in collaboration with the Earthquake Planning and Protection Organization of Greece (EPPO – OASP), the University Network of Seismic Engineering Laboratories of Italy (ReLUIS) and the University of Bristol, UK

# Albania earthquake of November 26, 2019

*Report on Structural and Geotechnical Damage*

**Reconnaissance Team:** Anastasios Sextos (President, HAEE-ETAM), Eftimios Lekkas (President EPPO-OASP), Stefanidou Sotiria (HAEE-ETAM), Baltzopoulos Georgios, (RELUIS, Italy), Fragkiadakis Michalis (HAEE-ETAM), Giarlelis Christos (HAEE-ETAM), Luca Lombardi (University of Bristol), Markogiannaki Olga (HAEE-ETAM), Mavroulis Spyridon (National and Kapodistrian University of Athens), Plaka Aristo, Pnevmatikos Nikolaos (HAEE-ETAM), Skoulidou Despoina (HAEE-ETAM), Tsiatas George (HAEE-ETAM), Tsopelas Panos (HAEE-ETAM).

November 2020

# Contents

# 1. INTRODUCTION

On November 26th 2019, Northwestern Albania was struck by an $M_w$6.4 earthquake, resulting in more than three thousand injuries, including fifty-one fatalities. The Hellenic Association of Earthquake Engineering (HAEE/ETAM) in collaboration with the Earthquake Planning and Protection Organization (EPPO/OASP), the University Network of Seismic Engineering Laboratories of Italy (ReLUIS) and the University of Bristol (UoB), UK, organized a field mission on the 14th and 15th of December 2019 to inspect structural and geotechnical damage in Durrës and Thumanë. The scope of the mission was to collect data related to damage patterns and extent, evaluate the seismic performance of structures providing preliminary conclusions and, potentially, to transfer knowledge regarding the current code provisions for the design and retrofit of earthquake-resistant structures.

The HAEE/EPPO/RELUIS/UoB team lead by Prof. A. Sextos, University of Bristol (HAEE president) and Prof. E. Lekkas, National & Kapodistrian University of Athens (EPPO president), consisted of 14 experienced Civil Engineers, Professors and Researchers from National Technical University of Athens, National & Kapodistrian University of Athens, Aristotle University of Thessaloniki, University of Patras, University of Naples Federico II, University of Bristol, University of West Attica, University of Western Macedonia and the University of Porto as well as freelancers and chartered civil engineers.

The agenda of the HAEE field mission in Albania is outlined below:

**December 14th, 2019 (Day 1 - Saturday)**

- Meeting with the staff of the Greek Embassy and the Ambassador Mrs. Sofia Filippidou. Description of the scope of the field mission. Discussion of potential actions related to knowledge transfer of current European code provisions for seismic design (including assessment and retrofit) to the local professional structural engineering community.
- Meeting with the European Union Civil Protection coordinating committee, located at the Prefecture building in Durrës, to be briefed on the progress of the post-earthquake inspection program in the area, as well as the general planning and coordination of the international inspection teams working on it.
- Field Inspections/reconnaissance mission in the city of Durrës.
- Participation in AACE (Albanian Association of Consulting Engineers) conference in Tirana. Prof. Anastasios Sextos was invited as a panellist to comment on the current European practice for the design and assessment of existing buildings.

Figure 1: ETAM mission - Meeting with the Ambassador Mrs. Sofia Filippidou at the Greek Embassy


Figure 2: ETAM mission - Meeting with the EU Civil Protection coordinating committee (left), participation in AACE (Albanian Association of Consulting Engineers) conference in Tirana (right)

**December 15th, 2019 (Day 2 - Sunday)**

- Meeting with Archbishop Anastasios of Tirana, Durrës and all Albania, to be informed about the extent of damage on religious establishments in the area.
- Field Inspections/reconnaissance mission in Thumanë and Romano Port.

## 2. SEISMOLOGICAL DATA AND RECORDED GROUND MOTION

According to the USGS National Earthquake Information Center, the epicenter of the moment magnitude $M_w$6.4 earthquake, was 16km southeast of Mamurras (long. 41.514°N, lat. 19.526°E; Fig.1). The same source reports that the causal focal mechanism is related to reverse movement on a NW-SE trending fault (USGS event page; last accessed 20/02/2020). The maximum macroseismic intensity, estimated by the USGS based on instrumental data and witness reports, was VIII on the Modified Mercalli intensity scale.

