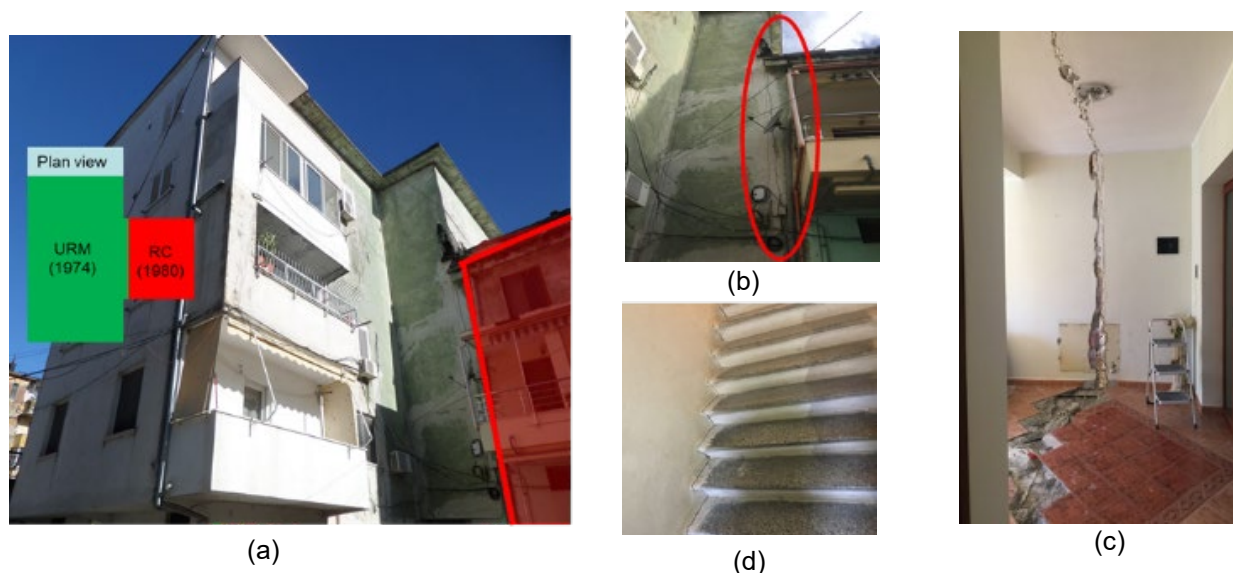


Figure 31. Damage patterns in mid-rise URM buildings: (a) five-story communist-era URM buildings made of silicate bricks and hollow core precast concrete slabs inspected in Lezhë (red tagged by local engineers), (b) pounding damage between the URM building and reinforced concrete building, (c) a gap opening, and d) detachment of the staircase (photos: EEFIT).

Four 5-story multi-family URM buildings in Thumanë collapsed in the November 2019 earthquake and caused 24 fatalities. The buildings were demolished before the visit. Note that low-rise URM buildings with cast-in-situ reinforced concrete floors and a tall reinforced concrete water tank located in the vicinity of collapsed buildings remained undamaged (Figure 32(a)). The collapsed buildings were constructed using silicate bricks and hollow core precast reinforced concrete slabs (Figure 32(b)). The collapse of these buildings can be attributed to simply supported hollow core floor slabs, a lack of integrity of the prefabricated slab elements/planks (no topping) (Figure 32(c)), and poor mechanical properties of silicate bricks. A nearby single-story building with a hollow core prefabricated roof structure partially collapsed in the earthquake, and it was possible to observe the floor-to-wall connection, as shown in Figure 32(d).

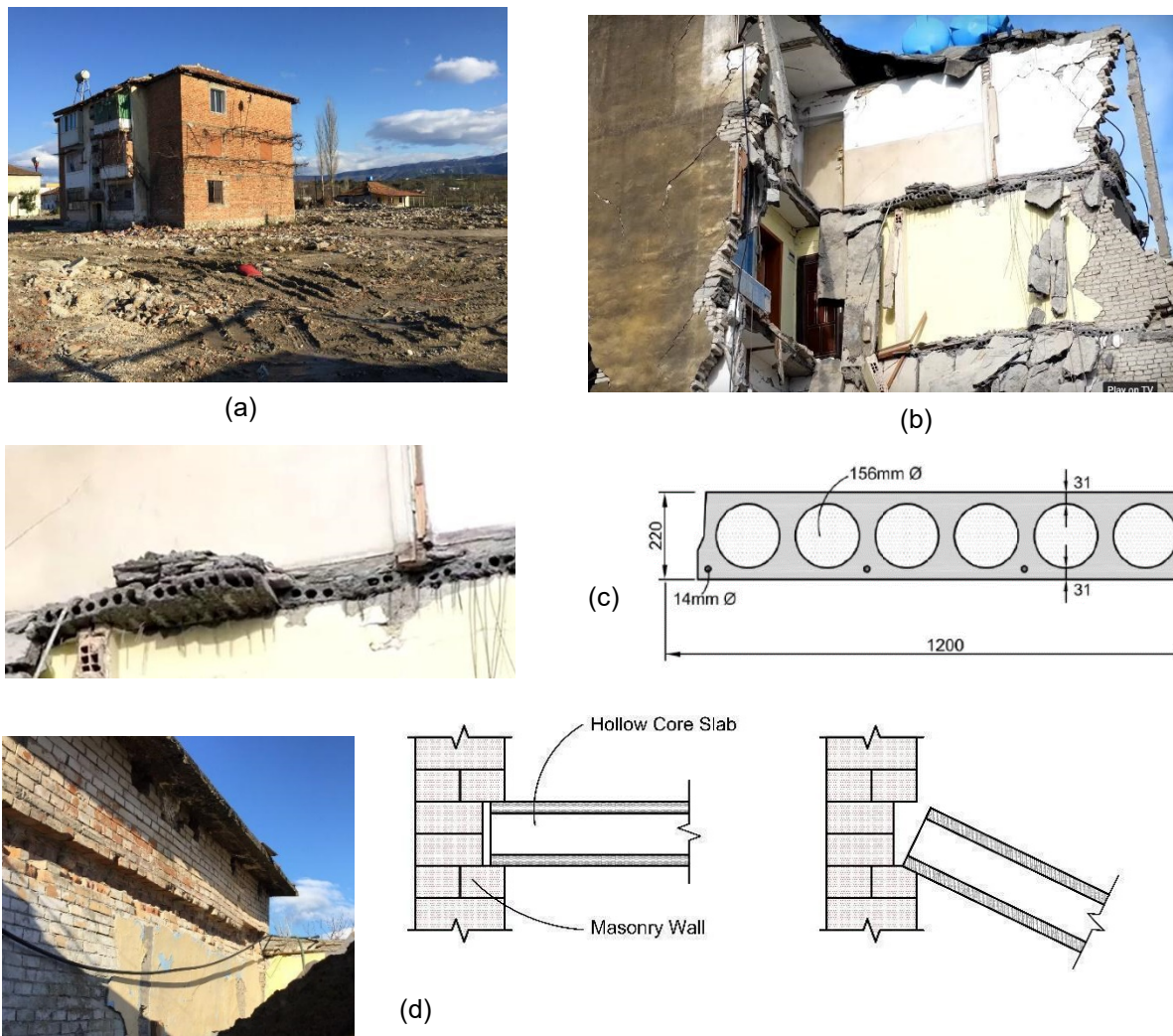
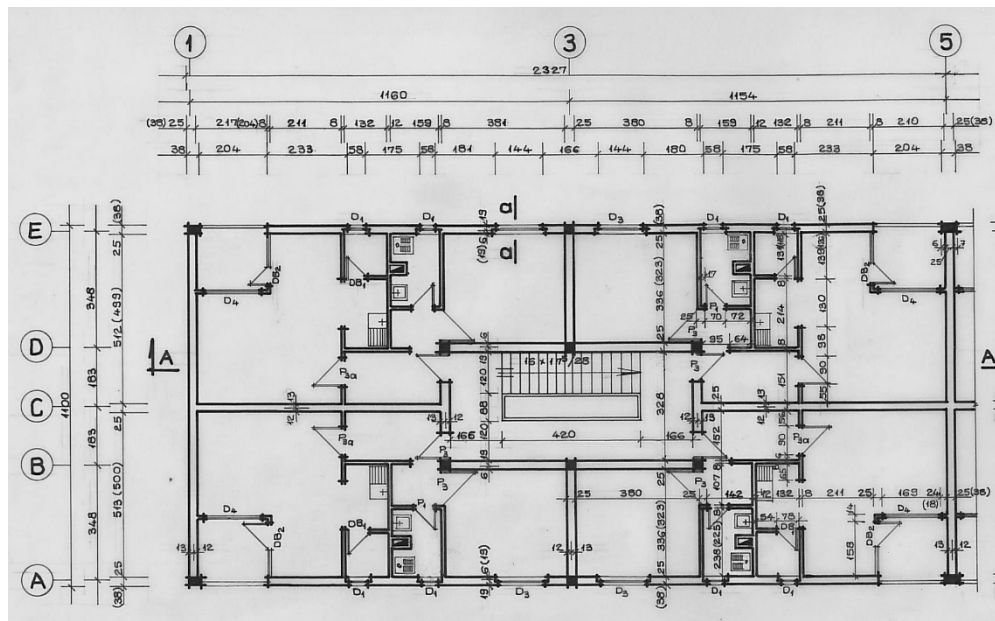


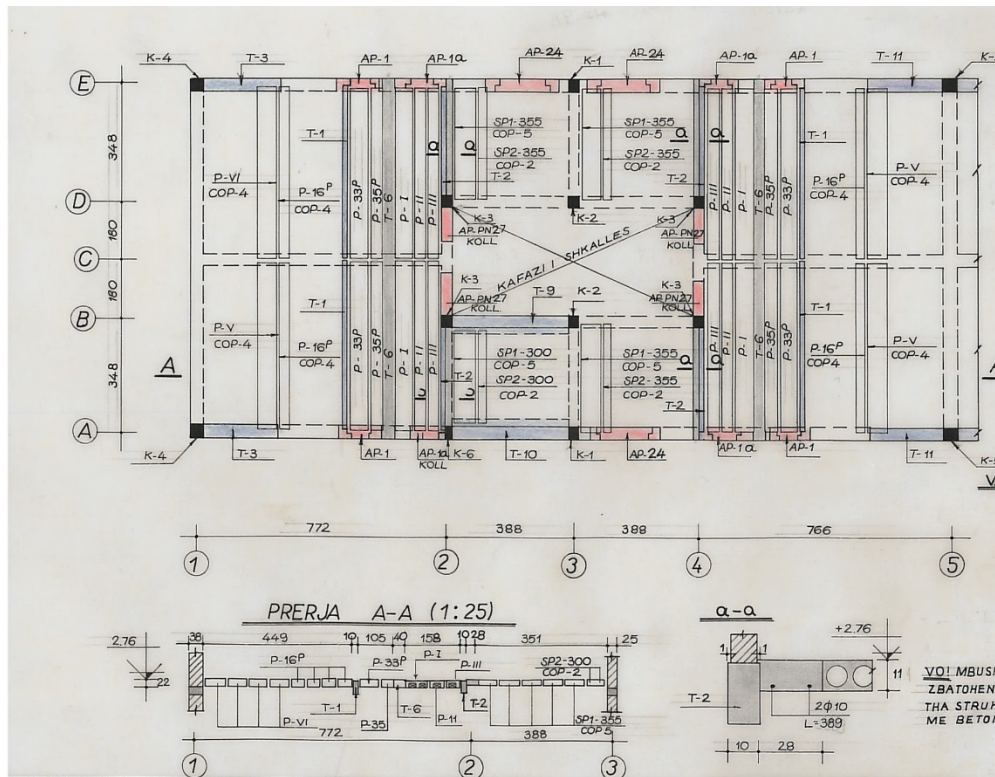
Figure 32. Collapse of mid-rise URM buildings in Thumanë: (a) an undamaged three-story URM building adjacent to the site of collapsed and demolished five-story building, (b) a partial collapse before the demolition (source: TV7 Albania (<https://www.youtube.com/watch?v=2RXiG1KHC7k>), (c) details of hollow core reinforced concrete slabs, and d) detail of floor-to-wall connection (source: SUZI-SAAE).

3.3.2 Confined masonry buildings

Confined masonry was used for construction of three- to five-story-high multi-family residential buildings in Albania since the 1980s. Confined masonry was addressed by the 1989 Albanian seismic code (KTP-N.2-89) (Academy of Sciences and Ministry for Construction, 1989), and it was referred to as a “complex system”. Figure 33(a) shows a typical architectural plan of a confined masonry building. It can be seen that there are three longitudinal walls and several transverse (cross) walls; note the reinforced concrete tie-columns marked by squares at the wall intersections. It can be seen from the structural plan (Figure 33(b)) that prefabricated hollow core reinforced concrete slabs were used as floor structures. The drawing shows that hollow core slabs were aligned in one direction and were supported by longitudinal walls only. The majority of confined masonry buildings did not experience significant damage in the November 2019 earthquake; hence, there are only a few examples of damaged buildings in this section. An example of a three-story confined masonry building in Durrës that experienced damage due to out-of-plane seismic effects is presented in Figure 34. It can be seen from the photos that a major horizontal crack developed in the wall on the level of the top floor, which extends into diagonal and vertical cracks close to the right end of the wall (Figure 34(a)). It appears that the vertical confining elements were constructed only at the building corners (Figure 34(b)), but an intermediate vertical confining element is absent; this contributed to the out-of-plane damage. It can be seen from the standardized floor plan for Albanian confined masonry buildings (Figure 33) that only two reinforced concrete tie-columns were provided in the exterior cross-wall - at wall ends (see grid 1). It appears that a reinforced concrete tie-column was not required at the intersection of the longitudinal wall (grid B) and cross-wall (grid 1). This is a deficiency, especially given the wall length (more than 9 m).



(a)



(b)

Figure 33. Standardized floor plan of a five-story confined masonry building in Albania: (a) the architectural plan and (b) structural plan (AQTN, 1983).



Figure 34. Damage of a confined masonry building in Durrës due to out-of-plane seismic effects: (a) cracks at the front facade (plastered) and (b) the rear side of the building revealing locations of reinforced concrete confining elements and floor slabs (photos: A. Charleson).

3.3.3 Hybrid reinforced concrete and confined masonry system

After 1990, many mid-rise masonry buildings had a mixed function: commercial use at the ground floor (e.g., shops, restaurants) and residential use at the upper floors. These buildings usually have a hybrid structural system, which consists of reinforced concrete frames at the ground floor level and confined masonry walls at the upper floors. The 1989 Albanian seismic code (KTP-N.2-89) permitted the application of this system in seismic zones VII and VIII, but it prescribed restrictions regarding the design of reinforced concrete frames at the ground floor level. It was prescribed that reinforced concrete frames should not cover more than 40% of the ground floor area and that the seismic load at the ground floor level should be multiplied by a coefficient $(1+p)$, where p is the ratio of the area covered by the reinforced concrete frame and the overall floor plan area. The code also prescribed continuity of reinforced concrete columns along the building height, but these columns were typically converted into vertical reinforced concrete confining elements at upper floors. The minimum reinforcement requirements were prescribed for the columns at ground floor level ($4\phi 12$ longitudinal bars and $\phi 6$ ties at 25-cm spacing) are the same as for confined masonry buildings; the minimum required concrete class C16/20 is rather low-strength. These requirements are significantly lower than the corresponding Eurocode requirements. The buildings of this typology were mostly constructed in the 1990s.

Some of these buildings experienced severe damage in the November 2019 earthquake. The SUZI-SAE team surveyed a collapsed five-story building of the 1990s vintage in the southern part of Durrës (Shkëmbi and Kavajës) (see Figure 35). This building had an open ground floor plan which was most likely used as a garage. The ground floor collapsed in the earthquake, whereas upper floors remained virtually undamaged. It was observed that reinforced concrete columns at the ground floor level were reinforced with $4\phi 16$ longitudinal bars, $\phi 8$ ties at 25-cm spacing with 90° hooks. Furthermore, it was noted that longitudinal reinforcement was missing in one of the columns, which indicates poor construction quality. The collapse occurred because of a flexible ground floor (soft-story mechanism), which is a common collapse mechanism in reinforced concrete frames with masonry infills with an open ground floor plan. It was clear that the reinforced concrete frame structure at the ground floor level was subjected to very-high seismic demand, both in terms of lateral deformations and the corresponding internal forces. The failure can be attributed to deficient reinforced concrete columns at the ground floor level, which did not have ductile detailing (e.g., closely spaced ties with 135° hooks) and were not able to develop a plastic failure mechanism. Instead, the columns experienced brittle shear failures, eventually resulting in the ground floor collapse.



Figure 35. Collapsed building with hybrid confined masonry and reinforced concrete frame system in Shkëmbi i Kavajës in south Durrës: details of reinforced concrete frame structure at the ground floor level (photos: SUZI-SAEI).

3.4 Conclusions

It can be concluded that masonry buildings performed reasonably well in the November 2019 earthquake, considering the intensity of ground shaking and large number of buildings of this typology that were exposed to the earthquake. Buildings with load-bearing masonry walls are generally vulnerable to earthquake effects; however, a few important factors, such as regular building configuration, adequate wall-to-floor or roof connections, type of diaphragm (flexible or rigid), presence of reinforcement (e.g., reinforced concrete confining elements in confined masonry buildings), and quality of masonry materials and construction, significantly influence their seismic performance.

The majority of masonry buildings that were exposed to the November 2019 earthquake were low-rise, single-family buildings, which constitute a significant portion of the Albanian building stock. These were mostly two-story, non-engineered URM buildings, which were, in most cases, designed and constructed by builders. The following conclusions can be made regarding the performance of these buildings in the November 2019 earthquake:

- In many cases, the damage was caused by building extensions (e.g., construction of an additional floor, irregular plan shapes (e.g., L-shape), and/or low-strength masonry (usually fired clay bricks)).
- Some URM buildings located in the epicentral area of the November 2019 earthquake experienced minor to moderate damage.
- Collapse of these buildings was not common, but it was observed that buildings that were constructed using hollow concrete blocks experienced more significant damage and even collapse in at least one case.
- Only a few damaged confined masonry buildings were observed during the reconnaissance visits, so it is expected that most buildings of this typology remained undamaged. The damage can be attributed to substandard quality of materials and construction, inadequate detailing of reinforced concrete confining elements, and other common issues related to masonry building typologies.

The existing mid-rise masonry buildings (usually three to five stories high) are common in Albania. These were mostly URM buildings constructed between 1960 and 1990 based on standardized designs prepared by government agencies. Confined masonry was also practiced since the 1980s, whereas the hybrid system (reinforced concrete frame at the ground floor and confined masonry above) was practiced after 1990. Construction of these buildings was executed by

government agencies, but in some cases, volunteers participated in the construction. The quality of masonry materials in these buildings is variable. The following conclusions can be made regarding the performance of these buildings in the November 2019 earthquake:

- A large majority of URM buildings are regular in shape and elevation and have regular wall layout/distribution. There are no reports of significant modifications/extensions that could negatively affect seismic safety of these buildings.
- Most mid-rise URM buildings remained undamaged, even in cities that were severely affected by the earthquake, such as Durrës.
- URM buildings with cast-in-situ reinforced concrete floor slabs in general performed well and did not experience severe damage or collapse.
- Buildings with precast hollow core floor slabs performed poorly in the earthquake, and several buildings of this type collapsed. The collapse can be attributed to simply supported hollow core slabs, which lost support at one or more floor levels, causing a partial or total building collapse. Masonry buildings with hollow core slabs are vulnerable to earthquake effects and need to be retrofitted or replaced to significantly reduce risk of collapse in future earthquakes.
- Confined masonry buildings had regular plans and elevations, and very few such buildings experienced damage. Out-of-plane damage was observed in a confined masonry building with a relatively long exterior wall, in which reinforced concrete tie-columns were not provided at the intersections between longitudinal and cross-walls.
- A few buildings with a hybrid structural system experienced severe damage or collapse at the ground floor level; this can be attributed to open ground floor soft story and increased seismic demand that exceeded the capacity of nonductile reinforced concrete columns at that level. The existing buildings with hybrid structural systems are vulnerable to earthquake effects and need to be retrofitted.

4 PERFORMANCE OF REINFORCED CONCRETE BUILDINGS

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4.1 Low-Rise Reinforced Concrete Buildings

The political and economic changes that occurred in the 1990s in Albania (see section 2.1 and 2.2) also affected the way private houses were built. As with larger structures, reinforced concrete started to gain popularity in low-rise structures, too. Many single-family houses built in Albania after the 1990s, especially in suburban and rural areas, were non-engineered and constructed in an informal manner (Potsiou and Augustinius, 2010).

Many low-rise reinforced concrete buildings in the earthquake-affected area suffered damage ranging from light, nonstructural damage to total collapse of the structure; however, the media and reconnaissance teams did not focus much on these buildings in their reporting. Two major issues are widespread in Durrës and the surrounding areas in collapsed low-rise reinforced concrete buildings. First, many of these buildings follow the "pilotis" typology, which is very widespread in the Mediterranean countries; that is, they have an open ground floor that is used as a garage or as a common area. Because shear walls are seldom used in low-rise reinforced concrete buildings in Albania, the open ground floor becomes susceptible to the formation of a soft-story mechanism. Second, many low-rise reinforced concrete buildings (especially in rural areas) are non-engineered and constructed with limited resources and technology. They also suffer from a lack of robustness, as indicated by the presence of frames in only one direction and one-way slabs. The following paragraphs discuss damage and other observed issues related to low-rise reinforced concrete buildings.

A collapsed single-family building that caused many casualties in Durrës is shown in Figure 36. The authors could not investigate this building closely because of its total collapse, but some observations are made based on media reports and Google Maps images from 2016 (see Figure 36(c)). The photo shows an open ground floor. The staircase was located on the side of the building, and an infill wall ran through the columns next to the staircase, likely giving rise to a torsional irregularity. Figure 36(a) indicates that the middle section of the roof slab rotated almost as a rigid body (Figure 36(a), (c)).