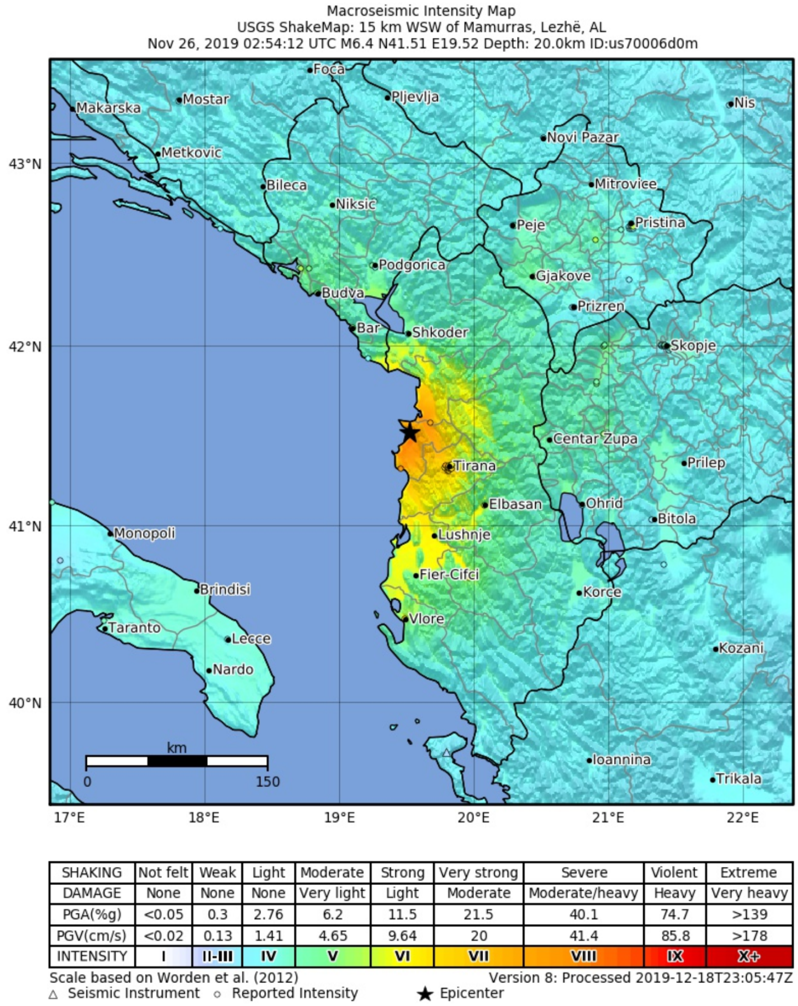



Figure 3 : Shakemap for the Nov 26, 2019, M6.4 Albania earthquake (source:USGS; last accessed 20/02/2020)

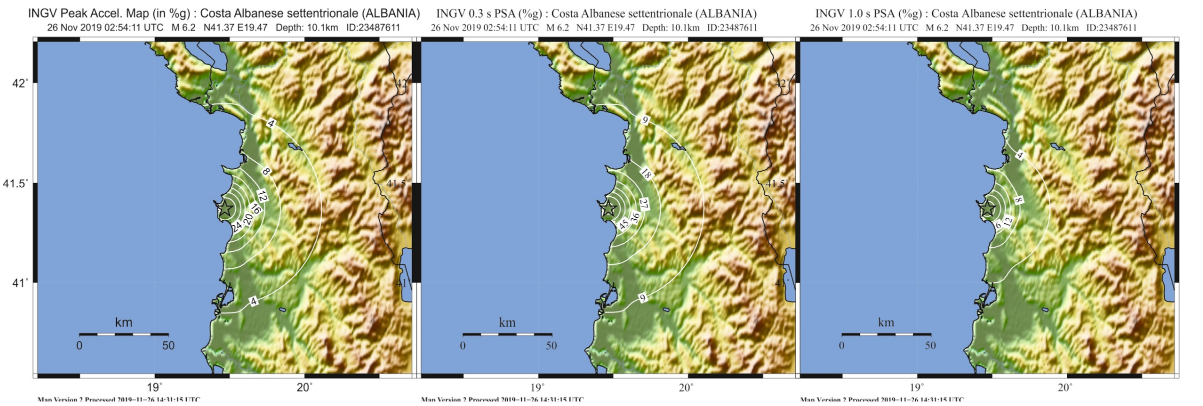



Figure 4. Shakemaps in terms of Peak Ground Acceleration (left), Peak Spectral Acceleration at 0.3s (middle) and Peak Spectral Acceleration at 1.0s (right); data retrieved from the INGV Shakemap archive (last accessed 18/02/2020).

The Italian Institute for Geophysics and Volcanology (INGV) shakemap service further provided estimates of the spatial distribution of instrumental shaking intensity in terms of peak ground acceleration (PGA) and 5% damped pseudo-spectral acceleration (PSA) at vibration periods of 0.3s and 1.0s, all of which are shown in Figure 4.

Four accelerometric recordings were obtained within an epicentral distance of 100 km or less (7 within 130km). The acceleration time history recorded closest to the epicenter was the one obtained at the building of the Institute of GeoSciences, Energy, Water and Environment (IGEWE) in Tirana, with a PGA of 0.114g. The PSA response spectra of the two as-recorded horizontal and vertical components are shown in Figure 5.

From the figure it can be seen that the two horizontal components exhibit similar spectral amplitudes, with a slight preponderance of the east-west component, and a PSA that peaks at 0.40g at a period of 0.22s. The vertical component has lower spectral amplitudes than the horizontal ones, which is not unexpected for ground motion not recorded near the fault. Epicenter locations for the mainshock and aftershocks with M>4.0 recorded within twenty days of the mainshock, are depicted in Figure 6. Until December 15, that the field mission took place, four aftershocks having M ≥ 5.0 were recorded and eighteen with magnitude between M4-M4.9. The largest aftershock occurred less than four hours after the mainshock in the vicinity of Thumanë, having a magnitude of M5.4.

It is noted that the unique ground motion recorded in Durrës is not complete due to electricity supply disruption. Processing and interpretation of the recording shows a horizontal PGA of 0.192g (N-S component), 0.122 (E-W component) and 0.114g (Z component) which is in good agreement with the average predicted value by a regional Ground Motion Prediction Equation (Duni & Theodoulidis, 2019). The same study also highlights the rich frequency content of the recorded motion with spectral acceleration at least 0.50g, along a wide range of periods between 0.3sec and 1.0sec, that is the result of the soft soil formations at the location of the recording station DURR characterized by an average shear wave velocity of the uppermost soil layers of Vs=200m/sec (Duni, 2013).

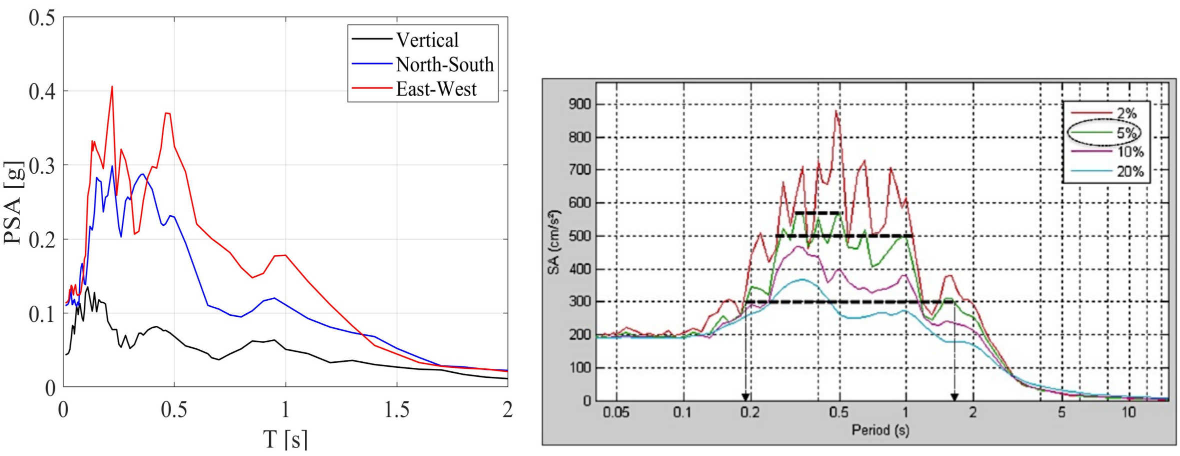



Figure 5. Pseudo-acceleration response spectra of the TIR1 station record's horizontal and vertical components. (epicentral distance 28.7 km, corrected acceleration time series obtained from the Engineering Strong Motion database, left). Pseudo-acceleration response spectra (for 2%, 5%, 10% and 20% damping) of the first 15sec of the acceleration time history recorded at the DURR station (Duni & Theodoulidis, 2019).