Figure 36. Collapsed single-family building in Durrës due to a soft-story mechanism: (a) a partially collapsed building after the main shock (source: <https://dosja.al/tragjedia-e-familjes-lala-ne-kenete-te-durresit-dalin-emrat-cilet-jane-viktimat-dhe-sa-gjenden-nen-rrenoja/>), (b) a building totally collapsed after several aftershocks (source: Balkanweb media <https://youtu.be/TjSA2nulJgs>), and (c) a pre-earthquake photo (source: Google Maps, available at <https://goo.gl/maps/6RMWmbfZz2huZ8Xr5>).

Photos of a four-story single-family house that partially collapsed in Thumanë are shown in Figure 37. The house had an open ground floor that was used as a parking garage, whereas upper floors had infill walls. The building had three bays in the longitudinal direction and two bays in the transverse direction. The columns were arranged in a regular pattern. The

columns were continuous from the ground to the top of the building. Circular columns were used at the ground floor only, supporting the balcony and two outside stairs to the first story. Framing along one direction only was present in some areas of the building (Figure 37(c)), but due to the limited access options, it could not be determined whether the entire building had frames in one direction only. Based on limited inspection, it was found that framing was present in the transversal direction of the building (shorter direction). Rectangular columns were 250 to 300 mm wide and 400 mm deep. Although the upper stories of the building remained almost intact, the ground floor columns were unable to sustain the imposed deformations in the longitudinal direction of the building (perpendicular to framing). According to locals that witnessed the construction of the building, the slabs were cast after the construction of the brick walls at each level to ensure a robust construction. Indeed, the upper stories were very rigid and suffered limited damage. A close-up examination of the failed columns at the ground floor revealed that the end regions were not detailed to sustain large deformations. Rectangular columns were reinforced with three or four vertical bars ($\varnothing 16$) at each column face (see Figure 37(b)). It was observed that the columns had $\varnothing 8$ ties with 90° hooks, which enclosed longitudinal reinforcement, at approximately 200-mm spacing in the end regions. Furthermore, reinforcement was absent in beam-column joints, and the longitudinal reinforcement in beams had insufficient anchorage length without hooks (see Figure 37(b)).

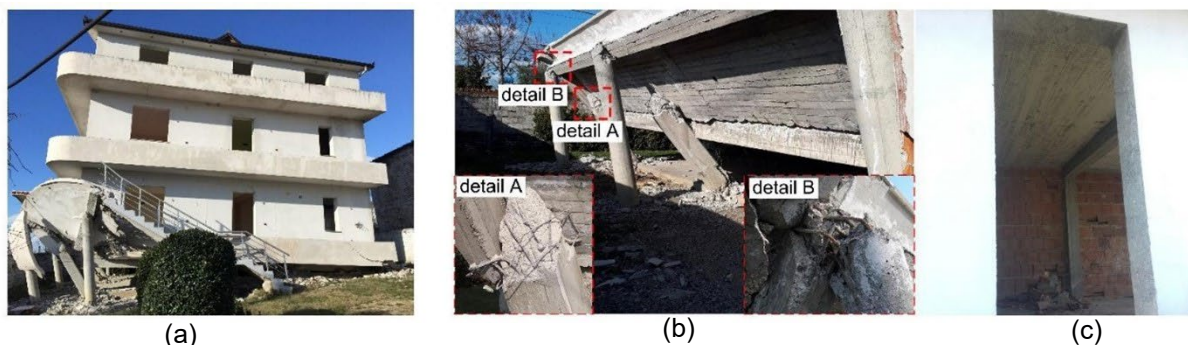


Figure 37. A partially collapsed four-story building in Thumanë due to a soft-story failure mechanism: (a) a general view of the collapsed building, (b) column failure at ground floor, and (c) frames spanning in one direction only (photos: SUZI-SAE).

Examples of low-rise reinforced concrete buildings that suffered damage but did not collapse are presented in Figure 38. Both buildings shown in Figure 38 suffered damage of masonry infills and partition walls at lower floor levels. Masonry infills in Building 1 (shown in Figure 38(a), (b)) experienced out-of-plane failure. Note that the exterior walls that failed out-of-plane were not aligned with the main frame; this pattern was also observed in mid-rise buildings (refer to section 5.2). The building shown in Figure 38(a) and (b) suffered structural damage as well. Columns at the first floor above the ground floor sustained damage near the wide beam-column connections, as shown in Figure 38(b).



Figure 38. Damaged low-rise buildings: (a) Building 1 in Bubq with out-of-plane masonry infill failure, (b) close-up of a damaged column in the same building, (c) Building 2 at the outskirts of Tirana, and (d) damaged masonry infills in the same building (photos: SUZI-SAE).

Damage of a three-story building with wide beam-column frames located at the outskirts of Tirana is shown in Figure 38(c) and (d). As the ground floor level was used as a restaurant, the interior space was completely open, and the exterior infill walls had large openings. The upper floors were used for residential purposes and had infill walls. Columns were 400×400 mm squares, whereas beams were 600 mm wide and 300 mm deep. A one-story annex building was attached to two

sides of the main building with a separation gap and doubled columns. The annex building had only one story at the time of the earthquake, but it was intended to be expanded. According to the structural drawings, the columns and beams were detailed for ductile performance because critical regions had relatively dense transverse reinforcement. Although exterior infill walls suffered damage at the ground floor level (see Figure 38(d)), no damage was observed in the reinforced concrete columns, except for limited cracking at separation gaps with the annex building.

Unlike mid-rise buildings, in which two or more building blocks were usually adjacent to one another, low-rise buildings in Albania are typically well separated from each other. Nonetheless, pounding was observed in a few instances in urban areas where low-rise buildings are close to one another. An example of damage of the seismic gap and the possible interaction between different building blocks or adjacent buildings is in Building 2 discussed in the previous paragraph (Figure 38).

4.2 Damage Patterns in Multi-Family Reinforced Concrete Buildings

4.2.1 Causes of damage and damage patterns

Table 4 provides a summary of the main damage patterns observed in multi-family residential reinforced concrete buildings and potential causes of such damage. The most widespread damage in these buildings was observed in masonry infills and partition walls. Structural damage varied from light cracking to damage/failure of structural elements and a total building collapse in some cases. Different damage patterns were observed in buildings of different vintages, as discussed in the following subsections (refer to section 5.3 for a more detailed discussion about different typologies).

Table 4. Main damage patterns and potential causes of damage in multi-family reinforced concrete buildings.

No.	Damage pattern	Potential causes of damage
1	Damage in infill walls, ranging from plaster cracks to in-plane and out-of-plane failures (section 4.4)	<ul style="list-style-type: none"> High seismic demand High flexibility of the reinforced concrete frame system Lack of restraint and proper measures to account for infill-to-frame interaction Brittle clay blocks used for infill construction
2	Light cracking and minor crushing in reinforced concrete members (section 4.2.2.2)	<ul style="list-style-type: none"> Foreseeable consequence given the severity of the earthquake In some cases, same as damage pattern 4
3	Failure of reinforced concrete members (mostly columns) (section 4.2.2.2)	<ul style="list-style-type: none"> Frame-infill interaction (in case of captive columns) Lack of ductile detailing for reinforced concrete beams and columns Substandard quality of materials Irregularities due to the distribution of infills
4	Global collapse mechanisms (section 4.2.2.1)	<ul style="list-style-type: none"> Soft stories due to a lack of proper detailing or irregular distribution of infill walls in elevation Irregularities in the plan Possible geotechnical effects Excessive loading or non-engineered renovations (e.g., horizontal or vertical building extensions)
5	Localized pounding-related damage (section 4.2.1)	<ul style="list-style-type: none"> High flexibility of the reinforced concrete frame system Insufficient seismic gap

Masonry infill walls in these buildings have been typically constructed using clay blocks. In many cases, these walls are constructed with an offset relative to the reinforced concrete frames (see example shown in Figure 39(b)), which is one of the main causes of damage to infills and partitions in these buildings. To ensure the stability of infills against the out-of-plane failure, horizontal concrete "belt beams" have been often provided in recently designed buildings. The behavior of infills in reinforced concrete buildings is discussed in detail in section 4.4.

These are mixed-function buildings (commercial and residential). Typically, the ground floor and, in some cases, the lower 2-3 floors were used for commercial activities, which often results in irregular distributions of infills in elevations and plans. For example, a heavily damaged building in Durrës (Figure 39(b)) suffered significant structural damage and nonstructural damage (shattered glazing) in the columns at the lower two stories, whereas the upper stories did not suffer noticeable damage.



(a)



(b)

Figure 39. *Masonry infill panels in multi-story reinforced concrete buildings: (a) exterior walls constructed with an offset relative to the frame structure (Photo: Chiara McKenney) and (b) a damaged building in Durrës with irregular distribution of infills in elevation (photo: Chiara McKenney).*

Another feature of post-1990 reinforced concrete multi-family residential buildings in Albania is the widespread use of wide/shallow beams, as described in section 2.2. Wide beams in combination with one-way or two-way cast-in-place slabs are the preferred floor system in modern reinforced concrete buildings in Albania. A typical detail is presented in Figure 40, showing the beam and the slab with typical dimensions. Low lateral stiffness and low energy dissipation capability characterizes wide beam/column frames; however, it should be acknowledged that the response of buildings with wide beams depends on many factors, such as the presence of shear walls, distribution of infills, and detailing of vertical reinforced concrete members. The effect of wide beams on the overall structural performance is important but cannot be quantified in a simple manner. It should be noted that in many buildings these wide/shallow beam-column frames were the only lateral load-resisting system (i.e., many buildings had no perimeter moment-resisting frames or shear walls), thereby rendering the structure very flexible.

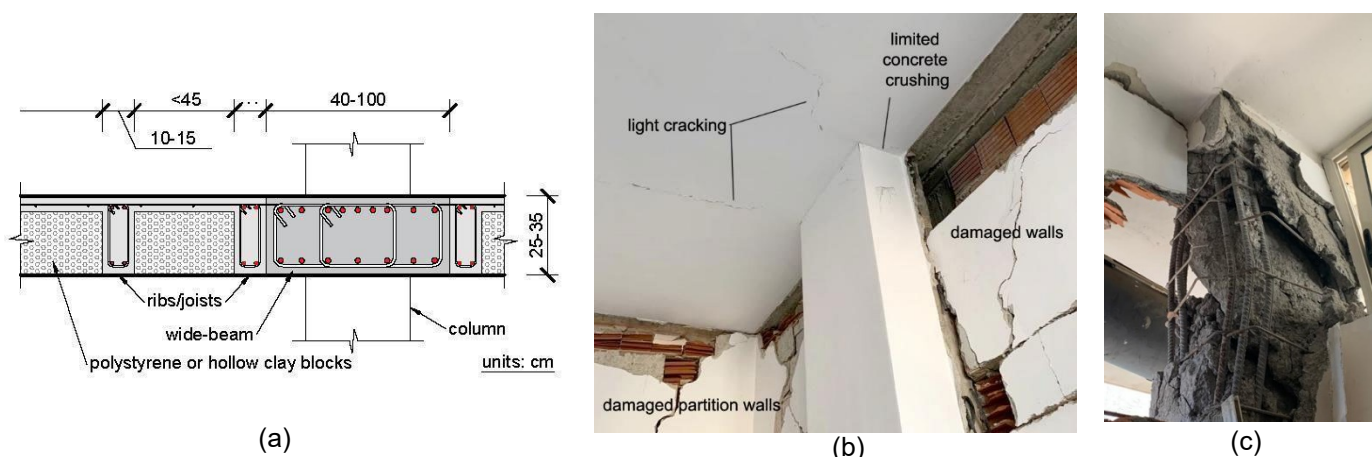


Figure 40. Wide beams in Albania: (a) typical detail (source: Brisid Isufi), (b) minor damage, and (c) a damaged column with poor detailing with the wide beams undamaged (photos: Markel Baballëku).

Minor cracking and spalling in the vicinity of wide beams was observed in a few buildings. An example of such damage in a 13-story reinforced concrete building in Durrës is shown in Figure 40(b). The lateral load-resisting system of the building consisted of reinforced concrete frames with an eccentric concrete core, which likely caused torsional effects in the building. Although the damage to wide beams was generally very limited, damage to partitions and infill walls was widespread in this building (refer to section 4.4 for further details on the behavior of infill walls). In general, the high flexibility of wide/shallow beams is a likely contributor to the widespread infill and partition damage in buildings, especially in buildings where shear walls were not provided.

In some cases, column failure was observed while the beams remained almost intact. An example is shown in Figure 39(c), which refers to a five-story building in the Durrës Beach area. The lateral load-resisting system consisted of columns (cross-sectional dimensions 400×400 mm to 400×600 mm) and shallow beams (700 mm wide and 250 mm deep). This building did not have shear walls; hence, the wide beam-column frames were the only lateral load-resisting system. In addition to the high deformation demands, the damage shown in Figure 40(c) is likely due to several factors, including poor detailing, insufficient confinement, and the presence of captive columns caused by partial-height infills.

As previously discussed in section 2.1, a major drawback of the Albanian seismic design code KTP-N.2-89 (Academy of Sciences and Ministry for Construction, 1989) is the lack of specific guidance and explicit recommendations regarding the inter-story drift limits, which are critical for the limitation of damage to infills. On the other hand, the code contains guidance for sizing seismic gaps between adjacent buildings or building blocks. According to KTP-N.2-89, the seismic gap should be determined based on the combined displacements of the adjacent blocks plus 20 mm, but not smaller than 30 mm, and $h/250$, where h is the overall building height. The code requirements for seismic gaps are not always followed, especially in the case of building extensions. Localized pounding-related damage was observed in several instances (see Figure 41). Although generally repairable, this type of damage caused panic to the inhabitants.



(a)



(b)



(c)

Figure 41. Pounding-related damage in multi-family reinforced concrete frame buildings in Durrës: (a) and (b) damage at seismic gaps between the building blocks of the same building (photos: Chiara McKenney) and (c) a reinforced concrete building block and an adjacent masonry building (photo: Brisid Isufi).





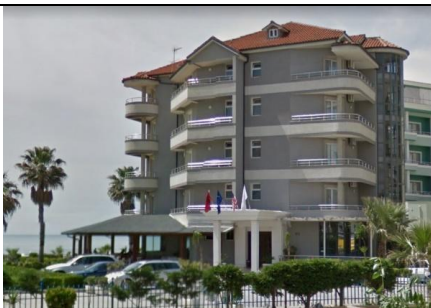



4.2.2 Structural damage

4.2.2.1 Global collapse mechanisms

Although the most widespread types of damage in mid-rise reinforced concrete buildings were described in section 4.2.1, it is important to mention that several buildings collapsed and several others were demolished in a controlled manner soon after the earthquake because of excessive damage. A detailed investigation of the collapsed buildings was not possible, but a general overview based on limited site visits (Lekkas et al., 2019; McKenney, 2019)²⁶ and information from media reports is provided in this subsection. This section is not intended to cover all the cases of collapsed reinforced concrete structures.

The collapse of reinforced concrete structures was the main cause of casualties in Durrës, unlike some other cities, where fatalities were due to the collapse of masonry structures or accidents during rescue operations. Examples of collapsed or severely damaged low-rise reinforced concrete buildings were presented in section 4.1. Examples of collapsed mid-rise buildings are illustrated in Table 5, accompanied by images of the same buildings before the earthquake.

Table 5. Examples of collapsed or partially collapsed buildings and Google Maps/Images (photos: Google Maps; Chiara McKenney).

No.	Before the earthquake	After the earthquake	Description
1			Collapsed six-story residential reinforced concrete building adjacent to another building that did not collapse
2			Collapsed five-story reinforced concrete hotel in Durrës
3			Six-story reinforced concrete hotel in Durrës; lower two stories collapsed
4			Reinforced concrete hotel in Durrës; ground floor collapsed

Buildings 1 and 2 in Table 5 suffered a total collapse, whereas the other two buildings (3 and 4) suffered damage to the lower stories that rendered them unrepairable. Building 1 was adjacent to a larger building of the same height (see Lekkas et al., 2019 for more photos and details). The other buildings shown in Table 5 were isolated. Buildings 2, 3, and 4 were located near each other in the Durrës Beach area. The collapse of these buildings can be attributed to a combination of structural and geotechnical failures (refer also to Volume 2 of this report).

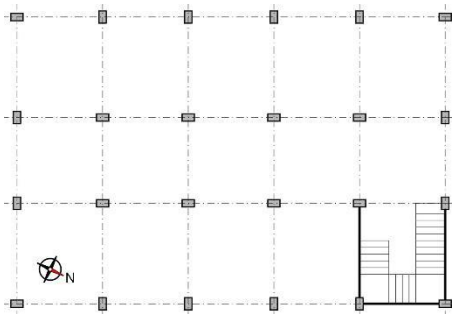
Besides the buildings discussed above, other notable cases of collapse in the Durrës area include the collapse of a six-story reinforced concrete residential building that caused seven fatalities (Gazeta Shqiptare, 2019),²⁷ a partial collapse of a five-story hotel dedicated to the employees of the Ministry of the Interior that caused one fatality (Report TV, 2019),²⁸ the collapse of another six-story hotel in Durrës that caused two fatalities (Shqiptarja.com, 2019),²⁹ and the collapse of a

six-story residential building that experienced failure of the lower stories and caused two fatalities (A2 | CNN Affiliate, 2019).³⁰

A severely damaged seven-story reinforced concrete frame building located at seaside Durrës is presented in Figure 42, Figure 43, and Figure 44. Based on the Google Earth images, the building was built between 2000 and 2005. The top floor was under construction and had a setback (see Figure 42(a)). The building had a grid of 4×6 rectangular columns arranged in a regular pattern with spans ranging from 3.5 to 4.2 m (see Figure 42(c)). Rectangular columns were around 300 mm wide and 500 mm deep. It can be noticed that most columns in longitudinal perimeter frames were oriented with their depths perpendicular to the frame direction, which reduced the torsional stiffness of the building. The floor system was in the form of a two-way ribbed reinforced concrete slab with 700 mm wide/shallow beams and polystyrene infill. The perimeter frame at the southeast façade had 300×500 mm beams at the first floor, but, because of limited access options, it could not be determined whether the perimeter beams were present at upper floors as well. The stairs, located at the north corner of the building, were supported by beams and adjacent perimeter columns (see Figure 43(b)). The building had an open ground floor with large openings in the exterior infill walls at the northeast and northwest façade, near the stairs (see Figure 42).



(a)



(c)



(b)

Figure 42. Six-story reinforced concrete building located at seaside Durrës: (a) the northwest façade (near stairs), (b) east corner, and (c) schematic floor plan (photos: SUZI-SAEF).



(a)



(b)



(c)

Figure 43. Damage of a six-story reinforced concrete building at seaside Durrës: (a) infill damage at the northeast façade, (b) infill and column damage at the stairs, and (c) shear and axial load damage of a staircase column (photos: SUZI-SAE).)



(a)



(b)



(c)

Figure 44. Damage at the ground floor of a six-story reinforced concrete building at seaside Durrës: (a) the southeast façade of the building, (b) damage to the corner column at the southeast façade, and (c) damage of the edge column at the southeast façade (photos: SUZI-SAE and Nikolla Vesho).

It is believed that both the stairs and infill, concentrated at the north corner of the building, had adverse local and global effects on the seismic performance of the flexible reinforced concrete building structure. Figure 43 shows damage of masonry infills on the north side and shear and axial load damage of a reinforced concrete column supporting the stairs resulting from lateral restraint along its height. Globally, stairs and adjacent infill walls caused higher displacement demands on perimeter frames due to torsional effects. This resulted in shear and flexural damage of perimeter columns at the southeast side, as shown in Figure 44. Apart from irregularities of the structure, inadequate detailing contributed to significant damage of the reinforced concrete columns. Figure 43 and Figure 44 show that reinforced concrete columns had $\varnothing 8$ ties with 90° hooks spaced at 200 to 250 mm. Reinforced concrete columns experienced a loss of concrete cover, buckling of longitudinal rebars, and fracture of ties and disintegration of concrete; see Figure 44(b) and (c).

4.2.2.2 Damage/failure of reinforced concrete members

This section illustrates examples of reinforced concrete buildings with reported damage or failure in specific reinforced concrete members but without the formation of global collapse mechanisms.

Figure 45 shows the failure of one external (Figure 45(a)) and one internal (Figure 45(b)) column of a reinforced concrete multi-story building in Durrës. The figure shows buckling of longitudinal reinforcement, opening of ties, and disaggregation of the concrete core. Although the year of construction is unknown, it is evident that the quality of both the materials and structural details was very poor. Figure 45 indicates low-strength concrete, smooth aggregate, mild steel longitudinal bars, and widely spaced, small diameter column ties without 135° hooks.



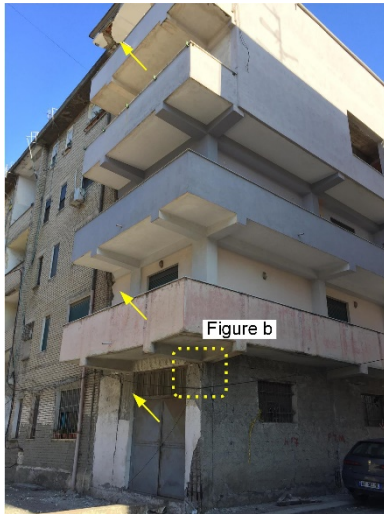
(a)



(b)

Figure 45. Examples of structural damage in mid-rise reinforced concrete buildings: (a) an exterior column and (b) an interior column (photos: EEFIT).

Damage to infill walls and reinforced concrete columns of a five-story reinforced concrete building is shown in Figure 46. The building was located near the fire station in downtown Durrës. The building had 3×2 rectangular columns arranged in a regular pattern. This building suffered minor damage due to the pounding effect with the adjacent masonry building (Figure 46(a)) caused by an insufficient seismic gap. Figure 46(b) shows damage at the top end of a reinforced concrete column, which was likely caused by interaction with the concrete block masonry infill (note the stepped cracks in infill that propagated into the column). Exterior column, damaged at the bottom end, had $\phi 6$ ties at 100- to 130-mm spacing and 90° hooks (Figure 46(c)).