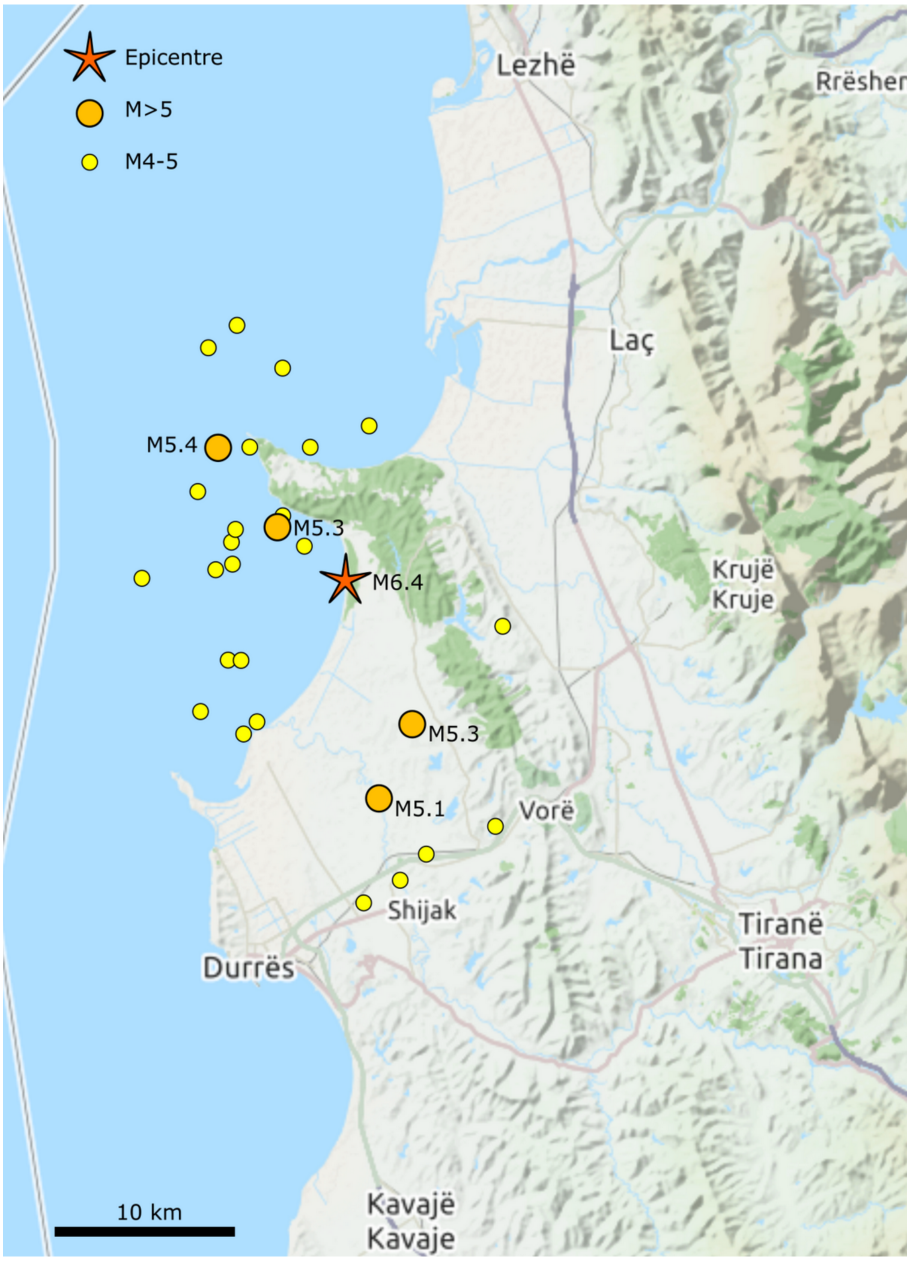



Figure 6. Location of epicentre and aftershocks within the first twenty days after the mainshock.

(source:https://en.wikipedia.org/wiki/2019_Albania_earthquake#/media/File:Aftershock_locations_Albania_2019.png)

An insight on the co-seismic ground deformation induced by the 26th November 2019 earthquake can also be found (Markogiannaki et al., 2020) combining SAR interferometry using Sentinel-1 images and open geospatial information to develop deformation maps of the affected area including local exposure data.

## 3. ALBANIAN SEISMIC CODE KTP-N.2-89

In order to evaluate the seismic performance of buildings in Durrës and Thumanë based on the observed damage modes and intensity, the provisions of the Albanian seismic code for the design of structures are presented herein along with the relevant of Eurocode 8 clauses for comparison. The details presented are based on recent literature (Frangu & Bilgin, 2014; Kokona et al., 2016).

Provisions for the design of earthquake resistant structures were incorporated in Albanian codes nearly five decades ago. The first version of Albanian code started as a legal provision (KTP – 63) in 1963. In 1970, the countries of the region (except for Albania) worked on projects REM/70/172 and REM/74/09 under the auspices of UNDP and UNESCO, providing a survey of seismicity for the region. Soon, the Albanian code was amended in 1978 (KTP-78), following the most recent revision implemented in 1989, that formed the KTP-89, or KTP-N.2-89 (Seismic Center, Academy of Science of Albania. Department of Design, 1989), which is the current code. According to this code, the spectral acceleration is defined as follows:

$$S_a = k_E k_r \psi \beta_i g \tag{1}$$

where $k_E$ is the seismic coefficient, $k_r$ a building importance coefficient (typically equal to 1 for standard structures), $\psi$ a structural coefficient (given in Table 4 of KTP-89) and $g$ is the gravitational constant. The dynamic coefficient $\beta_i$ is defined as:

$$0.65 \leq \beta_i = \frac{0.7}{T_i} \leq 2.3 \text{ for soil category I} \tag{2.1}$$

$$0.65 \leq \beta_i = \frac{0.8}{T_i} \leq 2.0 \text{ for soil category II} \tag{2.2}$$

$$0.65 \leq \beta_i = \frac{1.1}{T_i} \leq 1.7 \text{ for soil category III} \tag{2.3}$$

Seismic coefficient KE is listed in Table 1 as a function of soil types I, II, III that roughly correspond to Eurocode 8 (CEN, 2004) soil classes A, B and C, respectively (Frangu & Bilgin, 2014). There is no soil amplification factor as in recent versions of Eurocode 8. The division of seismic zones in Albania is made by means of the intensity seismic scale MSK-64 (as also shown in Table 1), while a probabilistic seismic hazard map for the country with 475 years return period is illustrated in Figure 7.

| Soil category | Seismic coefficient $k_E$ | | |
|---|---|---|---|
| | Intensity VII | Intensity VIII | Intensity IX |
| I | 0.08 | 0.16 | 0.27 |
| II | 0.11 | 0.22 | 0.36 |
| III | 0.14 | 0.26 | 0.42 |

Table 1. Seismic coefficient according to KTP-N.2-89 (Seismic Center, Academy of Science of Albania. Department of Design, 1989).

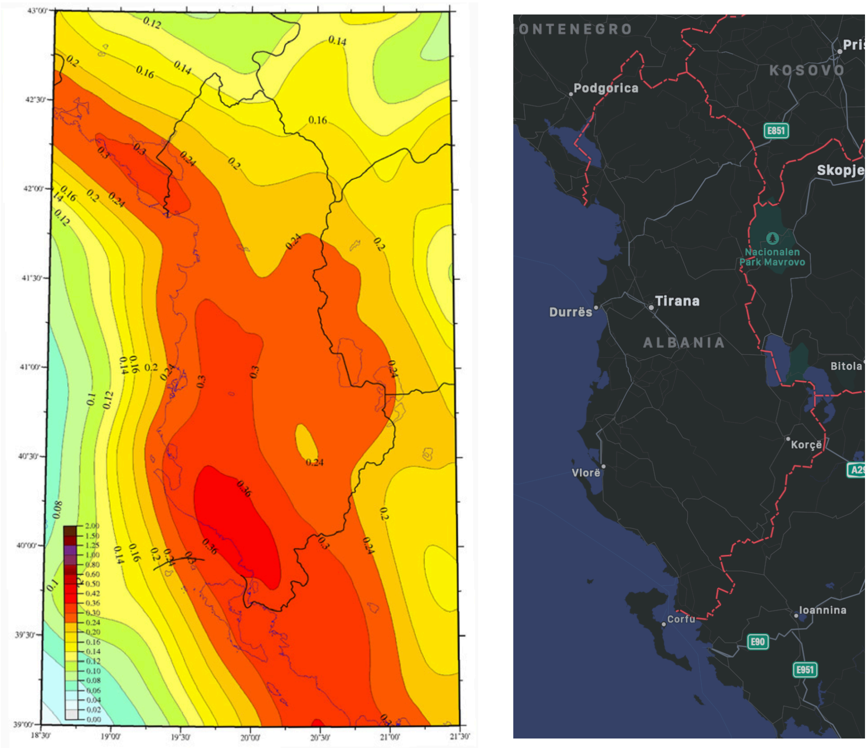



Figure 7. Probabilistic seismic hazard map of Albania with 475 years return period, expressed in PGA on rock soil (Fundo et al., 2012) (left) and map of Albania (Apple maps, right).