(a)



(b)



(c)

Figure 46. Five-story reinforced concrete frame building at downtown Durrës: (a) damage due to pounding with an adjacent building, (b) damage at the top of a column at the southwest corner due to interaction with the concrete block infill, and (c) damage at the base of a column at south east corner (photos: SUZI-SAEE).

Another case of a severely damaged reinforced concrete building is presented in Figure 47, which shows flexural and shear failures in the exterior columns (Figure 47(a)). Construction flaws observed in the previously described case studies, such as low quality of the concrete that resulted in the initiation of core crushing and widely spaced hoops, were observed in this case as well. An additional contributing factor that appears to have further aggravated the damage of the corner column is the interaction with the collapsed adjacent building (Figure 47(b)).



(a)



(b)

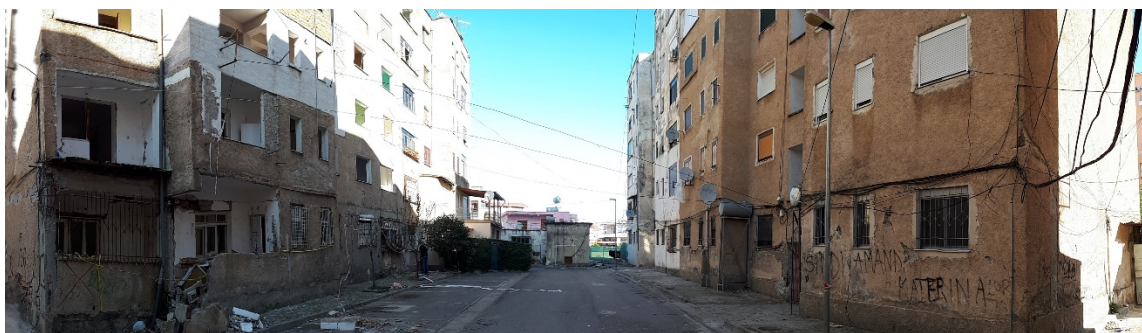
Figure 47. Damaged building in Durrës: (a) a damaged column base and (b) interaction with the adjacent collapsed building (photos: HAEE).

4.3 Case Studies of Mid-Rise Reinforced Concrete Buildings of Different Vintages

As discussed in section 2.1, the KTP-N.2-89 code is currently enforced in Albania. However, for more recent designs, it has become common practice among structural engineers to perform design according to Eurocodes in order to overcome the lack of detailed provisions in some parts of the Albanian code. The following three main typologies of reinforced concrete buildings are distinguished based on the construction period:

1. buildings designed and built in the 1980s based on older Albanian codes;
2. buildings designed and built in the 2000s based on KTP-N.2-89 and codes from neighboring countries; and
3. post-2010 buildings that were designed (partially or completely) according to Eurocode 8 (CEN, 2004).³¹

Albanian reinforced concrete multi-family residential buildings built around 1990 were up to six stories high and had a regular elevation and plan (Figure 48(a)). These buildings had moment frames as lateral load-resisting systems, small column sizes, and deep beams. Exterior masonry infills were aligned with the adjacent reinforced concrete frames.



(a)



(b)



(c)

Figure 48. Example of typical reinforced concrete multi-story buildings: (a) a typical 1980s building (photo: SUZISAE), (b) a typical 2000s building (photo: EEFIT), and (c) a typical post-2010 building (photo: Chiara McKenney (2019)).

Pre-2010 multi-family reinforced concrete residential buildings are typically regular and have simple shapes. Ground floors were typically used for offices, shops, or restaurants (Figure 48(b)). Compared to older buildings, these are taller buildings with more robust (larger size) columns, and wide/shallow beams. Shear walls are not always provided. Exterior masonry walls were often offset with regards to the reinforced concrete frames.

Gradual development of construction technology resulted in more irregular buildings (Figure 48(c)). The main structural components are typically arranged in a rectangular grid layout, and irregularly shaped buildings were typically divided into several adjacent blocks separated by seismic joints. Ground floors in post-2010 buildings were also typically reserved for commercial activities with only a few infill walls. Furthermore, story heights at ground floor levels are typically higher than that of the other stories reserved for residential purposes. Wide/shallow beams are very common in these buildings. Shear walls have been provided in most cases. Typical buildings representative of these three typologies are shown in Figure 48.

4.3.1 Damage patterns in multi-family reinforced concrete residential buildings constructed in the 1980s

Typical six-story reinforced concrete frame buildings built between 1988 and 1990 that sustained nonstructural and structural damage in the earthquake are shown in Figure 49. The buildings shown in the figure were located in downtown Durrës, near the collapsed reinforced concrete frame Building 1 shown in Table 5 (see also Lekkas et al., 2019).



Figure 49. Damage patterns in two 6-story reinforced concrete frame buildings in Durrës: (a) a street view showing the buildings; (b), (c), (d) damage of reinforced concrete columns in Building A; (e), (f), (g) damage of reinforced concrete columns and beams in Building B (photos: SUZI-SAE).)

Based on the survey, it was concluded that most of the damage to the masonry infill and reinforced concrete elements was concentrated at lower stories. Visual inspections showed that these two buildings had similar deficiencies regarding the size and detailing of reinforced concrete frame members. Figure 49(b) and (e) show reinforced concrete columns with smaller dimensions (300 to 400 mm) compared to the depth of reinforced concrete beams; this likely led to the undesirable “strong beam–weak column” mechanism characterized by severe damage in the end zones of reinforced concrete columns and limited damage of reinforced concrete beams. These columns were typically reinforced with 12- ϕ 16 longitudinal rebars (5 bars at each longer side of cross section). Figure 49(d) shows damage of a “captive” reinforced concrete column at the middle due to the presence of a partial-height infill wall on each side of the column. The following common detailing flaws were observed in these buildings (as illustrated in the figure):

1. absence of cross-ties in critical regions of reinforced concrete columns;
2. widely spaced transverse reinforcement (stirrups/ties) in “critical” regions and/or outside “critical” regions of beams and columns;
3. inadequate stirrup amount and detailing in beam-column joints;
4. ties with 90° hooks and insufficient anchorage length;

5. excessively small tie size ($\emptyset 6$).

It is likely that inadequate detailing as well as poor concrete quality contributed to the severe damage of reinforced concrete columns, including the spalling of concrete cover, buckling of longitudinal bars, opening-up of 90° ties at the column ends, and partial/full concrete disintegration.

4.3.2 Damage patterns in multi-family reinforced concrete residential buildings constructed in the 2000s

A typical building of the 2000s vintage located near Niko Dovana Stadium in Durrës is shown in Figure 50 (EEFIT, 2020). The building has nine stories with a 3.2 m story height and 5×4 bays with approximately a 5-m span length. The structure is regular in plan and elevation and is shown in Figure 50(a) and (b). Figure 50(c) shows a schematic floor plan. It is worth mentioning that the lateral load-resisting system in this building is a moment-resisting frame; there are no shear walls. It is common in buildings of this typology that the reinforced concrete core is absent (see example in Figure 10(d)). The building has shops at the ground level whereas the upper stories are intended for residential use.



Figure 50. Typical 2000s multi-family reinforced concrete building: (a) the east façade, (b) south façade, and (c) schematic floor plan (photos: EEFIT).

Interior and exterior columns have large cross-sectional dimensions, approximately 80×80 cm and 110×35 cm, respectively. The dimensions of the exterior column can be seen in Figure 51(a) because of the vertical cracks formed in the plaster. Figure 51(a) also shows the cracks corresponding to the position of the beams that have a depth equal to the thickness of the floor slab and beam (approximately 30 cm).



Figure 51. Typical 2000s multi-story reinforced concrete building: (a) plaster cracks and the dimensions of beams and columns and (b) dimension of clay block masonry units used for the infill construction (photos: EEFIT).

Infill panels are constructed using clay blocks (25×25×20 cm), as shown in Figure 51(b). The interaction of the flexible structure with the stiff infills caused a significant damage to infills. Moreover, some of the unconfined walls either collapsed or experienced heavy damage (Figure 50(a)). In addition, as shown in Figure 52, the damage pattern is also characterized by horizontal cracks at the floor level in the lower side of the floor slabs. This is related to the lack of construction detailing and a poor connection between the top side of the infill panels and floor slabs. This configuration promotes the detachment of the infills from the beams. This damage pattern is distributed over the bottom five stories in the building, and it can be observed in Figure 52(a). Figure 52(b) shows a close-up of the damage pattern at the eastern façade of the building, which highlights significant vulnerability of stiff masonry panels, especially when they are not enclosed by the reinforced concrete frames. For more information about infill panels, see section 4.4



Figure 52. Severe damage of masonry infills: (a) collapse of an infill panel and (b) detachment of the infill panel and formation of horizontal cracks (photos: EEFIT).

4.3.3 Damage patterns in post-2010 multi-family reinforced concrete residential buildings

A typical building located near Rruga Pavarësia, the main boulevard of the Durrës Beach area, is shown in Figure 53 (EEFIT, 2020). This is a residential building with commercial uses planned at the ground floor level. The building has 10 stories with a 3.2 m story height, except for the ground floor, which has a story height of about 4.00 m. The structure has 6×3 m bays with variable spans ranging between 4 and 6 m. The columns are particularly large (cross-sectional dimensions on the order of 80×80 cm). The frame structure is regular in plan and elevation and is illustrated in Figure 53(a) and (b); however, an eccentric core wall located close to the elevator induced some irregularity in the plan, as shown in Figure 53(c). The observed damage pattern was consistent with this irregularity. At the time of the survey, the building was still under construction; however, all the structural and the main nonstructural components were completed.

This structure differs from the one described in the previous section. Although the KTP-N.2-89 code is currently enforced in Albania, practicing engineers are increasingly adopting Eurocode 8 provisions in the design. For example, although the KTP-89 code requires that columns must be stronger than the adjacent beams, it does not provide a quantitative approach to achieve the desired capacity development hierarchy. In this case, the detailed Eurocode 8 provisions are usually adopted by practitioners.

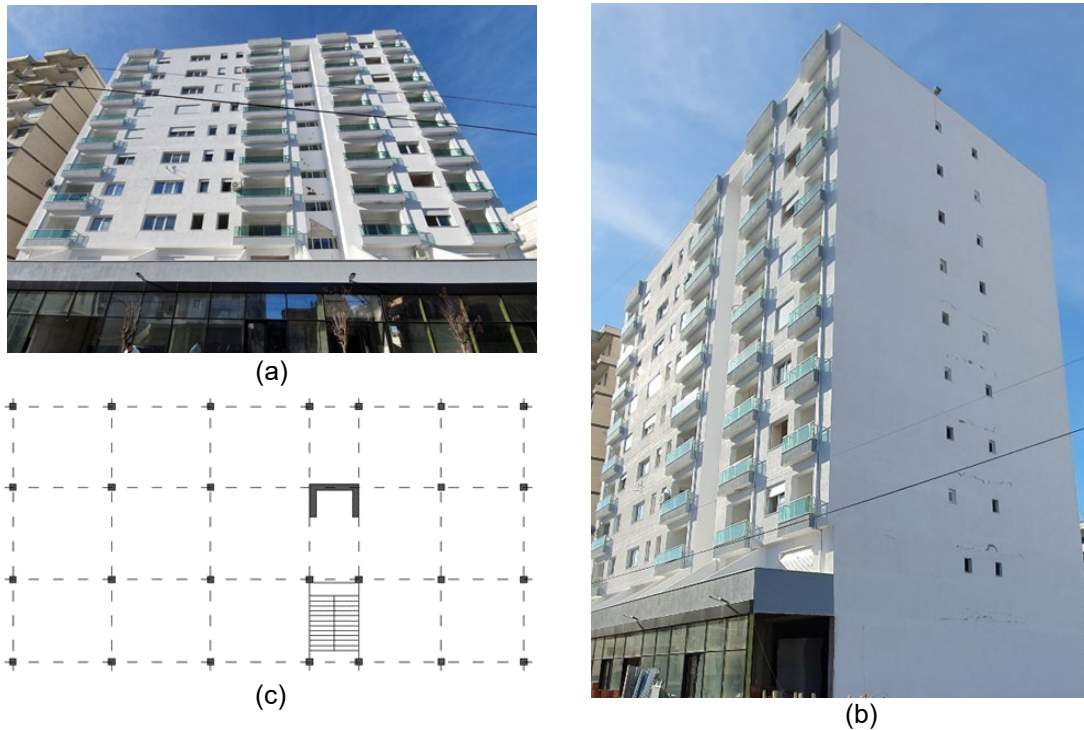


Figure 53. A typical post-2010 multi-family reinforced concrete residential building designed according to Eurocode 8 that was under construction at the time of the earthquake: (a) the northeast façade, (b) south east side, and (c) schematic floor plan (photos: EEFIT).

The damage was mostly concentrated in the staircase and interior infill panel areas of the building. The exterior and interior damage in the staircase area can be observed in Figure 54(a) and (b), respectively. This damage is likely due to large displacements caused by the presence of the core wall, which induced torsional effects. The staircase was unable to accommodate these displacements, and it experienced large shear cracks in the stair-landing area, specifically in the exterior beams and the adjacent nonstructural walls. Extensive damage was observed in the lower five stories of the building.



(a)



(b)

Figure 54. A typical post-2010 multi-family reinforced concrete residential building partially designed according to Eurocode 8: (a) exterior damage related to the interaction with the stairs and (b) damage in the stair-landing area (photos: EEFIT).

As in the case study described in Figure 51, the infill panels are generally composed of clay blocks (25×25×20 cm). The interaction of the flexible frame structure with the stiff infills resulted in significant damage to the infills. This extent of damage was more significant in internal partitions because of a lack of confinement of these walls by the reinforced concrete frame elements and inadequate connections at wall intersections. Figure 55(a) and (b) show the same intersection of internal masonry panels at the second and the fifth story, respectively.



(a)



(b)

Figure 55. Damage at the intersection of interior masonry partitions in a typical post-2010 multi-story reinforced concrete residential building: (a) the second story and (b) the fifth story (photos: EEFIT).

In addition, most likely due to the torsional effects, exterior infills furthest from the core wall experienced damage in the form of shear cracks. This was more apparent in an adjacent building (also under construction) with identical geometry and other characteristics (Figure 56). The damage of exterior partitions that were offset with regards to the reinforced concrete frames is shown in Figure 56. Clearly, the lack of partition connections to the reinforced concrete frames significantly affects seismic response of nonstructural components, results in cracking and in some cases out-of-plane failure of these walls. This is also highlighted in Figure 57, which shows that the belt beams are ineffective when a masonry wall is not aligned with the reinforced concrete frame. It is worth mentioning that many buildings with similar characteristics showed the same damage pattern. For more information about infill panels, see section 4.4.



(a)



(b)

Figure 56. A typical post-2010 multi-family reinforced concrete residential building designed partially according to Eurocode 8: (a) exterior damage due to torsional effects and (b) failure of exterior masonry walls offset with regard to the frame (photos: EEFIT).



Figure 57. A typical post-2010 multi-family reinforced concrete residential building partially designed according to Eurocode 8 (note the lack of effectiveness of belt beams in masonry infills) (photos: EEFIT).

The observed damage in the post-2010 multi-story reinforced concrete buildings is very similar to the one observed in the older structures. This damage pattern highlights a significant need for additional design requirements to be included within the KTP-N.2-89 code (e.g., the Damage Limit States checks and the need to address the safety of infills and partition walls).

4.4 Performance of Masonry Infills and Partitions in Reinforced Concrete Frame Structures

Masonry infill is generally, yet inappropriately, considered a nonstructural element in most modern reinforced concrete building designs in Albania; however, the interaction of infill walls with concrete frames and the adverse effects of damage to both have caused life loss and extensive property and functional losses. Especially in Durrës, a large majority of mid- and high-rise reinforced concrete buildings built in the post-1990 period have infill walls. These walls are quite inexpensive

and fast to build compared with other wall types. Their materials and necessary construction skills are widely available. Excellent thermal insulation properties as well as good fire resistance are additional important advantages of masonry infills. The requirements of modern, transparent architecture and great flexibility in terms of space utilization have been met by using masonry infills for construction of interior and exterior walls.

Many studies, however (Asteris et al., 2015; Kappos and Ellul, 2000; Kose, 2009; Ricci, Verderame, and Manfredi, 2011),^{32,33,34,35} show that masonry infill is not a nonstructural element because its stiffness significantly contributes to the overall structural stiffness and changes the dynamic characteristics of reinforced concrete structures. Furthermore, an infill actively participates in resisting seismic forces, although it is common practice to neglect its contribution in seismic design. As a result, several past earthquakes have caused damage of masonry infills (e.g. Izmit, Turkey (1999); Bhuj, India (2001); Boumerdes, Algeria (2003), and Gorkha, Nepal (2015)), as confirmed by past reports (Braga et al., 2011; De Luca et al., 2014; Manfredi et al., 2014).^{36,37,38} In many cases, the reinforced concrete buildings did not suffer significant structural damage, but infill walls were either damaged or experienced a complete collapse. Similar damage patterns were observed in the November 2019 Albania earthquake. The majority of the damaged reinforced concrete buildings did not collapse, but they were often uninhabitable. The reason for this was the high extent of nonstructural damage, predominantly in infill and partition walls. The building in Figure 58(a) is typical for dozens, if not hundreds, of other buildings. Extensive cracks and damage occurred in the infill walls, whereas the reinforced concrete structure remained relatively undamaged.



Figure 58. Damage of masonry infills in Durrës (photos: SUZI-SAE).

Infill damage in reinforced concrete structures was dominant in Durrës (Figure 58(b)) but was also observed in Fushë-Krujë (Figure 59(a)), Krujë (Figure 59(b)), and Tirana and Bubq (Figure 60). It is important to point out the influence of the infills on the global behavior of the whole structure and damage caused to the structure, as discussed in section 4.2. This section focuses on the damage of masonry infill walls, which was the predominant damage pattern in reinforced concrete buildings exposed to this earthquake.



(a)



(b)

Figure 59. Examples of masonry infill damage in reinforced concrete buildings: (a) Fushë-Krujë and (b) Krujë (source: Nikolić-Brzev et al., 2020).³⁹

Significant damage in masonry infills can be attributed to the relative flexibility of reinforced concrete frame structures, which by their deformations caused in-plane damage to the infills (see section 4.2). This type of damage can be manifested in the form of diagonal (“X”-shaped) cracks (Figure 59(a) and Figure 60) or damage in the corners of infill walls (Figure 55 and Figure 60(b)). Two other characteristic types of in-plane damage, which were also observed in this earthquake, are horizontal sliding along the mortar bed joints or damage in the central part of the wall (Figure 61).



(a)



(b)

Figure 60. Diagonal cracks in masonry infills (photos: SUZI-SAEE).



Figure 61. Damage of infill wall by bed joint sliding and failure at central portion of the wall (photo: Marko Marinkovic).

In addition to the in-plane damage, significant out-of-plane damage of the infills was also observed. As a result, the infills can fail or completely topple (Figure 58 and Figure 62). A common type of out-of-plane failure is the tilting of a wall as a rigid body (Figure 63). This occurs due to the loss of contact between the frame and the wall. Infills are traditionally constructed by filling a gap at the contact between the infill wall and the frame with a mortar, but the mortar can get damaged because of the deformation of the frame in the plane of the wall; thus, the connection between the frame and the infill can be severely degraded, which makes the infill wall vulnerable to out-of-plane seismic actions.



Figure 62. Damage and out-of-plane collapse of infill walls of a reinforced concrete building in Durrës (photo: SUZI-SAE).



Figure 63. Separation of the infill from the frame, leading to the tilting of the wall in Durrës (source: Nikolić-Brzev et al., 2020).

It has been observed in previous earthquakes elsewhere in the world, and again in the November 2019 earthquake, that the infills experience damage at the lower stories that is often characterized by a partial or complete out-of-the-plane failure. A large number of buildings suffered out-of-plane infill damage at the lower stories, whereas the infill walls at the upper floors remained intact. This out-of-plane failure at the lower floors of a building is not expected because the maximum horizontal accelerations increase (get amplified) along the height of the building. From a simplified perspective, a higher level of damage due to the frame deformation at the lower stories is expected, but higher damage is expected due to out-of-plane vibrations at higher floor levels. This can be explained by the fact that during any seismic event, the infill walls are exposed to simultaneous in-plane and out-of-plane seismic actions. Frame structures experience larger inter-story drifts at the lower stories, and the out-of-plane infill response is strongly influenced by this drift. Therefore, a combined effect of in-plane and out-of-plane seismic loading leads to a higher extent of damage in the masonry infills, which was confirmed after the November 2019 earthquake (Figure 64, Figure 65). In addition to the damage of infills in the exterior frames, the same effect was observed inside the buildings (Figure 66, Figure 67). The reason for such a high level of damage in infills subjected to simultaneous in-plane and out-of-plane loading can be explained by damage to the infills due to frame deformations, which leads to significant vulnerability of the infills to the loads perpendicular to the planes of the walls. It can be clearly seen from Figure 67 that the infill was initially damaged because of the in-plane action, and, after that, the damaged parts fell out-of-plane. Furthermore, out-of-plane infill failure may occur even without previous in-plane damage. This can be explained by the loss of contact between the frame and infill, which is caused by the frame deformation. Because there is no contact between the infill and frame, a small out-of-plane force is sufficient to cause the infill to fall outward. It should be pointed out that out-of-plane failures could potentially endanger the lives of passersby next to buildings (Figure 64).



Figure 64. Damage and out-of-plane failure of infill walls in Durrës (Lekkas et al., 2019).



Figure 65. Out-of-plane collapse of infill walls in Durrës. The red outline indicates the area of the detailed view shown in the right part of the figure (source: Nikolić-Brzev et al., 2020).



(a)



(b)

Figure 66. Damage of masonry infills inside the buildings in Durrës (photo: SUZI-SAE).



Figure 67. Severe damage/collapse of interior masonry infills at ground floor level of a reinforced concrete building in Durrës (photo: SUZI-SAE).

Modern seismic design codes such as Eurocode 8 and ASCE 7-16 (2017) require the consideration of infill walls in the design of frame structures, especially in cases when they can cause adverse effects to the structure. The action or failure of infills must not impair the vertical and seismic force-resisting capabilities of the reinforced concrete frame as it responds to design story drifts. In addition, the effects of these infill elements shall be considered when evaluating whether or not building systems have irregularities. According to ASCE 7-16 (2017),⁴⁰ all portions of structures shall be designed and constructed to act as an integral unit in resisting seismic forces unless separated structurally by a distance sufficient to avoiding damaging contact. Every structural component not included in the seismic force-resisting system shall be designed to be adequate for gravity load effects and the seismic forces resulting from the displacements caused by design story drifts. In the current Albanian seismic design code KTP-N.2-89, the designer is free to choose between masonry infills designed as a part of the seismic force-resisting system or as nonstructural elements. KTP-N.2-89 provisions to ensure the stability of the infills during an earthquake are “force-based” (i.e., design forces to be resisted by the infills are provided in the code instead of deformation-based criteria, such as limiting inter-story drifts or the isolation of

infills from the concrete structure to accommodate deformations). The earthquake in Albania on November 26, 2019, demonstrated that these provisions and criteria are not sufficient and an improvement of the code is needed.

To mitigate issues with infills, it is necessary to reduce irregularities and to increase stiffness of the structure; however, both aforementioned options are not "popular" from the aspect of modern requirements of architecture and interior design. Therefore, in the last 10 to 15 years, great attention has been paid to the modification of masonry infills with the aim of improving their behavior during earthquakes. Examples for improving the behavior of masonry infills are introduced in Eurocode 8, section 4.3.6.4. These examples include the strengthening of the infills by applying wire mesh anchored to the wall or steel bars in mortar joints that are fixed to the column and the application of vertical and horizontal lintels. These measures make the infill wall a structural element, which must be considered in the analysis and design of the entire structure. Due to this fact, but also due to the complexity of application of such measures, they have not been widely applied in practice. Another approach is to increase the deformation capacity of the infills by dividing the wall into several horizontal planes. This enables sliding along these planes and reaching higher levels of displacement by the formation of horizontal cracks in the mortar joints without significant damage to the blocks. In addition to the complexity of the application of sliding surfaces in mortar joints, the issue of wall stability to out-of-plane loads is not resolved with this approach. Due to these issues, even these measures have not been applied in practice. Finally, another possible approach is to isolate the infill wall from the surrounding frame, which truly makes the wall a nonstructural element. Isolation is carried out simply by leaving a space between the frame and infill that would compensate for the frame deformation and, thus, avoid activation of the infill. This solves the problem of changing the dynamic characteristics of the system because the stiffness of the infill is not activated. In this approach, it is necessary to provide a connection between the frame and the infill, which will prevent the wall from falling out of the plane and, at the same time, enable the deformation of the frame without activating the infill. Because of the difficulty of solving this problem, examples of applying this approach in practice are rare, but there are a few promising proposals (Marinković and Butenweg, 2019; Morandi, Milanesi, and Magenes, 2018).^{41,42}

4.5 Conclusions

This section of the report showed that the extent of damage in reinforced concrete buildings due to the earthquake on November 26, 2019, varied from light nonstructural to severe structural damage and total collapse.

In low-rise reinforced concrete buildings, the most severe damage was related to the formation of soft-story mechanisms and total collapses. This earthquake confirmed what was already known from past earthquakes and theoretical considerations: the combination of an open ground floor with upper stories stiffened by infill walls is dangerous because it favors the formation of soft-story mechanisms. The situation for low-rise reinforced concrete buildings was likely aggravated by the fact that many of these buildings were built informally (non-engineered). Other damage patterns observed in these buildings include damage to infill and partition walls and structural damage to specific reinforced concrete members. Damage to infills in low-rise buildings was similar in nature to mid-rise buildings.

In mid-rise reinforced concrete structures, damage varied from nonstructural to total collapse in a few cases. Damage to infill and partition walls was the most common damage pattern. Besides cracks and damage of infill panels, the complete failure and collapse of infills occurred in some cases because of the combined action of in-plane and out-of-plane loading. A few studies (Butenweg, Marinković, and Salatić, 2019; Kadysiewski and Mosalam, 2009; Yuen, Kuang, and Ali, 2016)^{43,44,45} have been conducted on the topic of combined (in-plane and out-of-plane) action, but in the last 3 to 4 years, there has been a noticeable increase in interest in these effects. Based on the observations of damage to infills, it can be recommended that the regular layout of infills is provided in plan and elevation. Also, reducing the flexibility of the reinforced concrete structures (for example, by adding sufficient reinforced concrete shear walls) is desirable in order to reduce the deformation of the frame and, thus, the impact of masonry infill irregularities.

Besides issues with infill walls, excessive deformations of mid-rise reinforced concrete structures cause other issues, such as additional damage due to pounding between adjacent building blocks or buildings. Observed characteristics that make the buildings in Durrës and surrounding areas flexible include the extensive use of wide/shallow beams and the insufficient or inexistent shear walls. To mitigate the issue of excessive deformations in the future, it is recommended to use properly designed stiffer structures that are capable of controlling inter-story drifts and roof displacements. Alternatively, passive seismic control technologies, such as base isolation, dampers, etc., can be considered where appropriate.

The design of flexible structures in the earthquake-affected areas might have been the result of the fact that the seismic design code KTP-N.2-89 does not provide specific guidance related to damage limitation or control of the inter-story drifts. Although this code can be considered advanced given the time of its publication (refer to section 2.1 for historical context and an overview of building typologies of the time), it does not contain the modern seismic design approaches, especially those related to the cast-in-place reinforced concrete buildings that became prevalent in Albania after 1990. Although the level of enforcement of the KTP-N.2-89 code in practice is not known and even though most of the Eurocode's parts are now approved as national standards in Albania (i.e., noncompulsory, refer to section 2.1), the revision of the design codes or the adoption of Eurocodes as the mandatory design codes is an urgent need to ensure that recent developments in the field are reflected in the design and construction of structures. Also, given the popularity of wide/shallow beams, the revised code should provide explicit and detailed provisions for the design of buildings containing such beams.

Structural damage to reinforced concrete members and collapses were less common in mid-rise reinforced concrete buildings compared to damage to infills and partitions. Among the potential causes of structural damage in mid-rise reinforced concrete buildings in Albania are irregularities in plan and elevation caused by infills (as discussed above), irregularities caused by the distribution of shear walls and mass, the detailing of steel reinforcement, geotechnical effects, and the quality of materials. In terms of regularity, the current design code KTP-N.2-89 imposes rather strict requirements related to the overall building shape; however, the earthquake showed that special attention is needed for the distribution of shear walls and infills inside the building. Finally, measures need to be taken to ensure the enforcement of the codes in practice and mitigate or eliminate informal construction practice.

5 PERFORMANCE OF PREFABRICATED REINFORCED CONCRETE BUILDINGS

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5.1 Introduction

Similar to other eastern European countries, in the 1960 and 1970s, Albania responded to the growing demand for new housing while taking advantage of industrialized construction process, which resulted in the mass construction of prefabricated residential buildings (Soviet model), mostly in the form of large panel buildings (LPBs). Some of the public buildings, such as schools, were constructed as prefabricated reinforced concrete frame buildings (PRCFBs). Both technologies will be discussed in this section.

5.2 Prefabricated Large Panel Buildings (LPBs)

5.2.1 Design and construction practices

Although in most other eastern European countries this technology was imported from the Soviet Union, prefabricated LPBs in Albania used construction technologies that were imported from China and aimed at building large residential complexes in a short time. In the early years after World War II, several studies were carried out to develop cost-effective projects for multi-family housing in Albania. In 1972, the Ministry of Construction approved the model design developed by The Institute of Design Studies no. 1 (Abazaj, 2019).⁴⁶ In the 1970s, LPBs were spread throughout Albania as the main urban housing construction practice in urban areas, including Shkodër, Tirana, Durrës, Lushnjë, Burrel, Elbasan, Berat, Pogradeci, Laç, Lezhë, Korçë, Tepelenë, and Gjirokastër. Typical wall panels used in these buildings are illustrated in Figure 68, and a construction sequence is shown in Figure 69. In most cases, these buildings are five or six stories high

with architectural layouts composed of one of four main planimetric modules: Module 1, Module 1a, Module 2, and Module 2a. The floor plans of the modules and some typical configurations of LPBs in Albania are shown in Figure 70. The construction of LPBs in Albania is illustrated in Figure 71.

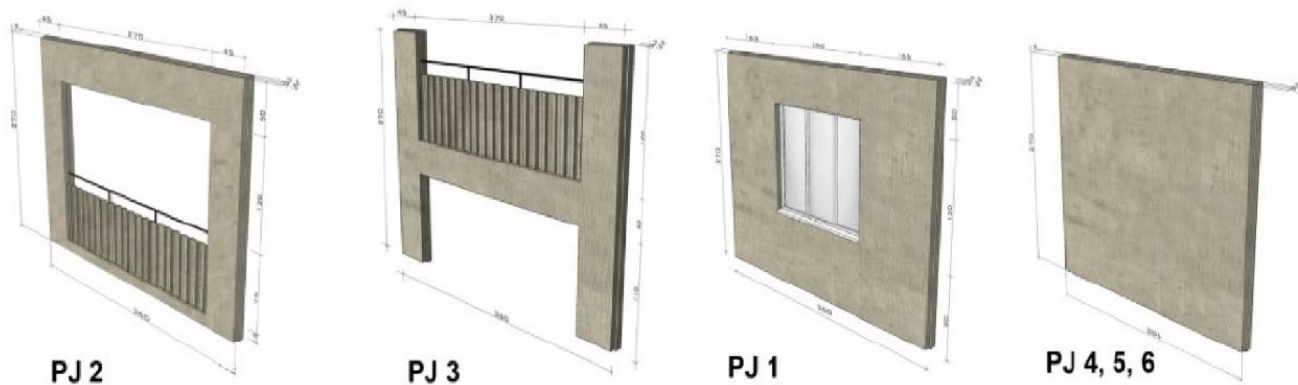


Figure 68. Types of prefabricated wall panels (solid and with openings) (source: Islami and Veizaj, 2014).⁴⁷

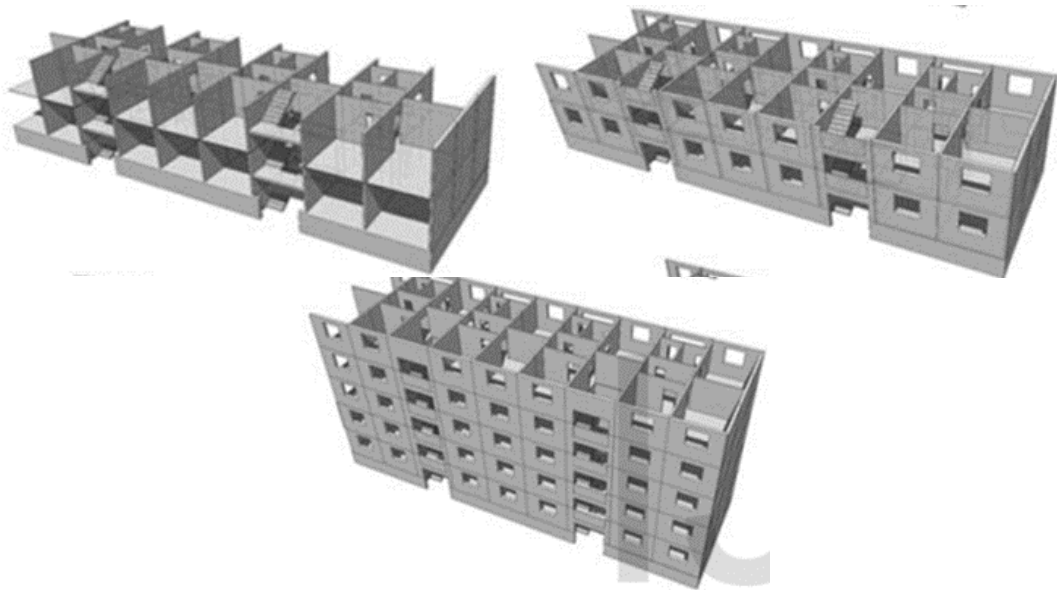
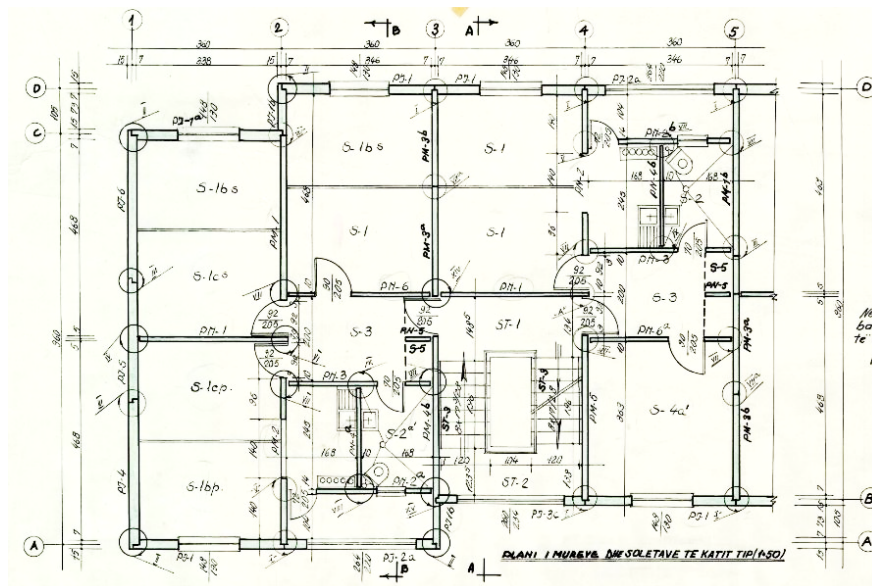
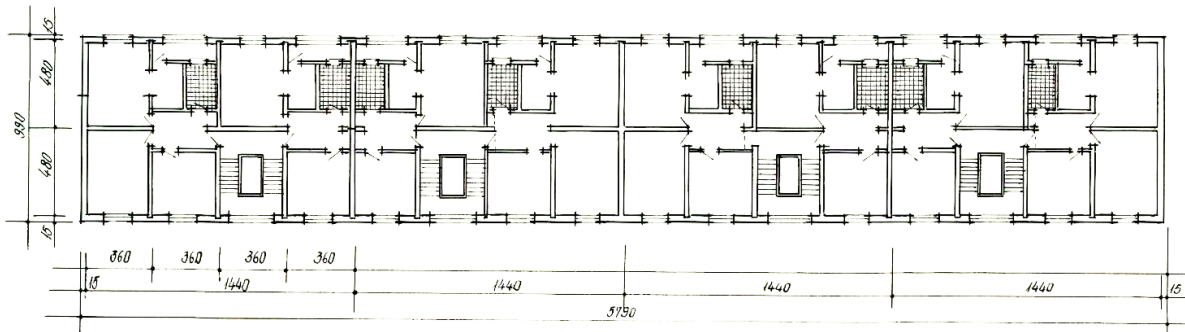


Figure 69. Three-dimensional view of a LPB construction sequence (source: Abazaj, 2019).

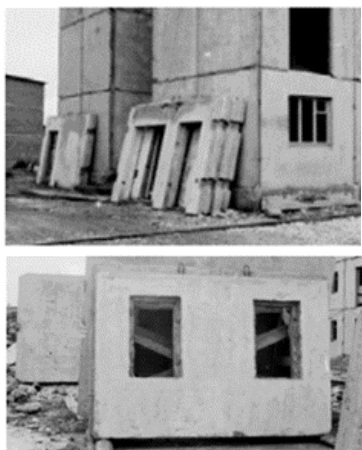


(a)

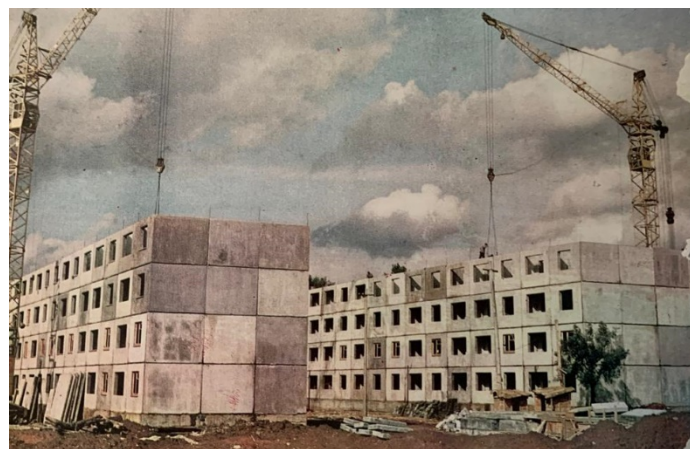


(b)

Figure 70. LPBs in Albania (example of Module 1 layout): (a) typical floor plans and (b) configurations (source: based on Abazaj, 2019).



(a)



(b)

Figure 71. Construction of LPBs in Albania: (a) panels at the construction site (source: Abazaj, 2019) and (b) buildings under construction (source: Ministria e Ndërtimit, 1981).⁴⁸

LPBs can be designed using one of the following structural configurations: a cross-wall system, long-wall system, or two-way system (Figure 72). A two-way configuration is ideal from the seismic performance perspective, whereas cross-wall and long-wall configurations are vulnerable to seismic actions in one of the principal horizontal directions in the building.

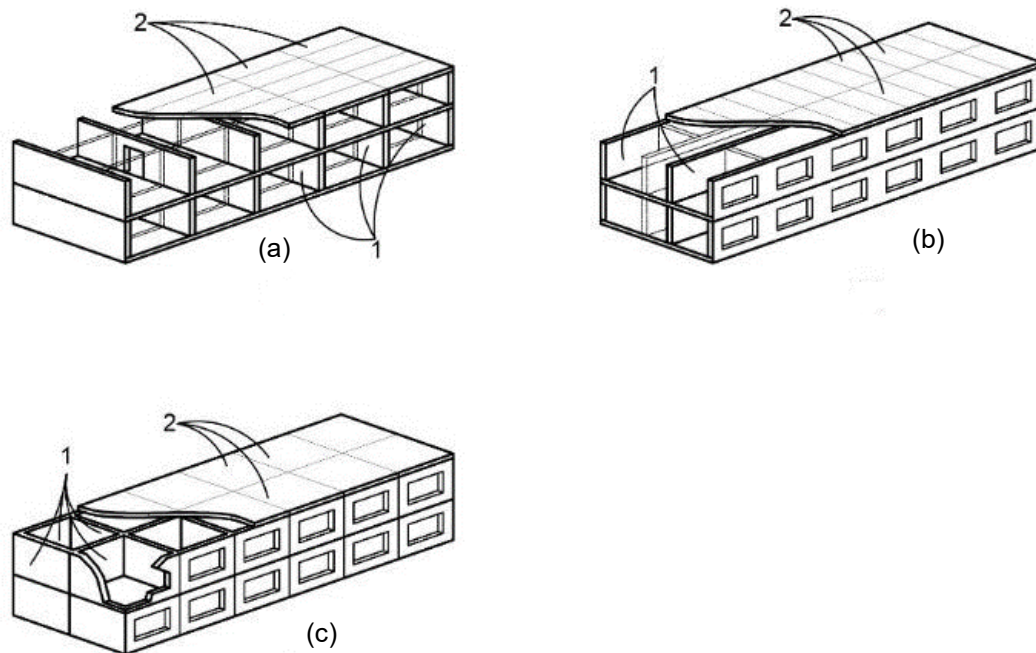


Figure 72. Basic structural configurations for LPBs: (a) a cross-wall system, (b) a long-wall system, and (c) a two-way system (note: 1, wall panel; 2, floor panel) (source: based on fib, 2008).⁴⁹

The joints of prefabricated elements are the points of transfer for bending moments, and axial and shear forces are induced by gravity and lateral loading. In LPBs, there are vertical joints (VJs) between the prefabricated wall panels (interior and exterior), horizontal joints (HJs) between the floor/roof slab panels, and horizontal joints between the walls and floor/roof slabs. Note that vertical and horizontal joints in LPBs are located at discrete points. Locations of vertical joints in a typical Albanian LPB are shown in Figure 73. Joints between the prefabricated reinforced concrete elements are usually classified into “wet” and “dry”, where wet joints use monolithic concrete to enclose the reinforcing bars and fill the gaps, whereas dry joints use welding to connect reinforcing bars extending from adjacent panels (fib, 2008; UNIDO, 1983).⁵⁰ In Albanian LPBs, dry joints were achieved by the field welding of mild steel bars using electrodes of type TL VIIS and kb IX/xs (according to the Albanian standards). Details of vertical joints and horizontal joints are illustrated in Figure 74.