Comparison between the Eurocode 8 and the KTP-89 design spectrum is presented in Figure 8 (Kokona et al., 2016) indicatively for soil type B, PGA=0.32g, importance factor 1.0 and behavior factor q=3.0. From Figures 7 and 8, it is seen that the design accelerations prescribed by the current Albanian code are lower compared to the respective EC8 ones. Moreover, the horizontal PGA of 0.192g recorded (on soft soil, Figure 5) in Durrës is also estimated to be lower than that derived by means of PSHA for the same area (given the value of 0.24g predicted on rock with the free field one assumed to be typically higher, Figure 7). The above observations imply that the buildings in the region have been designed for lower base shear compared to Eurocode 8, but on the other hand, the ground motion acceleration itself was also less intense compared to the corresponding one predicted with 10% probability to be exceeded in 50 years.

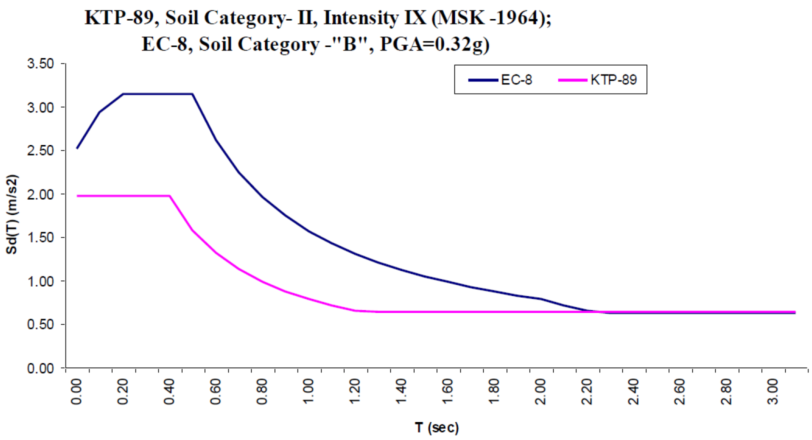



Figure 7. Design response spectrum according to KTP-89 & EC8 (Kokona et al., 2016).

## 4. EUROPEAN UNION CIVIL PROTECTION

At the time of the visit, the European Union Civil Protection Team had already been working in Albania for more than a month, organizing field missions for visual inspections mainly in Durrës and Thumanë, involving a large number of civil engineers working in groups (of the order of 100 at the peak of their activities). The HAEE/EPPO/RELUIS/UoB team visited the European Union Civil Protection office, located at the Prefecture Building in Durrës, and was informed of the building damage recorded in Durrës, Thumanë, Lezhë, Krujë and other regions that were affected by the earthquake (Figure 8). Until December 14th, approximately 2,000 visual building inspections had been completed. The most severe damage was recorded in Durrës and Thumanë. Based on the recommendations of the European Union Civil Protection Team, the HAEE/EPPO/RELUIS/UoB team organized two daily field missions in Durrës and Thumanë in order to gather data and photos related to structural and geotechnical damage, perform Rapid Visual Inspections (RVI) for the evaluation of damage and make proposals to the Albanian authorities about recovery plans and retrofit prioritization.


Figure 8. Premises of the European Union Civil Protection Team, Prefecture Building, Durrës.

## 5. POST-QUAKE RAPID VISUAL INSPECTION (RVI) TOOL

Many methodologies are available for pre- and post-earthquake rapid visual inspection of structures, while the most popular and widely used is the FEMA method for Rapid Visual Screening (RVS) or Rapid Visual Inspection (RVI) of Buildings (FEMA P-154 (2015), FEMA 356, (2000)). The NZSEE (New Zealand National Society for Earthquake Engineering), JBDPA (Japan Building Disaster Prevention Association, 1990) and the GNTD (Gruppo Nationale Per La Difesa Dai Terremoti, 1993) are also widely applied methodologies for Rapid Visual Screening. The RVI procedure prescribed by FEMA uses a methodology based on the building survey inspection and requires the filling of a data collection form based on visual observation of the building from the exterior, and if possible, the interior. The two-page data collection form includes building identification information (i.e. usage, area, floor number, etc.), a photograph of the building, sketches, and documentation of pertinent data related to seismic performance. Based on the data collected during the survey, a score is calculated that provides an indication of the expected seismic performance of the building.