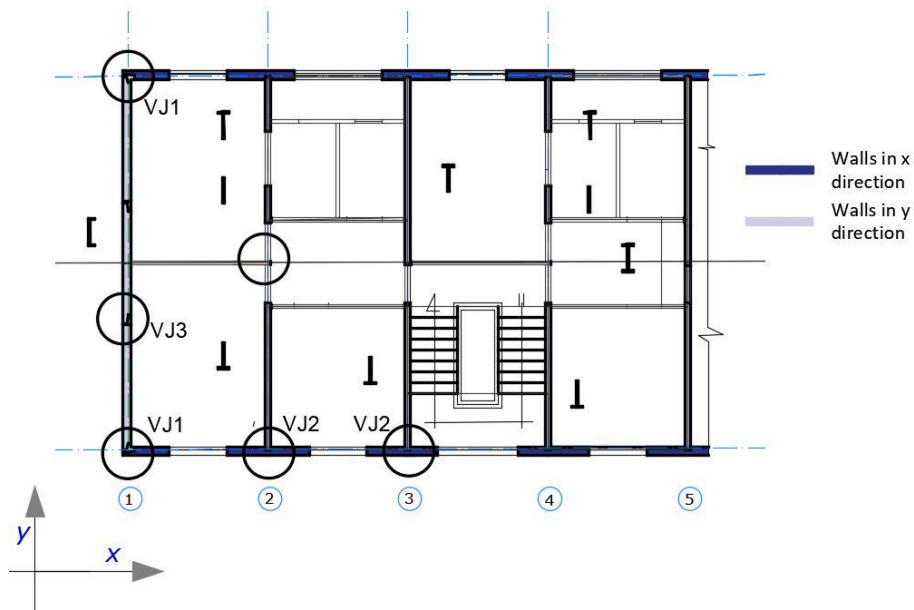


Figure 73. Floor plan of an Albanian LPB showing the locations of vertical joints VJ1, VJ2, and VJ3 (source: AQTN, 1999).⁵¹

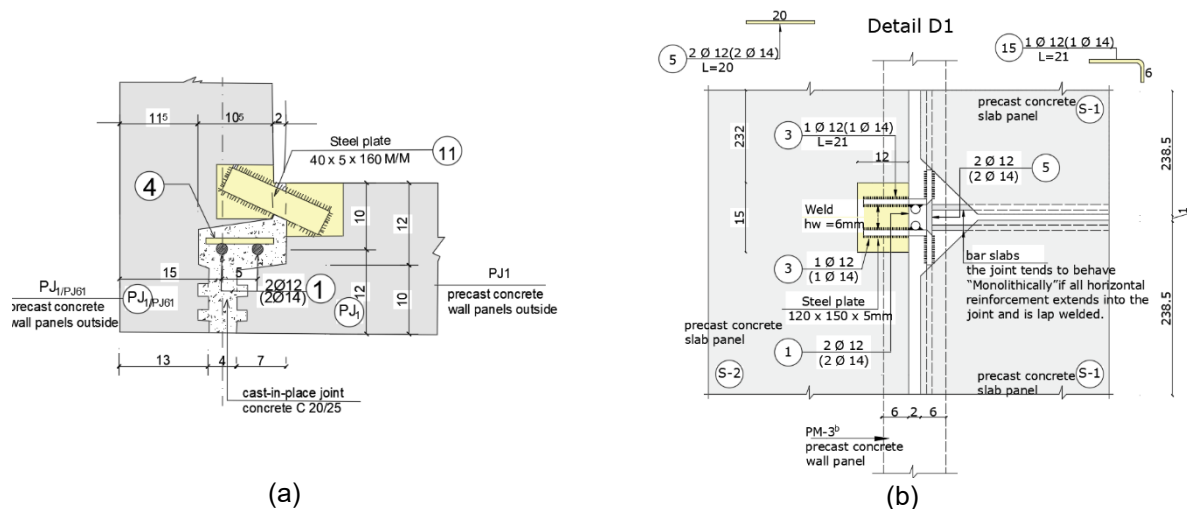


Figure 74. Connections between adjacent panels in LPBs: (a) connection VJ1 between vertical panels and (b) connection between the horizontal slab panels (source: AQTN, 1999).

A prefabricated shear wall subjected to in-plane earthquake shaking should behave as a structural unit composed of interacting wall elements; see Figure 75. This structural interaction within the wall needs to be secured by structural connections that resist the required shear, tensile, and compressive forces. When the strength of the horizontal and vertical joints exceeds the seismic demand at the interface between the panels, a structural wall composed of these panels is expected to show monolithic behavior (see Figure 76(a)), where the structural damage is concentrated in the form of diagonal cracks within the panels; however, significant sliding displacements (slippage) may develop along the vertical and horizontal joints in prefabricated reinforced concrete wall systems. Figure 76(b) and (c) shows horizontal actions applied to a shear wall composed of several panels, in which slippage has occurred along both the vertical and horizontal joints because of shear forces transferred along these joints. The effect of slippage along the horizontal and vertical joints is to reduce the stiffness of the system. It is difficult to predict the prevailing seismic response and failure mode in existing large panel walls under earthquake loads. The observations from past earthquakes in Romania, Armenia, and Bulgaria suggest that slippage between the panels is likely to occur because the damage was mostly in the form of horizontal and vertical cracks along the panel interfaces; this can be referred to as a “strong panels–weak joints”

mechanism. It is expected that the concrete quality and the strength of the panels will be higher than the connections because of the higher quality control during construction of prefabricated elements that were manufactured in a plant. An alternative failure mechanism called “strong joints–weak panels” is also possible. Slippage between the panels is likely to be a source of significant energy dissipation and could be one of the reasons for good seismic performance of LPBs reported in past earthquakes.

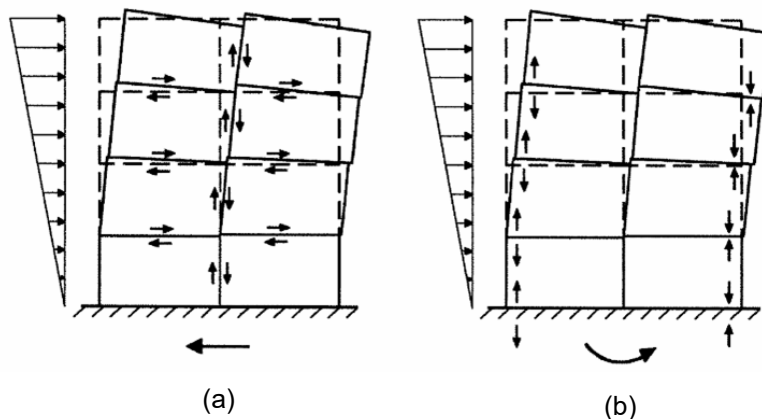


Figure 75. In-plane action of a prefabricated reinforced concrete shear wall: (a) shear forces and (b) tensile and compressive forces (source: fib, 2008).

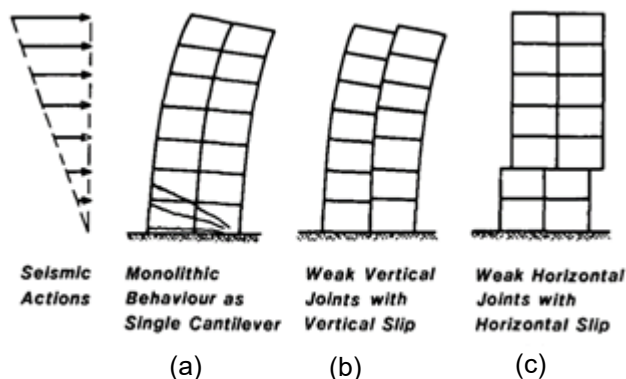


Figure 76. Seismic behavior of a prefabricated shear wall constructed using large panel shear walls: (a) monolithic behavior, (b) vertical slippage between the panels, and (c) horizontal slippage (source: UNIDO, 1983).

5.2.2 Observed earthquake damage

Existing LPBs were exposed to the November 2019 earthquake at several locations in Albania, including cities such as Tirana (Kombinat area), Durrës, and Laç. In general, these buildings performed well and did not experience severe damage like URM buildings or reinforced concrete frame buildings with masonry infills did.

Most of these buildings are more than 40 years old and poorly maintained. In many instances, the pre-earthquake condition of the buildings was poor because of the deterioration of concrete and steel in exterior panels as a result of the aging and exposure to atmospheric agents as well as the strain effects (e.g., temperature-induced cracks). Another factor that contributed to the deterioration was interventions (modifications) of the original structure performed by the building inhabitants, which usually occurred illegally and without input by qualified engineers. It should be noted that it was not easy to make modifications in these buildings, so the cases of intervention are not very common. Figure 77 illustrates the condition of Albanian LPBs, including deterioration and building modifications/interventions.



(a)



(b)



(c)



(d)



(e)

Figure 77. *Pre-earthquake condition of Albanian LPBs: (a) deterioration of facade elements, (b) the use of masonry to build exterior walls, (c) deterioration of concrete and corrosion of the reinforcement in an exterior wall at the ground floor level, (d) an example of illegal horizontal and vertical building extensions, and (e) an inappropriate ground-floor intervention (photos: Merita Guri, Svetlana Brzev, and Markel Baballëku).*

LPBs either remained undamaged or experienced minor structural damage during the November 2019 earthquake, as discussed by Guri, Brzev, and Lluka (2021).⁵² The damage patterns were mostly in the form of horizontal or vertical cracks within the panel connections. The extent of cracking ranged from minor plaster cracks to moderate cracks in the joints. These crack patterns signify the onset of structural damage in LPBs, where the damage is mainly in the form of cracking in the grout between the panels and does not affect the structural safety. The extent of damage also depended on the soil conditions at the building location. Durrës and some areas of Tirana (e.g., the Kombinat area) are well known for soft soil conditions that amplify earthquake effects. LPBs are rigid structures and are more vulnerable to earthquake effects in soft soil areas due to soil-structure interaction. Figure 78 and Figure 79 show the cracking pattern for LPBs in the Kombinat area of Tirana. Figure 78 shows horizontal cracks at the wall-floor connection and vertical cracks where the wall panels connect at the wall intersections. Figure 79 shows vertical cracking along the interface between adjacent interior subpanels PM3a and PM3b (note that interior panels had to be subdivided to limit the weight below 3.6 tons—the crane capacity).



Figure 78. Cracking pattern at the interface between horizontal and vertical panels and at the wall intersections (Kombinat area in Tirana) (source: Guri et al., 2020).⁵³

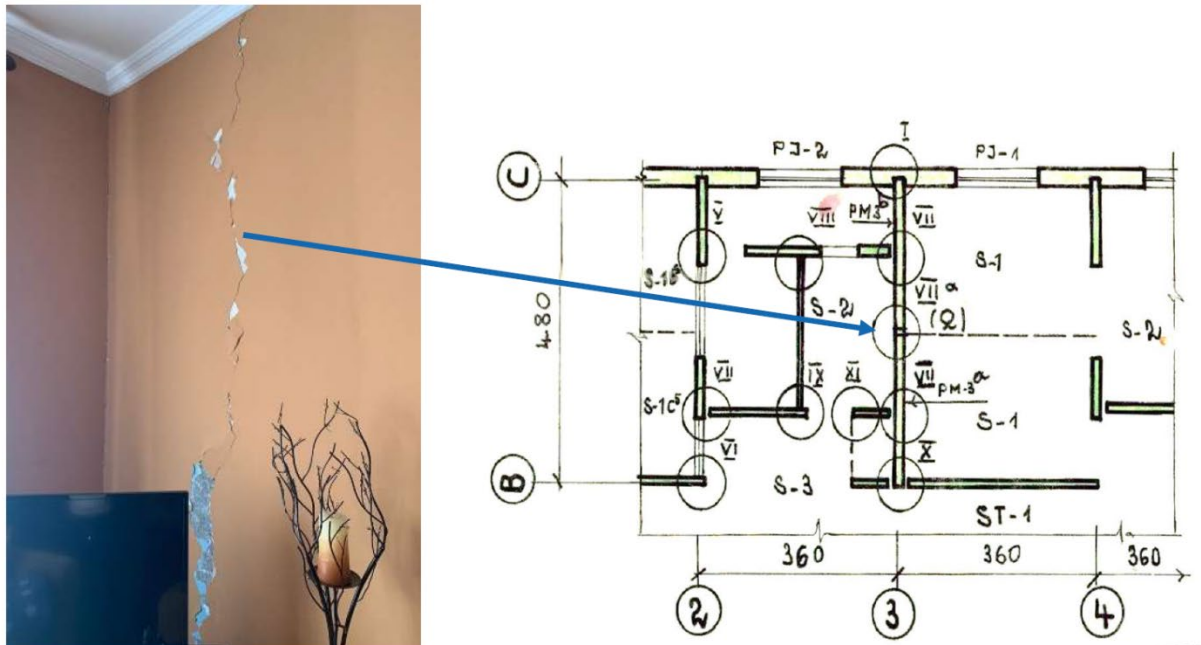
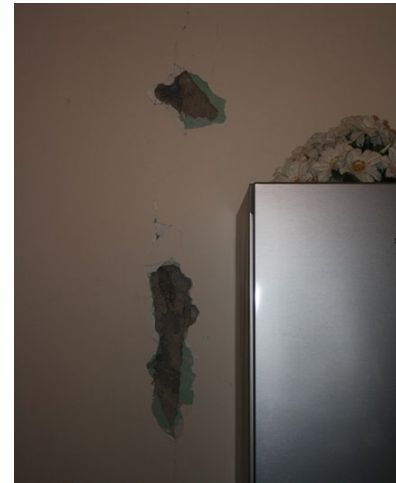


Figure 79. Cracking pattern at the interface between adjacent vertical panels (Kombinat area in Tirana) (photos: Merita Guri).

LPBs in Laç seemed to have poor maintenance, and the deterioration of exterior wall panels was visible (see Figure 80(a)). There were no external signs of earthquake-induced damage in any of the buildings. Minor cracking along the panel connections at the bottom two stories was visible from the inside. For example, vertical cracks developed along the wall panel connections, and horizontal cracks developed along the slab-to-wall connections (Figure 80-b).



(a)



(b)

Figure 80. LPBs in Laç: (a) a typical building, Module 1, and (b) cracking at the wall panel connections (photos: EEFIT).

5.3 Prefabricated Reinforced Concrete Frame Buildings (PRCFBs)

PRCFBs belong to the same period as LPBs (between the 1960s and 1990s), but wide application occurred in the 1980s. Prefabricated technology was used to optimize, speed up, and maintain the quality of construction of frame elements in these buildings, whereas masonry infill walls and finishes were constructed on site after the building erection was completed.

5.3.1 Design and construction practices

PRCFBs have been used for the construction of both residential and public buildings. Main applications were for buildings with large open spaces, especially on the ground floor. These buildings had standardized designs that were developed based on the Albanian codes of the 1960s and 1970s. International codes, such as the Chinese codes as well as an Albanian national code (KTZ 10-78, 1979),⁵⁴ were also followed at the construction stage.

In most cases, this system was used for the construction of low- to mid-rise buildings (two to six stories high); however, in the mid-1980s, the PRCFB system was used for the construction of nine-story buildings in Tirana (Figure 81) with a triangular-shaped monolithic reinforced concrete core in the center. No structural damage was reported in these buildings due to the September 2019 foreshock and the November 2019 earthquake.

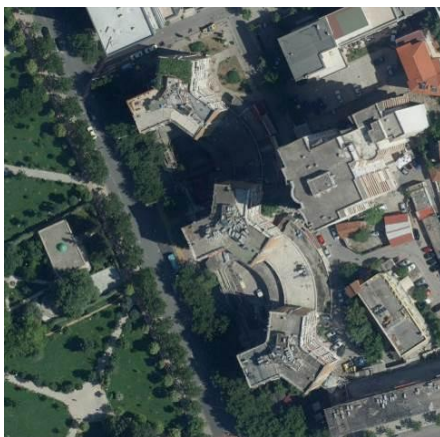


Figure 81. Nine-story prefabricated frame buildings (source: asig.gov.al and skyscrapercity.com).

PRCFBs have a spatial frame structural system. The frames have different properties (stiffness and strength) in each orthogonal direction and different structural and seismic behavior due to different span lengths, the use of one-way prefabricated slabs, partially/fully rigid connections, and infill walls. Beams and columns were designed with the same



Figure 86. Masonry infills damaged in the National Territory Planning Agency building in Tirana. Shear cracks and partial separation from the frame shown (photos: Markel Baballëku).



Figure 87. Damage of the National Territory Planning Agency building in Tirana. Frame damage was caused by the frame-infill interaction (photos: Markel Baballëku and T. Dano).

The building for the Faculty of Civil Engineering (FIN Building) at the Polytechnic University of Tirana was designed in 1981. It is a five-story building with an irregular plan shape. The building is composed of five blocks (structural units): a masonry core surrounded by four PRCFB blocks, as shown in Figure 88. The masonry core encloses the main staircase and has plan dimensions that are 12×10 m and a wall thickness ranging from 25 to 38 cm. Four PRCFB blocks surrounding the masonry core are connected to the core by means of steel connectors. The PRCFBs are designed as multi-span frames in the longitudinal direction and single-span frames in the transverse direction. The foundations are strip footings within the masonry core area and spread footings connected by tie beams in the PRCFB blocks.

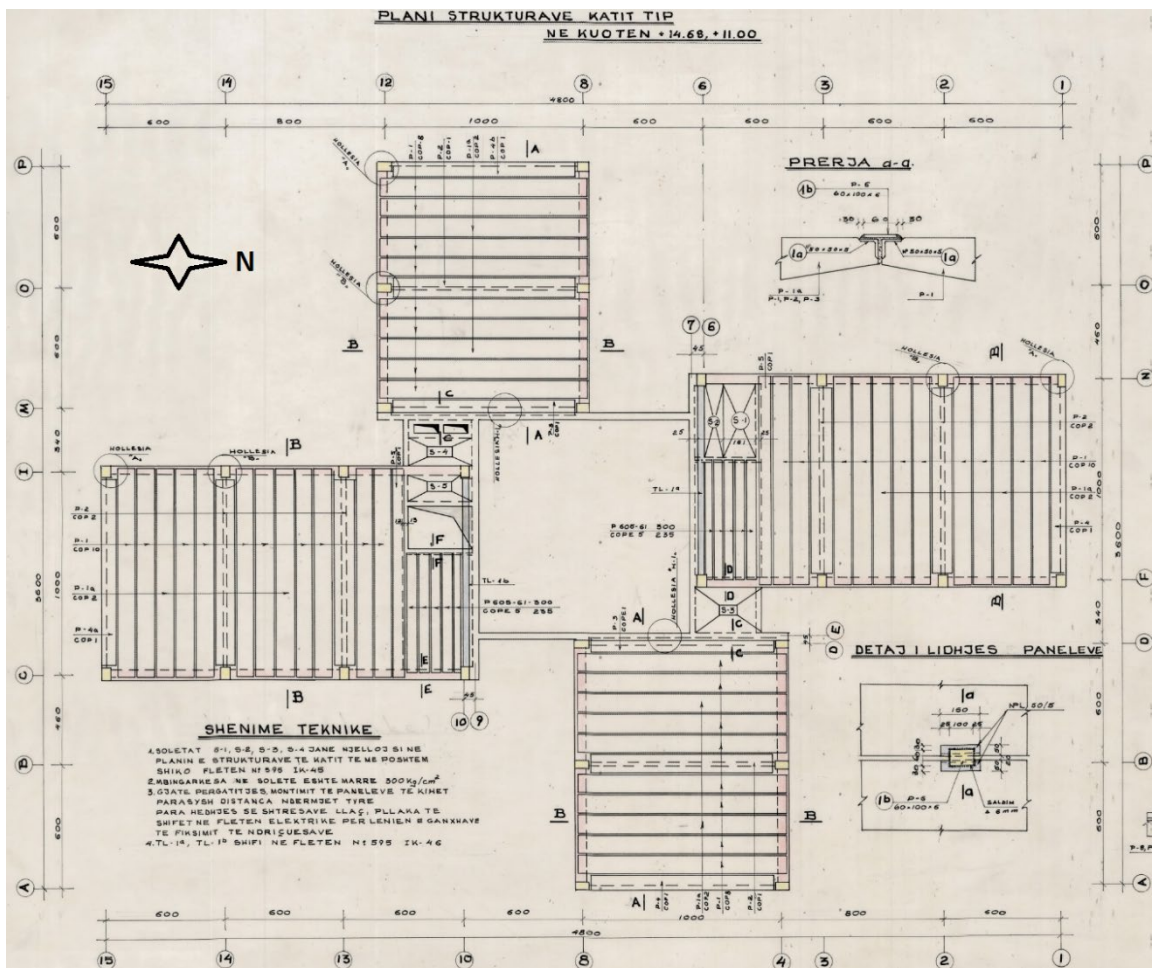


Figure 88. Structural layout of the FIN Building at the Polytechnic University of Tirana showing a masonry core (central block) and four PRCF blocks (source: Instituti i Studimeve Projektimit No. 4 – Plani Strukturate Katit Tip (1981)).

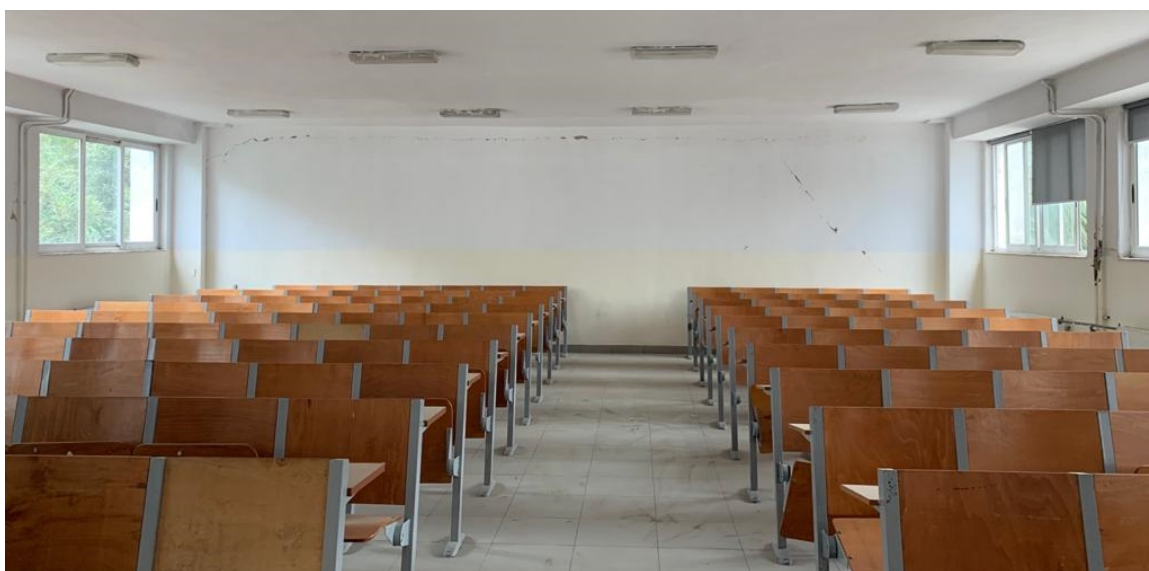
According to the available data, this building experienced moderate damage due to the January 1988 Tirana earthquake, especially in the connections and nonstructural masonry walls. The September 2019 earthquake caused damages similar to the January 1988 earthquake; however, the masonry core experienced further damage due to the November 2019 earthquake. Diagonal cracks were observed around the main entrance. Damage induced by pounding effects was also observed in the masonry core. In the PRCFBs, damage was observed only in the infill walls and one-way prefabricated reinforced concrete slabs (Figure 89, Figure 90, and Figure 91).



(a)



(b)



(c)

Figure 89. Minor damage of infill walls in the FIN Building at the Polytechnic University of Tirana: (a) the façade of the west block with cracks in the infill walls between windows, (b) façade of the south block with the infill wall separated from concrete frame (damage after the September 2019 foreshock), and (c) interior view of east block with damage and separation to the infill wall (photos: Markel Baballëku).



Figure 90. Sliding-induced cracking at the interface between prefabricated reinforced concrete slab panels in the FIN Building at the Polytechnic University of Tirana (photos: Markel Baballëku).



(a)

(b)

Figure 91. Staircase area of the FIN Building at the Polytechnic University of Tirana: (a) damage at the beam support area and (b) an exposed reinforced concrete column after the inspection (no damage observed) (photos: Markel Baballëku).

5.4 Conclusions

It can be concluded that prefabricated reinforced concrete structures performed well in the November 2019 earthquake. There are two types of prefabricated reinforced concrete buildings in Albania, namely, Large Panel Buildings, which were mostly used for housing construction, and prefabricated reinforced concrete frame buildings, which were used for the construction of public buildings. These two prefabricated building typologies have different structural systems and dynamic properties and exhibited different damage patterns due to the November 2019 earthquake.

Although a significant number of LPBs were exposed to the earthquake, they either remained undamaged or experienced minor damage. Good seismic performance of these buildings can be explained by the robustness of these buildings and their appropriate seismic resistance. Also, rigid structures that are characterized by small fundamental periods usually experience less damage in earthquakes, especially in soft soil areas, compared with flexible structures characterized by larger fundamental periods (such as PRCFBs). There is a significant redundancy in the LPB system due to a significant amount of structural walls, particularly in transverse (cross) direction. It was observed that the damage was concentrated within panel connections, whereas the panels remained undamaged. It is expected that a failure mechanism for these buildings at higher seismic intensities will be characterized by more extensive damage of the connections due to shear-induced sliding behavior ("strong panels–weak joints"), whereas the panels will remain mostly undamaged. It is recommended that the seismic retrofitting of panel connection regions be undertaken in order to enhance their seismic safety for future earthquakes.

PRCFBs were mostly used for the construction of public buildings in Albania; hence, fewer buildings of this type were exposed to the November 2019 earthquake compared to the LPBs. Based on the post-earthquake building inspection as well as the seismic assessment, it can be concluded that the structural performance of PRCFBs in the November 2019 earthquake was satisfactory. These buildings experienced moderate nonstructural damage and minor structural damage in the connections between prefabricated elements due to considerable lateral drifts. In many cases, damage of these structures in the Tirana area initially occurred because of the September 2019 foreshock.

6 PERFORMANCE OF CRITICAL FACILITIES

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6.1 Introduction

This section presents a summary of the observed performance of school and healthcare facilities during the earthquake on November 26, 2019.

Following the earthquake, the "Post-Disaster Needs Assessment" (Government of Albania et al., 2020),⁵⁵ an actionable and sustainable recovery strategy plan for mobilizing financial and technological resources, was completed by the Government of Albania with support from the European Union, the United Nations, and the World Bank. Healthcare infrastructure was estimated to require 9.93 million Euros for recovery and reconstruction.

6.2 Performance of Schools

6.2.1 Typology of school buildings in Albania

As with other structures (section 2.2), there is a rather clear distinction between school building typologies before and after 1990 in Albania. A distinction is made in this report between pre-university school buildings and university buildings because of their specifics, as discussed below.

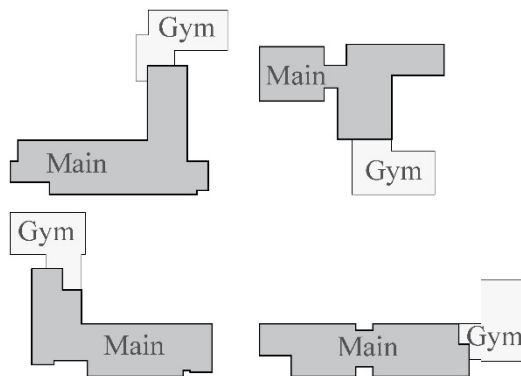
Pre-university school buildings before 1990 were typically one- to four-story masonry or confined masonry structures. Within urban areas of Durrës and Tirana, school buildings typically have three to four stories. School buildings built after 1990 are predominantly made of reinforced concrete with structural characteristics similar to residential buildings (see section 2.2). Examples of typical pre-university school buildings are given in Figure 92(a) and (b). Elongated, almost rectangular, planar layouts are common, even in modern reinforced concrete schools. Irregular layouts are also found, especially in schools designed between 1960 and 1980 (refer to Figure 92(c) and Baballëku (2014)⁵⁶ for more details and examples).



(a)



(b)



(c)



(d)

Figure 92. Typical school buildings in Albania: (a) a masonry pre-1990 school, (b) a reinforced concrete modern school (photos: Markel Baballëku), (c) examples of template designs for schools before 1990 (source: Baballëku, 2014), and (d) two structurally independent units of the "Shaqe Mazreku" school building in Durrës (photo: Markel Baballëku).

As mentioned earlier, the design of structures during the communist rule was performed and controlled by centralized institutions. The use of "template designs" was common: A typical school was designed, and several schools were built based on that design. The design sheets contained notes and typical details that allowed the adaptation of the template design for various conditions (for example, by providing notes about the thickness of the walls and materials depending on the seismicity and weather). Examples of template layouts are given in Figure 92(c). Gym buildings or other annexes serving different purpose are commonly present, as illustrated in Figure 92(c). In both older and newer schools, these

annex buildings or floor extensions are typically structurally independent (separated by a joint from the main school building), as shown in Figure 92(d). The annex buildings, especially when used as a gym area, are flexible, often made of reinforced concrete frames, and quite different from the rigid main structure. The use of prefabricated slab panels is very common.

According to Baballëku (2014), based on a database compiled by the Ministry of Education in 2004, there are almost 500 school buildings built before 1990 in the area affected by the earthquake that occurred on November 26, 2019 and fewer newer reinforced concrete ones.

University buildings are very different from pre-university ones. Most of these buildings are located in Tirana, but smaller universities (public and private) are also found in Durrës. These buildings have unique designs that vary significantly between them. The majority of university buildings follow the trends described in section 2.2 regarding materials and typologies (before and after 1990), but there are some exceptions. For instance, reinforced concrete frames are found in some university buildings built before 1990, for example, the building hosting the Faculty of Civil Engineering at the Polytechnic University of Tirana (refer to section 5.3 for a detailed description of this building).

With the natural population growth and the rapid densification of Tirana and Durrës after 1990, several modifications have been made to existing schools throughout the years to expand their area. The most common interventions have been the addition of stories and the expansion of floor area by building adjacent new structures. In a few cases, such as the building of the Faculty of Civil Engineering in Tirana, buildings previously designed for other purposes changed destination and were used as school buildings. The Faculty of Civil Engineering building in Tirana was initially designed as "Institute no. 4 for study and design—ISP4". It is worth mentioning that the seismic design code currently in force KTP-N.2-89 (Academy of Sciences and Ministry for Construction, 1989), implies an increase of the seismic demands for school buildings compared with ordinary buildings.

To combat aging and deterioration of existing school buildings, many schools have been refurbished throughout the years (Mezini, 2016).⁵⁷ The refurbishment is typically focused on the improvement of conditions (heating, ventilation, fire safety, laboratory equipment, etc.), replacement of deteriorated materials (roofs, tiles, windows, etc.), and structural repairs when necessary but not on a seismic upgrade of the existing schools.

6.2.2 Damage patterns and examples

Based on a briefing of the Minister of Education two months after the earthquake (Komisioni për Edukimin dhe Mjetet e Informimit Publik, 2020),⁵⁸ 56 pre-university school buildings were heavily damaged (damage states 4 and 5 on a scale of one through five). Although major collapses did not occur, damages were severe enough to declare these school buildings unsafe, requiring either demolition or major retrofitting. According to the same briefing, another 66 school buildings suffered damages classified into damage states 2 and 3, and further analysis and verification was required for 151 buildings with apparently light damage.

Damages were encountered in both pre- and post-1990 schools. For masonry structures (typically pre-1990), the most severely damaged schools suffered in-plane shear failure of the load-bearing walls. Based on the limited reconnaissance conducted by the authors, out-of-plane wall failures and the unseating of slabs were not encountered in contrast with masonry residential buildings (section 4), in which such failure modes were present in some cases.

A two-story masonry school in Thumanë was among the most damaged. It was declared unsafe and demolished subsequently. The school was built in the 1970s and recently refurbished. Its structure was regular, symmetric about one axis, and relatively small compared to schools in Tirana and Durrës (approximately 34×11 m). A general view of the school is shown in Figure 93(a). Although limited damage was visible from the exterior of the school, the structure was severely damaged in the interior. A failed masonry wall can be seen in Figure 93(b). From limited investigation due to safety concerns, only in-plane failures were detected. After uncovering the plaster and thermal coating of the façade, it was observed that the masonry piers between the windows were also damaged and deteriorated because of aging. It has been reported that the same school had suffered structural damage from a M5.1 earthquake on July 4, 2018.



(a)



(b)



(c)

Figure 93. Severely damaged school in Thumanë: (a) the exterior of the school, (b) shear failure of a wall, and (c) damaged masonry piers (photos: Markel Baballëku).

A school in Pezë was also considered unsafe and demolished (Figure 94). The two-story structure was made of masonry with silicate solid bricks. The first story was covered by narrow prefabricated panels, whereas the second story was covered by a timber roof. Diagonal cracking of the walls was visible from the exterior in this case (Figure 94(a)). Damage at the slab panels and the slab-wall connection was present. In several locations, the walls were disconnected from the slab, constituting a hazard for out-of-plane collapse (Figure 94(b)).



(a)



(b)

Figure 94. Severely damaged school in Pezë: (a) diagonal cracking of second story walls and (b) damage from the inside (photos: Markel Baballëku).

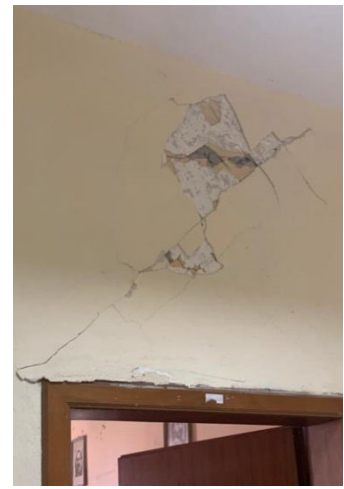
A school in Shijak (near Durrës) that was built in 1983 suffered damage during the earthquake (Figure 95). The case of this school is special because it originally had three stories and a masonry structure, but a fourth story was added in 1988. Damage at the junction of the old building with the new story is visible from the exterior of the building (Figure 95(a)). From the inside, the building suffered severe damage of the plaster, both in the old structure (with solid bricks) and the new story (containing hollow bricks; Figure 95(b)). Diagonal cracking of the spandrels above doors was also present (Figure 95(c)). Examples of minor structural or nonstructural damage to masonry schools in Durrës and Maminas is shown in Figure 96.



(a)



(b)



(c)

Figure 95. School in Shijak with damage concentrated near the added story: (a) Exterior of the school, (b) a damaged wall at fourth floor, and (c) damage above door openings (photos: Markel Baballëku).

Ground-floor exterior columns were severely damaged in this school. The interior columns suffered damage, too (Figure 97(d)). Damage was concentrated at the column's section near the beam-column connection of the ground floor. Excessive plastic lateral deformation of the structure was present at the end of ground shaking, as can be induced by Figure 97(b) and (c). These figures show also that the severely damaged columns had only one Ø8-mm hoop encircling the 12 longitudinal Ø20-mm bars. The hoops were not anchored into the concrete core but bent at 90°. Figure 97(c) indicates that the anchorage of the hoops was insufficient because the hoops opened. Nonstructural damage (damage to infill walls) was extensive in this school, as shown in Figure 97(e).



(a)



(b)

Figure 96. Minor structural or nonstructural damage to masonry schools: (a) damaged plaster at a three-story school in Durrës and (b) deteriorated materials and damage likely aggravated by the earthquake in a two-story school in Maminas (photos: Markel Baballëku).



(a)



(b)



(c)



(d)



(e)

Figure 97. Severely damaged reinforced concrete school in Durrës: (a) a general view, (b), (c), (d) damaged columns, and (e) nonstructural infill damage (photos: Markel Baballëku and M. Carmi).

Although fewer in number, damages in reinforced concrete school buildings were encountered as well. Typical damages in these types of schools were similar to those encountered in residential buildings (section 5), which was mostly nonstructural damage to the infill and partition walls. The school "Neim Babameto" in Durrës represents a case of severe structural damage. This is a relatively new four-story school (Figure 97(a)). The structure consists of reinforced concrete spatial moment-resisting frames (no shear walls). The stories are of the same height, and the structure is regular in elevation. The beams in this structure are deeper than the slab, unlike the wide/shallow beams that are often used in residential buildings (section 5). The school had a rectangular grid of columns with a spacing of approximately 5 m in the longer direction and 6m – 3m – 6m in the shorter direction. Columns were square, with 300×300 mm sections in the exterior, and the beams were 300 mm wide and 500 mm deep. The beams were more heavily reinforced than the columns, especially for hogging bending moments. While also considering the dimensions of the columns and beams mentioned above, it appears that this building had a strong beam–weak columns configuration.

6.2.3 Societal impact and crisis management

Teaching activities were temporarily interrupted until December 2, 2019, all over Albania, except for Tirana, Durrës, Vorë and Kurbin, in which teaching activities resumed only on December 9, 2019. Some 21,000 students from damaged schools were temporarily displaced to undamaged school buildings or temporary teaching centers to follow the normal teaching activities. Because the main shock struck at night, the school buildings were largely unoccupied by students, and no casualties were reported.

It is worth mentioning that there were many schools that either did not suffer any damage whatsoever or suffered very minor nonstructural damage. Examples of good performance can be found in both older (typically masonry) and newer (typically reinforced concrete) schools. These undamaged buildings served for very important purposes after the earthquake, such as shelter and for the continuation of classes for the students from damaged schools.

6.2.4 Conclusions

The earthquake brought to light issues with the safety of school buildings in Albania. Although global collapses did not occur, a considerable number of schools in the earthquake-affected areas around Durrës and Tirana were severely damaged and deemed unsafe. Masonry schools, which are in fact the oldest but also more in number, suffered the most. Cases of damaged reinforced concrete schools are also present, although they are fewer in number. The major issues encountered are summarized below.

- Diagonal cracking of load-bearing masonry walls and damages near window/door openings in severely damaged masonry schools occurred.
- Several damages can be attributed to interventions throughout the years (for example, the addition of stories, extension of floor areas, new openings or closures of existing openings, etc., without due consideration about the effects on seismic safety).
- The light cracking of masonry and damage to plaster, parapets, and other nonstructural elements are widespread in masonry schools.
- There were issues related to seismic joints between two adjacent building blocks; although this type of damage is expected and easily repairable, it can cause panic to the occupants.
- Issues related to deterioration of materials and lack of maintenance occurred. Because of the lateral displacement that took place during the earthquake, the damage caused by aging and deterioration became more pronounced and led to uncertainties in the seismic safety evaluation process after the earthquake.

Although prefabricated slab panels are widely used in masonry schools (especially those built based on template designs), to the best of the authors' knowledge, major failures such as those encountered in Thumanë in residential buildings did not occur in schools. A likely explanation is the higher lateral stiffness caused by the limitation of the number of stories to only four, the higher "importance factor" applied in the Albanian design codes for schools (leading to an increase of the design seismic demands for which these buildings are verified), and the higher quality of workmanship and materials compared with Thumanë. In this context, it is recommended to pay special attention to educational facilities that were not initially designed as school buildings with an increased importance class.

It is worth noting that, in general, interventions to existing school buildings throughout the years in Albania have not been focused primarily on seismic safety but on the improvement of conditions for use (heating, architectural aspects, replacement of deteriorated materials, etc.). For the near future, it is recommended to pay more attention to the seismic safety of schools alongside the improvement of conditions. An example of a potential strategy that can be followed is based on "Incremental Seismic Rehabilitation of School Buildings, K-12" (FEMA, 2003)⁵⁹ and adapted for the specifics of school buildings in Albania. Based on this strategy, the seismic rehabilitation of school buildings can be performed over a period of several years, prioritizing interventions that are more urgent for ensuring safety of the occupants. An appropriate time to perform nonurgent structural rehabilitation works, for example, is when refurbishment works are scheduled (replacement of windows, roof repair, plaster, tiles, etc.).

Additionally, it is important to have an up-to-date detailed database on the condition of existing school buildings, a program for continuous monitoring of the state of these buildings, and detailed studies on the seismic vulnerability and risk of school buildings. Works that can serve as a starting point and be further extended and improved to accomplish the latter include Baballëku and Pojani (2008)⁶⁰ and Baballëku (2006, 2014).⁶¹

6.3 Performance of Healthcare Infrastructure

Based on the level of healthcare services provided, healthcare facilities in Albania are divided into primary level (primary healthcare centers, polyclinics and municipality hospitals), secondary level (regional and specialized hospitals) and tertiary level hospitals ("Mother Teresa" University Hospital Center (QSUT) in Tirana).

Secondary and tertiary level facilities comprise buildings constructed in different time periods ranging from the 1930s to recently. Several typologies of construction interventions can be found on these facilities: a) rehabilitating existing buildings with a focus on services and comfort improvement, b) increasing hospital capacity by adding new spaces on existing buildings, and c) adding new units or rebuilding old ones to increase hospital capacity.

Hospital building structures are generally composed of more than one independent structural unit. Functionally, the units are connected to each other. The connection of different structural units is made through seismic gaps or bridges. Typically, the units are structurally regular, although the overall shape of the building composed of several units might appear irregular.

Different structural typologies have been employed for hospital buildings in Albania. The oldest hospital buildings were designed and constructed by employing load-bearing masonry structural systems. In some cases, confined masonry structures or combined systems (concrete plus masonry) were employed. Between the 1960s and 1990s, cast-in-place and prefabricated reinforced concrete structural systems became more prevalent. After the 1990s, the majority of hospital buildings were built as cast-in-place reinforced concrete structures that were mostly reinforced concrete frames with brick masonry infills.

Masonry structures are usually supported on cyclopean, plain, or reinforced concrete strip foundations, whereas reinforced concrete building structures are generally supported on spread footings connected with tie beams. Mat foundations have also been used in newer hospital buildings. Hospital buildings in Albania are covered by either a roof or a reinforced concrete slab.

6.3.1 Primary healthcare facilities

After the November 2019 earthquake, initial medical help was immediate and effective. Neither significant delays nor the inability to help the injured inhabitants were reported because the majority of healthcare facilities did not suffer any major damages from the earthquake. In addition to this, the primary healthcare facilities, which are larger in number and well distributed in the affected areas, had not suffered significant damage, and, consequently, those were immediately operational. Only in a few peripheral areas was medical help provided to panic-affected people outside the healthcare buildings. The medical services were transferred to a temporary shelter because of the damage to the hospital buildings at the Ishmi healthcare center near Durrës (Figure 98).

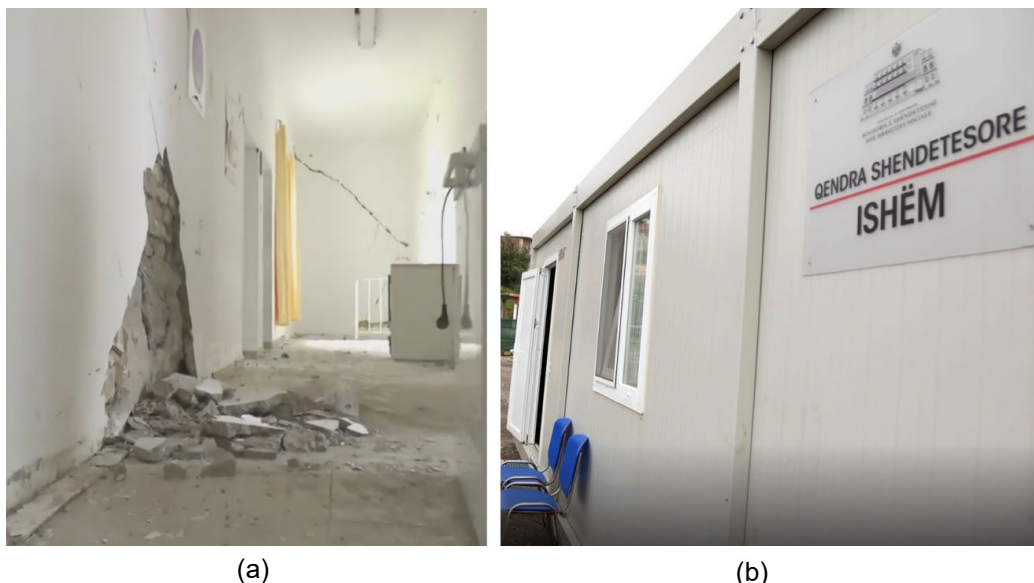


Figure 98. *Ishëm healthcare center suffering damages from November 2019 earthquake: (a) the damaged hospital building and (b) temporary shelter for healthcare services (source: https://www.youtube.com/watch?v=iQnEyL_PIE&list=ULbzHFOD3Cgw0&index=35624; https://www.youtube.com/watch?v=Wxk06YFdiro&feature=emb_err_woyt).*

6.3.2 Hospitals

6.3.2.1 “Mother Teresa” Hospital Center - QSUT

The “Mother Teresa” Hospital Center in Tirana – QSUT in Tirana consists of 13 buildings designed and constructed mostly between the years 1957 and 1990. The first building was designed and constructed out of unreinforced masonry in 1928 (Islami, Thomai, and Tuxhari, 2016),⁶² whereas the latest one was constructed with cast-in-place reinforced concrete. The buildings are mostly two to four stories high with various main materials (unreinforced masonry, prefabricated reinforced concrete, and cast-in-place concrete). Some of the buildings have basements. The masonry buildings were designed mainly as unreinforced masonry, but in some cases, reinforced concrete frames can be found inside the structure because of requirements for large interior spaces. Buildings built after the 1980s are designed as confined masonry buildings. The wall thickness of masonry buildings ranges between 25 and 51 cm. The masonry walls are generally composed of clay or silicate bricks with a compressive strength of 8 to 13 MPa and a structural mortar strength of 2.5 to 5 MPa. In the case of concrete structures, the concrete compressive strength varies from 20 to 30 MPa for cast-in-place buildings and above 30 MPa for prefabricated structural members. Reinforcement steel strength varies between 210 and 240 MPa.