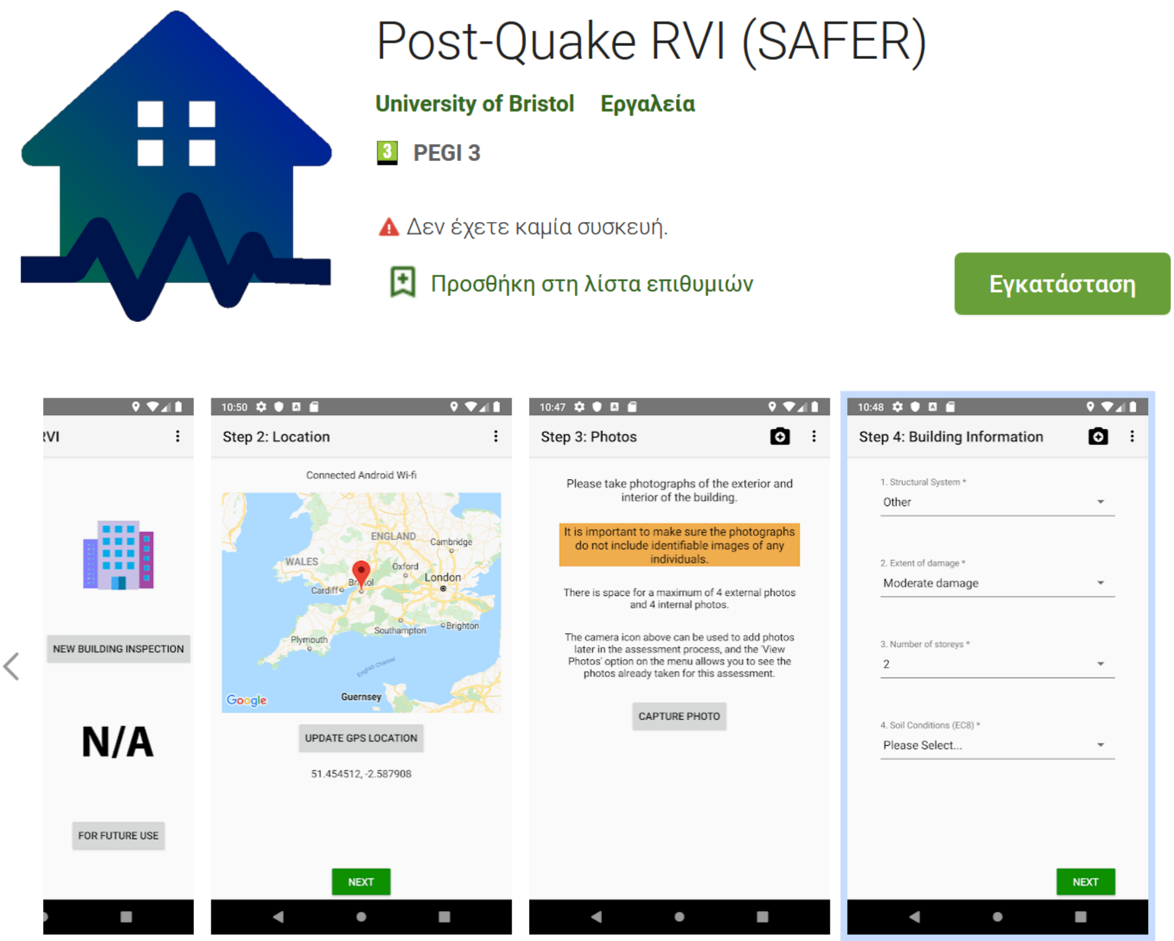



Figure 10. Post-Quake RVI (Safer) mobile app.

Simple survey procedures for seismic risk assessment are proposed and applied to urban building stocks to provide damage statistics (Sucuoglu & Yazgan, 2003). In order to perform Post-Quake RVI, store the relative information in an online database, the use of a tool for rapid visual survey was necessary. The HAEE/EPPO/RELUIS/UoB team, consisting of experienced and qualified civil engineers, used the Post-Quake RVI (SAFER) app[1] (Figure 10), a tool developed by the

1 https://play.google.com/store/apps/details?id=uk.ac.bristol.rit.safer2&hl=el

University of Bristol following its first pilot application during the 2016 central Italy earthquake (Sextos et al., 2018; Stewart et al., 2018). For every building inspected, the app retrieves the GPS location (Sextos et al., 2008), while the user stores (and the app wirelessly transmits) external and internal photos and general building information affecting its seismic performance (structural system, extent of damage, number of storeys, soil conditions, etc.). Furthermore, information related to the type of damage (i.e. beam flexural or shear damage, panel out-of-plane cracking, etc) is also collected for every building. The data of all buildings inspected is then saved and uploaded to a central data server, that is accessible through a dedicated WebApp (more in Section 7).