Damages to QSUT were very limited. The distance from the epicenter and the consideration of these buildings as important during design might have contributed to this lack of damage. Limited nonstructural damage was reported (cracked plaster and other minor damages). An example of a minor structural crack in a reinforced concrete prefabricated beam in a prefabricated frame building is shown in Figure 99.



Figure 99. Minor cracks on a prefabricated concrete beam at ground floor of a prefabricated frame building in QSUT (photos: Markel Baballëku).

6.3.2.2 Durrës Healthcare Center

The construction of the Durrës Healthcare Center started during the 1950s. The healthcare center has undergone many functional changes and improvements over the years. The first major refurbishment took place in 1976 included the addition of the pediatric hospital building. The last intervention was from 1998 to 2010 when two of the most important buildings of the facility were constructed. Both these buildings were designed and constructed as reinforced concrete frame structures with masonry infills.

The Durrës Healthcare Center suffered minor damage during the main shock on November 26, 2019. The hospital staff reported more damage to the building after the M5.3 aftershock on November 28, 2019. The aftershock caused panic to hospital staff and patients for about an hour. The subsequent inspection showed that most of the damages were limited to infill walls. Some photos are presented in Figure 100.



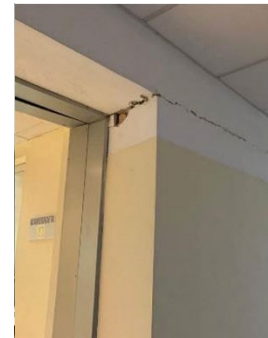
(a)



(b)



(c)



(d)

Figure 100. Damage patterns in the healthcare center of Durrës: (a) slight damage to exterior infill walls, (b) interaction with an external elevator, (c) shear cracks in infill and partition walls, and (d) damage at seismic joints (photos: Chiara McKenney).

6.3.2.3 Kruja Hospital

The Kruja Hospital was built from 1975 to 1976. The building shape is irregular in plan, and it is composed of at least two independent structural units. One of the units is a reinforced concrete frame structure with masonry infill walls, and the other one is a confined masonry structure. As the buildings are constructed on a sloping terrain, they have a different number of floors in the front and rear, making each building irregular in elevation.

Minor to moderate damage was observed. Shear cracks are the main damage pattern and are largely concentrated around openings that were mainly created during previous structural interventions (openings of new doors in structural walls).

The three-story administrative building constructed as a reinforced concrete frame with masonry infill walls suffered moderate damage in its entrance area where one of the columns was damaged (shear cracks near to the joint). The administrative building was evacuated after the earthquake and was subsequently demolished (Figure 101).



Figure 101. Demolition of administrative building of the Kruja hospital building (photo: Aida Dedja).

6.3.3 Observed earthquake damage on healthcare centers

The hospital buildings sustained the following damage patterns after the November earthquake:

- damages to seismic joint area due to inadequate seismic gaps;
- diagonal cracks to masonry infill walls and separation of masonry infill walls from the concrete frames;
- corner masonry wall cracks at the top story in the case of masonry structures;
- cracks on parapets;
- the small deformation of steel connections of prefabricated elements;
- hairline cracks in concrete members;
- relative sliding of adjacent slab panels, confirming the absence of rigid diaphragms;
- steel rebar deterioration due to an insufficient or damaged concrete cover.

6.3.4 Health system resilience

The healthcare facilities performed adequately against the seismic action of the earthquake shaking on November 26, 2019. Most of the buildings were not damaged or suffered minor damages and were operational after the earthquake. Only a few healthcare facilities were evacuated, and their services were adopted in adjacent buildings or temporary shelters.

6.3.5 Conclusions

Although heavy damages did not occur, some healthcare facilities in the earthquake-affected areas were exposed, and some were considered unsafe. Slight and moderate damages were present in both masonry and reinforced concrete structures, as summarized below:

- shear cracks in structural and nonstructural masonry walls, especially near weakened zones (windows and doors openings);
- local damage to seismic joint areas;
- damages attributed to structural interventions made for improving functionality that did not thoroughly consider seismic safety implications (for example, addition of stories, new openings adjacent to the existing ones, removal of structural or nonstructural walls, etc.);
- deformations of steel connections of prefabricated elements and small concrete cracks.
- rebar deterioration due to a lack of concrete cover;
- relative sliding of adjacent slab panels, indicating the presence of inadequate rigid diaphragms;
- damages to nonstructural elements, such as plaster, parapets, installation shafts, etc.;
- issues related to deterioration of materials as well as lack of maintenance.

Although the hospital buildings did not suffer severe damage or catastrophic collapse, it is important to ensure their safety against future events and to reduce uncertainties. Recommendations include the development of an inventory of all the hospital buildings that includes their general condition, seismic capacity, and structural weaknesses and the development of retrofitting strategies and intervention plans for hospital buildings that can be used when needed. Special attention is needed in addressing issues with infill walls in reinforced concrete hospital buildings. As it was discussed in section 4.4, these walls can be a major source of hazard, and they can cause interruptions that are unacceptable for hospital buildings.

7 HERITAGE AND RELIGIOUS STRUCTURES

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7.1 Heritage Structures

Albania has a rich history and a large presence of built heritage around the country. The report published by the Government of Albania and its international partner soon after the November earthquake locates 352 monuments/sites and 41 protected zones in the earthquake-affected areas (Government of Albania et al., 2020). Multiple historic buildings and monuments were affected by the November 2019 earthquake. An analysis of the damage that occurred to ancient masonry buildings is the necessary first step to understand the seismic behavior of their structural components. This section presents the damage observed at the heritage sites of Krujë, Prezë, and Durrës (Figure 102).



Figure 102. Location of the castles visited by the Earthquake Engineering Field Investigation Team (EEFIT) Team. Tirana shown for reference (source: Google Maps).

7.1.1 Durrës Castle

The castle was built in the first century BCE and acquired its final form in the fifth century during the rule of Byzantine emperor Anastasius I Dicorus. The fortification walls were devastated in the 1273 earthquake and had to be extensively repaired (Wikipedia, n.d.).⁶³ The castle was reinforced with several guard towers under the Republic of Venice (Figure 103(a)), whereas the walls were reinforced during the Ottoman Empire. The walls present different typologies of stone and brick masonry. Signs of the alterations and repairs of the walls and towers are visible, including local reconstruction of masonry walls and provision of metal ties for stitching the wall corners at the exterior (see Figure 103(b)).



(a)



(b)

Figure 103. Alterations and repairs of the Durrës Castle: (a) the Venetian tower and (b) gate tower (photos: EEFIT).

The damage caused by the November 2019 earthquake was concentrated in the tower gate located at the intersection between Anastas Durrsaku Street and Xhamia Street. A view of the tower before and after the earthquake is presented in Figure 104. The tower has a squared shape and is offset toward the road with respect to the fortification walls. By observing Figure 104(a), it is possible to identify different masonry technologies possibly associated with numerous alterations over time. The north façade shows a stone masonry base course supporting brick masonry walls. Toward the top, the wall changes from brick to stone masonry. On the contrary, the west façade was constructed with uniform stone masonry except for the merlons, which show a different type of stone masonry. The local repair of stones with brick is also visible on the wall. The stone masonry at the merlons appears to be in poor condition, with a visible decay and loss of mortar. Different types of masonry are connected at the corner, where the two walls rely on a poor interlocking, if any. Although it was not possible to access the interior of the tower, it was possible to observe extensive vegetation on the interior wall surface, which is a sign of a lack of roofing but also a lack of maintenance before the earthquake, possibly leading to the earthquake damage.



(a)



(b)

Figure 104. North (N) and west façade (W) of Durrës Castle before (a) (source: Google Maps) and after (b) the November earthquake (photot: EEFIT).

The type of failure observed in the tower consisted of the failure at the corners, which resulted in the obstruction of pavement and a part of the road due to the out-of-plane collapse of the masonry walls. Figure 105 shows a significant presence of roots on the failure plane of the north wall, whereas the failure plane on the west wall is vertical and regular, suggesting the absence of an interlocking between different masonry segments. Also, it appears that an exterior layer of masonry was added at a later stage but without transversal connectors to the existing masonry. This technique for increasing the thickness of existing masonry walls in defensive architecture structures was practiced during the Ottoman period (Nicolle, 2010).⁶⁴

The collapsed material is quite varied (Figure 104(b)), and the masonry appears to have failed in blocks, which can be explained by the presence of very thick mortar joints, which are generally thicker than the masonry units (Figure 106). It is unknown whether the existing brick masonry is a part of the original wall or a result of a more recent alteration; this construction practice was quite common in the Byzantine time, particularly in seismic areas and/or in soft soil conditions (Binda, Tedeschi, and Baronio, 1999).⁶⁵ Studies on similar masonry structures showed that this type of material behaves more like concrete than mortar because its aggregate size reaches values closer to a modern concrete (Baronio, Binda, and Tedeschi, 1997).⁶⁶



Figure 105. View of the north (N) and west façade (W) of the damaged tower at Durrës Castle (photo: EEFIT).



Figure 106. Close-up view of the collapsed masonry wall with thick mortar joints (photo: Federica Greco).

7.1.2 Krujë Castle

The castle is located on a hilltop overlooking the town of Krujë and is considered as the symbol of Skanderbeg's rebellion against the Ottoman Empire. It is considered as one of the most significant medieval heritage structures in Albania. Within the castle area, there are a number of monuments, some of which experienced significant damage in the earthquake. The

castle is surrounded by fortification walls and sits on a rocky substructure formed by different blocks of rocks fallen off the mountain that constitute the base of the castle. “The Preliminary Technical Assessment of the Architectural and Archaeological Heritage in South East Europe,” published by the European Commission and adopted by the Ministry of Tourism, Culture, Youth, and Sports in 2006, reports that the rocky substructure located under the clock tower and under the southwestern wall close to the Tekke of Dollma (a religious building that will be discussed in section 7.2) is in dangerous condition because of earthquake-induced fissures and cavities (Regional Programme for Cultural and Natural Heritage in South East Europe, 2006).⁶⁷

The concerns related to the geological stability of the rocky hill led to a series of interventions in critical areas, such as the installation of anchors that are visible on the hill side near the clock tower. The earthquake caused the formation of some new cracks in the ground around the tower.

The clock tower also experienced extensive damage due to the November 2019 earthquake. The tower is an unreinforced stone masonry structure dating from the twelfth century, with a quasi-pyramidal shape at the bottom and a squared geometry at the top. Access to the tower is at the front and rear sides through two doors located at different levels. A timber staircase connects the entrance to the top floor. The structure underwent a series of interventions. The first intervention took place in the 1920s and 1930s and consisted of a masonry reconstruction at the middle portion of the tower. The second intervention took place in the 1970s with an aim to reconstruct the top of the tower and included the introduction of a rigid reinforced concrete floor (possibly with ring beams) and columns with tuff cladding supporting the timber roof.

A view of the tower before and after the earthquake is shown in Figure 107. The type of failure observed is a global mechanism consisting of long vertical cracks in the walls and a significant out-of-plane displacement of the masonry walls toward the corners. No damage is observed on the belfry at the top of the tower, which proves the negative effect of the rigid floor system that was a part of the 1970s intervention. Such a high rigidity is usually not compatible with historic masonry and is often the source of earthquake damage.

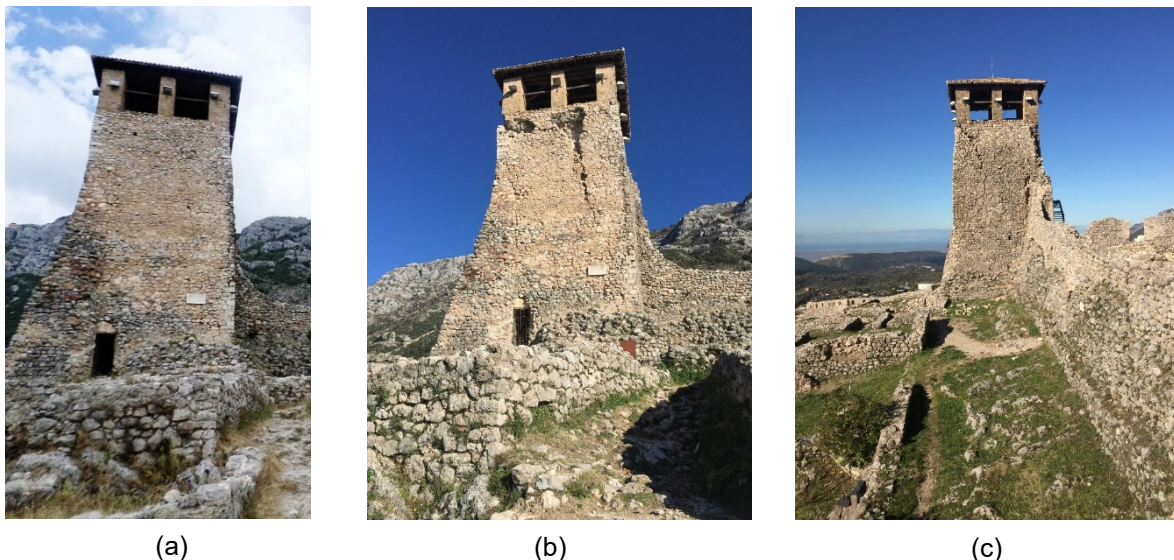


Figure 107. A view of the tower at Krujë Castle: (a) front view before the earthquake in 2005 (source: copyright image available at https://commons.wikimedia.org/wiki/File:Krujë_Watchtower_and_Castle_Walls.JPG), (b) front view after the earthquake, and (c) side view after the earthquake (photos: EEFIT).

The seismic performance of historic masonry towers depends on several parameters, including the soil-structure interaction, slenderness, quality of materials, presence of openings, walls, interlocking and typology of floors (Formisano and Milani, 2019).⁶⁸ The intrinsic critical vulnerabilities of this structural typology can be further aggravated because of inadequate restoration works that were implemented without proper understanding of the properties of existing materials (Colapietro et al., 2015).⁶⁹ Studies on the structural behavior of towers under seismic loading were performed to evaluate the performance of different retrofitting techniques. Tying of the walls using steel rods has been proven to increase the out-of-plane capacity of towers, whereas the replacement of the old timber floors and roof with reinforced concrete slabs,

which is widely used as a restoration technique, affects the mass and stiffness of the structure and leads to undesirable changes in dynamic behavior (Stavroulaki, 2019).⁷⁰

7.1.3 Prezë Castle

The castle was built in the fifteenth century and follows the geologic formation at the hilltop, resulting in an irregular pentagonal shape at the base and towers constructed at each corner that are connected to the fortification walls (Figure 108). The towers have a circular shape with the exception of one tower, which was converted into a 14.5-m high clock tower in 1852. The clock tower has a square shape (4.2×4.2 m) and two stories accessible through an internal staircase. The tower has lost its original Ottoman features, which are visible from the archive photos (Mustafaraj and Yardim, 2014)⁷¹ (Figure 109). The photos capture the damage of the towers reported in different periods, which was most likely due to earthquakes. The current configuration of the tower is the result of a series of alterations that occurred over time. Mustafaraj and Yardim (2014) conducted a structural assessment of the tower in 2014 and provided information on the pre-earthquake condition of the tower. The results of the assessment identified the need for retrofitting because of the surface degradation and structural cracking in the masonry structure that propagated over the entire height, with the most significant cracking observed on the east side. Intervention was undertaken in the summer of 2019, probably with the intention of adding an internal steel structure to support a staircase and providing access to the top floor. The intervention appears to have also included the installation of steel ties (Figure 110).



Figure 108. Painting of the Prezë Castle located on the wall of the restaurant within the castle (photo: Federica Greco).



Figure 109. Damage of the tower in the Prezë Castle at different time periods (source: Mustafaraj and Yardim, 2014).



Figure 110. Photos showing the intervention on the tower undertaken in the summer of 2019 (source: <https://www.facebook.com/LeonKonstruksion/photos/a.380581722076822/1671278643007117/?type=3&theater>).

A view of the tower before and after the earthquake is presented in Figure 111. From Figure 111(b), it is possible to observe that the clock tower completely lost the roof and the columns framing the top floor. Figure 112 shows the opposite side of the tower, where the damage is more extensive and includes the loss of masonry in the upper third of the tower height (below the top floor).



(a)



(b)

Figure 111. View of the tower: (a) before (source: <https://qarkutirane.gov.al/2015/10/23/castle-preza/> accessed 2020) and (b) after the earthquake (source: EEFIT).



(a)



(b)

Figure 112. Damage of the clock tower at the south side (a) and close-up of the damaged portion (b) (photos: EEFIT).

Masonry walls reinforced with anchors resisted the out-of-plane seismic vibrations by activating the parallel wall and/or the internal steel structure and engaging the shear capacity of the transverse walls. Vertical cracking was observed between the ties, but some of these cracks could have developed before the November 2019 earthquake.

The damage was also observed in the north tower (Figure 108), which has a circular shape and stone masonry walls. Visible alterations of the original tower observed during the visit included the introduction of a reinforced concrete slab to create a terrace at the roof level (Figure 113(a)) and a new building on the side of the fortification walls adjacent to the tower (Figure 113(b)). The damage occurred in the exterior wall of the tower facing the cliff, which is the most vulnerable location because of the lack of confinement provided by adjacent structures. The masonry collapsed out-of-plane,

whereas the new reinforced concrete slab remained undamaged (Figure 114). The presence of the new, heavy floor activated a larger seismic mass and resulted in an increased seismic demand for overturning capacity on the wall.



(a)



(b)

Figure 113. View of the tower and an alteration of the original configuration: (a) the new reinforced concrete slab and (b) new constructions adjacent to one side of the tower (photos: EEFIT).



Figure 114. Close-up of the tower showing damages (photo: EEFIT).

7.1.4 Fortified walls

Fortified walls at a few sites suffered damage due to the November 2019 earthquake, particularly the fortified walls within the Krujë and Prezë castles. The damage was localized and consisted of the out-of-plane failure of the masonry merlons, as shown in Figure 115. Seismic vulnerability of the merlons, especially due to out-of-plane earthquake effects, is common and characteristic for ancient, fortified structures. This mechanism was observed occurring even at low-peak ground accelerations starting at about 0.05 g (Ferretti, Coisson, and Lenticchia, 2018).⁷²



(a)



(b)

Figure 115. Collapsed areas of the fortified walls: (a) Krujë Castle and (b) Prezë Castle (source: EEFIT).

7.2 Religious Structures

There were no reports of major or moderate damage in most of the religious structures in the earthquake-affected area. In fact, the Muslim Community of Albania opened its mosques and madrasas immediately after the earthquake, and the Orthodox Church of Albania opened the local monasteries and churches as shelters for the earthquake victims; the Catholic Church of Albania held mass in its churches.

An exception was the mosque located in the Thumanë village (Figure 116), which experienced major damage. The structural system consists of exterior load-bearing masonry walls and reinforced concrete frames inside the interior of the mosque. The horizontal and vertical mortar joints are irregular in terms of the shape and thickness, and the thickness is variable.



Figure 116. Exterior view of the mosque in Thumanë showing damage in masonry walls and minaret (photos: HAEE).

Wide shear cracks due to in-plane seismic actions (diagonal tension cracks) were observed in the exterior masonry walls (and were also visible in the interior of the mosque). Small cracks were observed in the dome, particularly around the dome ring, that were due to horizontal stresses (Figure 117). No significant damage was observed in reinforced concrete columns. This can be explained by a smaller stiffness of the reinforced concrete structure compared with the masonry walls, which are located at the perimeter of the structure and provide the main seismic resistance.



Figure 117. Interior view of the mosque in Thumanë showing damage in masonry walls and the dome (photos: HAEE).

The minaret suffered moderate damage. In general, minarets exhibit shear-dominant behavior under seismic loading because of their unique characteristics, such as the slenderness and the shape. The minaret of the Thumanë mosque had a hexagonal cross section; see Figure 118. It can be seen that the minaret was constructed using masonry for the shaft, but reinforced concrete vertical elements (approximately 10 cm square) were provided at each vertex of the hexagon, and reinforced concrete tie beams were provided at a 3-m vertical spacing along its height. Extensive cracking and spalling were observed at both the base and along the height of the minaret. The cracks were also present at the connection between the minaret and the mosque structure. These cracking patterns are very common in minarets that are integrated with the mosque, and they occur because of asynchronous vibrations that are caused by the difference between the fundamental periods of the two parts of the structure.



Figure 118. Major damage of mosque in Thumanë (photos: HAEE).

The Tekke of Dollma inside the Krujë Castle also suffered damage in the earthquake. The building has a square shape that becomes hexagonal in the upper part to envelope the central dome (Figure 119). The dome is sitting on squinches, which are in turn resting on the stone masonry walls. In-plane cracking was observed in the masonry walls. The cracks propagated diagonally from the bottom portion of the walls at corners and extended through the openings (Figure 120(b)). The corner failure is likely to be the cause of the cracking in the dome, which can be seen in Figure 121. From a glimpse of the inside, the dome presents a meridian crack pattern without cracking at the crown portion but with regular cracking (like “slices”) in the lower part, as shown in the schematic illustration by Heyman (1995)⁷³ presented in Figure 122. This type of failure is generally caused by movement in the dome’s support, causing an increase of the dome’s span.



(a)



(b)

Figure 119. Tekke of Dollma: (a) front view (source: https://en.wikipedia.org/wiki/Dollma_Tekke) and (b) rear view (source: <https://mapio.net/pic/p-63037109/>).



(a)



(b)

Figure 120. Tekke of Dollma: (a) before the earthquake (in 2010) (source: <http://www.visionsoftravel.org/Krujë-dollma-teqe-albania/>) and (b) after the earthquake (photo: EEFIT).



Figure 121. Cracking pattern in the dome (photo: EEFIT).

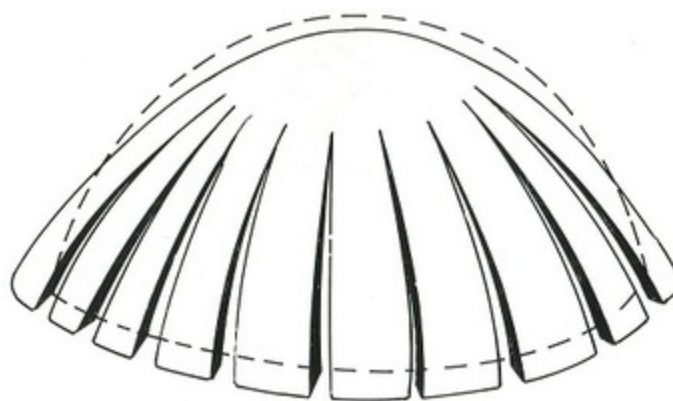


Figure 122. An exaggerated schematic illustration of the cracking pattern in the dome due to the span increase (source: Heyman, 1995).

A comparison of the “before” and “after” exterior photos of the Tekke of Dollma (Figure 120) revealed that the cracking was present in the masonry walls at the same locations before the earthquake. The original causes for this cracking could be due to the ground instability observed in the area, as well as previous earthquakes. Therefore, the November 2019 earthquake appears to have caused a progression of the existing damage and significantly increased the size of the pre-existing crack pattern.

7.3 Conclusions

Albania has a rich history and a large presence of built heritage around the country. These buildings are particularly vulnerable to disasters such as earthquakes, and this poses a risk to their legacy. Cultural heritage is not only the carrier of historical, social, cultural values; it has also an important economic value for some parts of the country. The preservation of cultural heritage in locations like Krujë and Prezë is essential for the economic development of these towns.

Part of the cultural heritage present in the most affected areas suffered extensive damage because of the earthquake on November 26, 2019. Based on the observation of the defensive architecture visited during the mission, the damage mainly occurred in the towers and merlons. The failure mechanisms observed often consisted of out-of-plane movements of the masonry walls; however, the causes of damage are quite diverse and often a combination of multiple factors. Alongside pre-existing damage and soil settlements, the status of the conservation of the structures was found to be one of the main causes leading to the observed failure mechanisms. Moreover, historical alterations and past structural interventions can substantially modify the dynamic behavior of the historic structures and can result in an increase of their vulnerability.

REFERENCES

- ¹ Council of Ministers, 1952. Provisions for Earthquake Resistant Constructions [Dispozita për ndërtimë antisizmike, in Albanian]. VKM Nr. 817 dt. 27-XII-1952. Tirana.
- ² Academy of Sciences and Ministry for Construction, 1989. Kusht teknik projektimi për ndërtimet antisizmike KTP-N.2-89. Tirana, Albania.
- ³ Baballëku, M. and Myftaraga, E., 2020. A Short History of Seismic Design Codes in Albania. In International Conference on Geosciences and Earthquake Engineering, Challenges for Balkan Region (ICGEE). Tirana: Academy of Sciences of Albania, (DOI: 10.13140/RG.2.2.33632.40960).
- ⁴ Novikova, A., Szalay, Z., Simaku, G., Thimjo, T., Salamon, B., Plaku, T., Csoknyai, T., and Feiler, J., 2015. The Typology of the Residential Building Stock in Albania and the Modelling of its Low-Carbon Transformation, available at http://sled.rec.org/documents/SLED_Albania_BUILDING_ENG.pdf (accessed November 17, 2021).
- ⁵ KTP 2-78, 1978. Kushtet Teknike të Projektimit për Ndërtimet në Zona Sizmike, KTP 2-78. Tirana, Albania.
- ⁶ Qendra Sizmologjike e Akademisë së Shkencave, 1979. Harta e Rajonizimit Sizmik të RPS të Shqipërisë [in Albanian]. Scale 1:500000. Tirana.
- ⁷ Koçiu, S., Sulstarova, E., Aliaj, S., Duni, L., Peçi, V., Konomi, N., Dokoli, H., Fuga, I., Goga, K., Zeqo, A., Kapllani, L., Kozmaj, S., and Lika, M., 1985. Seismic Microzonation of Durrës. Internal Report [in Albanian]. Archive of Seismological Institute, Tirana.
- ⁸ Chryssy A. P. and Augustinius, C., 2010. Informal Urban Development in Europe: Experiences From Albania and Greece (Summary Version). United Nations Human Settlements Programme (UN-HABITAT). Kenya: UN.
- ⁹ Fischer, E., Hakhamaneshi, M., Alam, M., Alberto, Y., Aranha, C., Diaz-Fanas, G., DJIMA, W., Gartner, M., Hassan, W., Isufi, B., Lim, E., McKenney, C., Rodriguez-Nikl, T., Unal, M., Wibowo, H., and Yoo, D., 2019. Virtual Earthquake Reconnaissance Team (VERT): Phase 1 Response to M6.4 Albania Earthquake November 26, 2019, (DOI: 10.17603/ds2-fv1f-6v64).
- ¹⁰ Albanian Institute of Statistics (INSTAT), 2011. Population and Housing Census 2011. Tirana: Albanian Institute of Statistics.
- ¹¹ Sextos, A. G., Lekkas, E., Stefanidou, S. P., Baltzopoulos, G., Fragiadakis, M., Giarelis, C., Lombardi, L., Olga, M., Spyridon, M., Aristo, P., Nikolaos, P., Despoina, S., George, T., and Tsopelas, P., 2020. Albania Earthquake of November 26, 2019 Report on Structural and Geotechnical Damage, (DOI: 10.13140/RG.2.2.16153.24167).
- ¹² Charleson, A. W., Vesho, N., and Marku, A., 2020. Structural Engineering Observations from the 26 November 2019 Mw 6.4 Albanian Earthquake. In: NZSEE 2020 Annual Conference Paper, paper 191.
- ¹³ Lekkas, E., Mavroulis, S., Papa, D., and Carydis, P., 2019. The November 26, 2019 Mw 6.4 Durrës (Albania) Earthquake. Newsletter of Environmental, Disaster, and Crises Management Strategies, (15), ISSN 2653-9454, 1–80.
- ¹⁴ American Society of Civil Engineers (ASCE) 41-17, 2017. Seismic Evaluation and Retrofit of Existing Buildings. ASCE.
- ¹⁵ Earthquake Engineering Field Investigation Team (EEFIT), 2020. The Mw6.4 Albania Earthquake on the 26th November 2019 - A Field Report by EEFIT. London.
- ¹⁶ Freddi, F., Novelli, V., Gentile, R., Velu, E., Andreev, S., Andonov, A., Greco, F., and Zhuleku, E., 2021. Observations from the 26th November 2019 Albania earthquake: The Earthquake Engineering Field

Investigation Team (EEFIT) Mission. Bulletin of Earthquake Engineering, 19(5), 2013–2044, (DOI: 10.1007/s10518-021-01062-8).

- ¹⁷ Federal Emergency Management Agency (FEMA), 2000. FEMA 365: Prestandard and Commentary for the Seismic Rehabilitation of Buildings. FEMA.
- ¹⁸ Federal Emergency Management Agency (FEMA), 2015. FEMA P-154: Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook. Third Edition. FEMA.
- ¹⁹ Japan Building Disaster Prevention Association, 1990. Standard for Evaluation of Seismic Capacity and Guidelines for Seismic Retrofit Design of Existing Reinforced Concrete Buildings [in Japanese].
- ²⁰ Italian Group for the Defense against Earthquakes (GNDT), 1993. Seismic Risk of Public Buildings—Part 1—Methodology Aspects [in Italian]. Rome: CNR.
- ²¹ World Bank GPURL Disaster-Resilience Analytics and Solutions (D-RAS) Team, 2019. M 6.4 Albania Earthquake Global Rapid Post Disaster Damage Estimation (Grade) Report.
- ²² Guri, M., 2016. Kërkime mbi teknikat bashkëkohore për përf forcimin e ndërtesave me muraturë [Research About “State of the Art” Techniques Related to the Reinforcement of Masonry Structures, in English]. Polytechnic University of Tirana.
- ²³ Bilgin, H. and Huta, E., 2018. Earthquake Performance Assessment of Low and Mid-Rise Buildings: Emphasis on URM Buildings in Albania. Earthquakes and Structures, 14(6), 599–614, (DOI: 10.12989/eas.2018.14.6.599).
- ²⁴ KTP 9-78, 1978. KTP 78-9: Llogaritja e mureve dhe themeleve me teorinë e gjendjes kufitare. The Scientific Council of Ministry of Construction, Albania.
- ²⁵ Bilgin, H. and Korini, O., 2012. Seismic Capacity Evaluation of Unreinforced Masonry Residential Buildings in Albania. Natural Hazards and Earth System Science, 12(12), 3753–3764, (DOI: 10.5194/nhess-12-3753-2012).
- ²⁶ McKenney, C., 2019. Reconnaissance Observation Report: Albania M6.4 Earthquake on November 26, 2019 available at http://learningfromearthquakes.org/images/earthquakes/2019_Albania_Earthquake/Albania_EQ_Report_-_Chiara_McKenney.pdf (accessed November 17, 2021).
- ²⁷ Gazeta Shqiptare, 2019. Durrës/ Mbyllet operacioni i kërkim shpëtimit tek godina pranë Kryqit të Kuq, available at <http://www.gsh.al/2019/11/28/durres-mbyllet-operacioni-kerkim-shpetimit-tek-godina-prane-kryqit-te-kuq/> (accessed November 17, 2021).
- ²⁸ Report TV, 2019. Komisari vdiq në gjumë në mesin 10 vjeçare, 112 studentë shpëtuan në pjesën e Konvaleshencës, available at https://www.youtube.com/watch?v=CQK3G2XD_8 (accessed November 17, 2021).
- ²⁹ Shqiptarja.com, 2019. Nën gërmadha ende të bllokuar dy kosovarë! Si ishte dhe si u rrafshua nga tërmeti hotel “Tropikal” në Durrës. Published November 26, 2019, available at <https://shqiptarja.com/lajm/nen-germadha-ende-te-blokuar-dy-kosovare-si-ishte-dhe-si-u-rrafshua-nga-termeti-hotel-tropikal-ne-durres>.
- ³⁰ A2 | CNN Affiliate, 2019. Pa koment: Pallati në Durrës zhytet në tokë nga tërmeti. Published on November 26, 2019, available at <https://www.youtube.com/watch?v=dZ2I-VTDGPw>.
- ³¹ European Committee for Standardization (CEN), 2004. EN 1998-1. Eurocode 8: Design of Structures for Earthquake Resistance - Part 1: General Rules, Seismic Actions and Rules for Buildings.
- ³² Asteris, P. G., Repapis, C. C., Tsaris, A. K., Di Trapani, F., and Cavaleri, L., 2015. Parameters Affecting the Fundamental Period of Infilled RC Frame Structures. Earthquake and Structures, 9(5), 999–1028, (DOI: 10.12989/eas.2015.9.5.999).
- ³³ Kappos, A. J. and Ellul, F., 2000. Seismic Design and Performance Assessment of Masonry Infilled R/C Frames. In: Proceedings of 12th World Conference on Earthquake Engineering, Auckland, New Zealand.
- ³⁴ Kose, M. M., 2009. Parameters Affecting the Fundamental Period of RC Buildings with Infill Walls. Engineering Structures, 31(1), 93–102, (DOI: 10.1016/j.engstruct.2008.07.017).
- ³⁵ Ricci, P., Verderame, G. M., and Manfredi, G., 2011. Analytical Investigation of Elastic Period of Infilled RC MRF Buildings. Engineering Structures, 33(2), 308–319, (DOI: 10.1016/j.engstruct.2010.10.009).

- ³⁶ Braga, F., Manfredi, V., Masi, A., Salvatori, A., and Vona, M., 2011. Performance of Non-Structural Elements in RC Buildings During the L'Aquila, 2009 Earthquake. *Bulletin of Earthquake Engineering*, 9(1), 307–324, (DOI: 10.1007/s10518-010-9205-7).
- ³⁷ De Luca, F., Verderame, G. M., Gómez-Martínez, F., and Pérez-García, A., 2014. The Structural Role Played by Masonry Infills on RC Building Performances After the 2011 Lorca, Spain, Earthquake. *Bulletin of Earthquake Engineering*, 12(5), 1999–2026, (DOI: 10.1007/s10518-013-9500-1).
- ³⁸ Manfredi, G., Prota, A., Verderame, G. M., De Luca, F., and Ricci, P., 2014. 2012 Emilia Earthquake, Italy: Reinforced Concrete Buildings Response. *Bulletin of Earthquake Engineering*, 12(5), 2275–2298, (DOI: 10.1007/s10518-013-9512-x).
- ³⁹ Nikolić-Brzev, S., Marinković, M., Milićević, I., Blagojević, N., and Isufi, B., 2020. Posledice zemljotresa u Albaniji od 26.11.2019. godine na objekte i infrastrukturu [Consequences of the 26.11.2019 Albania earthquake on buildings and infrastructure]. Belgrade: Serbian Association for Earthquake Engineering (SUZI-SAEE).
- ⁴⁰ American Society of Civil Engineers (ASCE) 7-16, 2017. Minimum Design Loads and Associated Criteria for Buildings and Other Structures (7-16). ASCE.
- ⁴¹ Marinković, M. and Butenweg, C., 2019. Innovative Decoupling System for the Seismic Protection of Masonry Infill Walls in Reinforced Concrete Frames. *Engineering Structures*, 197(2019), 109435, (DOI: 10.1016/j.engstruct.2019.109435).
- ⁴² Morandi, P., Milanese, R. R., and Magenes, G., 2018. Innovative Solution for Seismic-Resistant Masonry Infills With Sliding Joints: In-Plane Experimental Performance. *Engineering Structures*, 176(January), 719–733, (DOI: 10.1016/j.engstruct.2018.09.018).
- ⁴³ Butenweg, C., Marinković, M., and Salatić, R. 2019. Experimental Results of Reinforced Concrete Frames With Masonry Infills Under Combined Quasi-Static In-Plane and Out-of-Plane Seismic Loading. *Bulletin of Earthquake Engineering*, 17(6), 3397–3422, (DOI: 10.1007/s10518-019-00602-7).
- ⁴⁴ Kadysiewski, S. and Mosalam, K. M., 2009. Modeling of Unreinforced Masonry Infill Walls Considering In-Plane and Out-of-Plane Interaction. PEER Report 2008/102, available at https://peer.berkeley.edu/sites/default/files/web_peer8102_stephen_kadysiewski_khalid_m._mosalam_.pdf (accessed November 17, 2021).
- ⁴⁵ Yuen, T. Y. P., Kuang, J. S., and Ali, B. S. M., 2016. Assessing the Effect of Bi-directional Loading on Nonlinear Static and Dynamic Behaviour of Masonry-Infilled Frames With Openings. *Bulletin of Earthquake Engineering*, 14(6), 1721–1755, (DOI: 10.1007/s10518-016-9899-2).
- ⁴⁶ Abazaj, A., 2019. Prefabrication and Modular Construction Dwellings in Albania. *International Journal of Scientific & Engineering Research*, 10(8), 811–819.
- ⁴⁷ Islami, G. and Veizaj, D., 2014. Comfort Conditions and Energy Consumption in Prefabricated Houses in Tirana. In: *Proceedings of the 2nd ICAUD International Conference in Architecture and Urban Design*, paper 321. Tirana, Albania.
- ⁴⁸ Ministria e Ndërtimit, 1981. *Revista Ndërtuesi*, 68(3), cover.
- ⁴⁹ International Federation for Structural Concrete (fib), 2008. *fib Bulletin No. 43. Structural Connections for Precast Concrete Buildings*. fib Bulletin number 43.
- ⁵⁰ United Nations Industrial Development Organization (UNIDO), 1983. *Design and Construction of Prefabricated Reinforced Concrete Frame and Shear-Wall Buildings. Volume 2. Building Construction Under Seismic Conditions in the Balkan Region*. UNDP/UNIDO Project RER/79/015. Vienna.
- ⁵¹ Technical Construction Archive (AQTN), 1999. *Informative Bulletin nr.2 [in Albanian]*. Tirana.
- ⁵² Guri, M., Brzev, S., and Lluka, D., 2021. Performance of Prefabricated Large Panel Reinforced Concrete Buildings in the November 2019 Albania Earthquake. *Journal of Earthquake Engineering*, 1–27, (DOI: 10.1080/13632469.2021.1887010).
- ⁵³ Guri, M., Lluka, D., and Brzev, S., 2020. Seismic Issues in Prefabricated Reinforced Buildings Affected by the 26 November 2019 Earthquake. In: *International Symposium on Durrës Earthquake and Eurocodes*. Tirana, Albania.
- ⁵⁴ KTZ 10-78, 1979. Kushte teknike të zbatimit dhe marrjes në dorëzim të strukturave prej betoni e betonarmeje në veprat industriale, qytetare dhe bujqësore [Technical Codes for the Execution and Handing Over of the Concrete and Reinforced Concrete Structures in Industrial, in English].

- ⁵⁵ Government of Albania, European Union, United Nations agencies, and World Bank, 2020. Albania Post-Disaster Needs Assessment, Volume A Report. Tirana, Albania.
- ⁵⁶ Baballëku, M., 2014. Vlerësimi i dëmtimeve strukturore në ndërtesat tip të sistemit arsimor. Doctoral thesis, Polytechnic University of Tirana.
- ⁵⁷ Mezini, L., 2016. Ndërtesat arsimore në Shqipëri: Analizë e zhvillimeve historike e tipologjike. Polytechnic University of Tirana, available at <http://upt.al/artikuj-shkencore/639-fau-ndertesat-arsimore-ne-shqiperi-analize-e-zhvillimeve-historike-e-tipologjike> (accessed November 17, 2021).
- ⁵⁸ Komisioni për Edukimin dhe Mjetet e Informimit Publik, 2020. Minutes of the meeting, Tirana, 05/02/2020 at 10AM [in Albanian], available at https://www.parlament.al/Files/Procesverbale/20200309140101Komisioni_i_Medies_datë_05.02.2020.pdf (accessed September 1, 2020).
- ⁵⁹ Federal Emergency Management Agency (FEMA), 2003. FEMA 395: Incremental Seismic Rehabilitation of School Buildings (K-12). FEMA.
- ⁶⁰ Baballëku, M. and Pojani, N., 2008. Fragility Evaluation of Existing Typified School Buildings in Albania. *Acta Geodaetica et Geophysica Hungarica*, 43(2–3), 309–325, (DOI: 10.1556/AGeod.43.2008.2-3.16).
- ⁶¹ Baballëku, M., 2006. Vulnerability of Typified Facilities Building in Albania. Thesis, Institute of Earthquake Engineering and Engineering Seismology, (DOI: 10.13140/rg.2.2.17061.45282).
- ⁶² Islami, G., Thomai, G., and Tuxhari, M., 2016. Hospital Buildings in Albania 1945-1990 [Ndërtesa të bardha - Arkitektura e spitaleve 1945-1990, in Albanian], (DOI: 10.13140/RG.2.2.12310.14400).
- ⁶³ Wikipedia. (n.d.). Durrës Castle, available at https://en.wikipedia.org/wiki/Durrës_Castle (accessed November 17, 2021).
- ⁶⁴ Nicolle, D., 2010. Ottoman Fortifications, 1300-1710. M. Cowper (Ed.).
- ⁶⁵ Binda, L., Tedeschi, C., and Baronio, G., 1999. Influence of Thick Mortar Joints on the Early and Late Mechanical Behaviour of Byzantine Constructions. *Transactions on the Built Environment*, 39, 1743–3509.
- ⁶⁶ Baronio, G., Binda, L., and Tedeschi, C., 1997. Thick Mortar Joints in Byzantine Buildings: Study of their Composition and Mechanical Behaviour. In: G. Ozsen (Ed.), *Int. Conf. on Studies in Ancient Structures* (pp. 235–244). Istanbul.
- ⁶⁷ Regional Programme for Cultural and Natural Heritage in South East Europe, 2006. Integrated Rehabilitation Project Plan. Survey of the Architectural and Archaeological Heritage (IRPP/SAAH) in the Framework of the European Commission/Council of Europe Joint Programme. Regional Programme for Cultural and Natural Heritage in South East E.
- ⁶⁸ Formisano, A. and Milani, G., 2019. Seismic Vulnerability Analysis and Retrofitting of the SS. Rosario Church Bell Tower in Finale Emilia (Modena, Italy). *Frontiers in Built Environment*, 5, (DOI: 10.3389/fbuil.2019.00070).
- ⁶⁹ Colapietro, D., Fiore, A., De Fino, M., Netti, A., Fatiguso, F., and Marano, C. G., 2015. Assessment of the Seismic Vulnerability of a Masonry Bell Tower by Non-Destructive Experimental Techniques. *Seismic Assessment, Behavior and Retrofit of Heritage Buildings and Monuments*, Psycharis, I. N., Pantazopoulou, S. J., and M. Papadrakakis M. (Eds.), *Computational Methods in Applied Sciences*.
- ⁷⁰ Stavroulaki, M. E., 2019. Dynamic Behavior of Aggregated Buildings With Different Floor Systems and Their Finite Element Modeling. *Frontiers in Built Environment*, 5, (DOI: 10.3389/fbuil.2019.00138).
- ⁷¹ Mustafaraj, E. and Yardim, Y., 2014. Structural Assessment of Preza Clock Tower. In: *ICESA 2014: International Civil Engineering & Architecture Symposium for Academicians*. Antalya, Turkey, pp. 311–317).
- ⁷² Ferretti, D., Coisson, E., and Lenticchia, E., 2018. Seismic Damage on Merlons in Masonry Fortified Buildings: A Parametric Analysis for Overturning Mechanism. *Engineering Structures*, 177, 117–132, (DOI: 10.1016/j.engstruct.2018.09.048).
- ⁷³ Heyman, J., 1995. *The Stone Skeleton, Structural Engineering of Masonry Architecture*. Cambridge: Cambridge University Press.