# 6. STRUCTURAL DAMAGE

According to the European Union Civil Protection, the most severe structural damage was observed along the coastline around the large port city of Durrës and the village of Kodër-Thumanë, which was near to the epicentre of the earthquake. For this reason, the HAEE/EPPO/RELUIS/UoB team efforts focused on the city of Durrës and the village of Thumanë. In all cases, the RVI was performed for selected buildings using the Post-Quake RVI (SAFER) application described above. 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 in the following, along with damage classification and preliminary conclusions based on field observations. The damage extent was classified as light, moderate, severe (major) and collapse in accordance to the four pre-earthquake performance objectives defined in FEMA 356 against which the post-earthquake damage description is classified (Table 2). It should be noted that in Albania the majority of the existing buildings, were designed to resist only vertical loads until the implementation of the seismic code of 1989 (Bilgin & Korini, 2013), which unavoidably contributed to the poor seismic performance of a number of structures considering the earthquake magnitude and ground motion intensity of the November 26th event. Given that a number of parameters such as, the structural system and materials used, construction age, building height (number of storeys), the existence of irregularities in plan and elevation, construction stages, soil type, etc. strongly affect the structural performance, they were also collected as part of structural performance assessment. However, for the majority of cases where architectural and design drawings were not available, or for cases that it was impossible to inspect the interior of buildings and identify the structural configuration on site, this report does not make any explicit (i.e., building specific) interpretation of the damage mechanisms.

Table 2. Qualitative description of damage states according to FEAM 356 (American Society of Civil Engineers (ASCE), 2000) and association with observed post-earthquake damage states.

| Target Building Performance Levels | Post-earthquake Damage | Qualitative description (FEMA 356) |
|---|---|---|
| *Immediate Occupancy Level (1-B)* | *Light* | No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable |
| *Life Safety Level (3-C)* | *Moderate* | Some residual strength and stiffness left in all stories. Gravity-load- bearing elements function. No out-of- plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair. |
| *Collapse Prevention Level (5-E)* | *Severe (major)* | Little residual stiffness and strength, but load- bearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Building is near collapse. |
| | *Collapse* | - |

### 6.1 Building performance in Durrës

The majority of buildings in Durrës are reinforced concrete buildings of 4-10 storeys. i.e., mid- to high-rise for the Albanian standards, constructed after 1990. The use of precast panels and masonry is also common. Regarding masonry building typologies, it is noted that unreinforced masonry buildings (URM), and in particular confined masonry, had been widely used before the 1980's, while confined reinforced masonry buildings were introduced later (Kokona & Kokona, 2015)). When the KTP-89 was established it included specific provisions for the latter under the description of a 'complex system'. Based on the data presented at the AACE (Albanian Association of Consulting Engineers) conference in Tirana on 14/12/2019 (Table 3 (Novikova et al., 2015)), the buildings that were built after 1990 are more than 40% of the total building stock. This figure is even higher in the capital where, as anticipated, newer construction is more extensive. Overall, they both reflect the trends of urbanization and internal migration of the population towards the capital and the coastal areas of the country (INSTAT, 2016; Novikova et al., 2015).

Table 3. Number of buildings per time of construction and seismic code in Durrës

| City | Time of construction | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Before 1945** | **1945-1960** | **1961-1980** | **1981-1990** | **1991-1995** | **1996+** | **Total** |
| **Durrës** (population 113,000) | 1,778 | 3,485 | 7,016 | 5,188 | 4,312 | 8,417 | 30,196 |
| Without seismic code | 57.8% | | | | | | |
| With seismic code | | | | | 42.2% | | |

Table 4. Number of buildings per time of construction and seismic code in Tirana

| City | Time of construction | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Before 1945** | **1945-1960** | **1961-1980** | **1981-1990** | **1991-1995** | **1996+** | **Total** |
| **Tirana** (population 418,000) | 5713 | 5905 | 11,698 | 10,585 | 11,406 | 21,231 | 66,538 |
| Without seismic code | 50.9% | | | | | | |
| With seismic code | | | | | 49.1% | | |

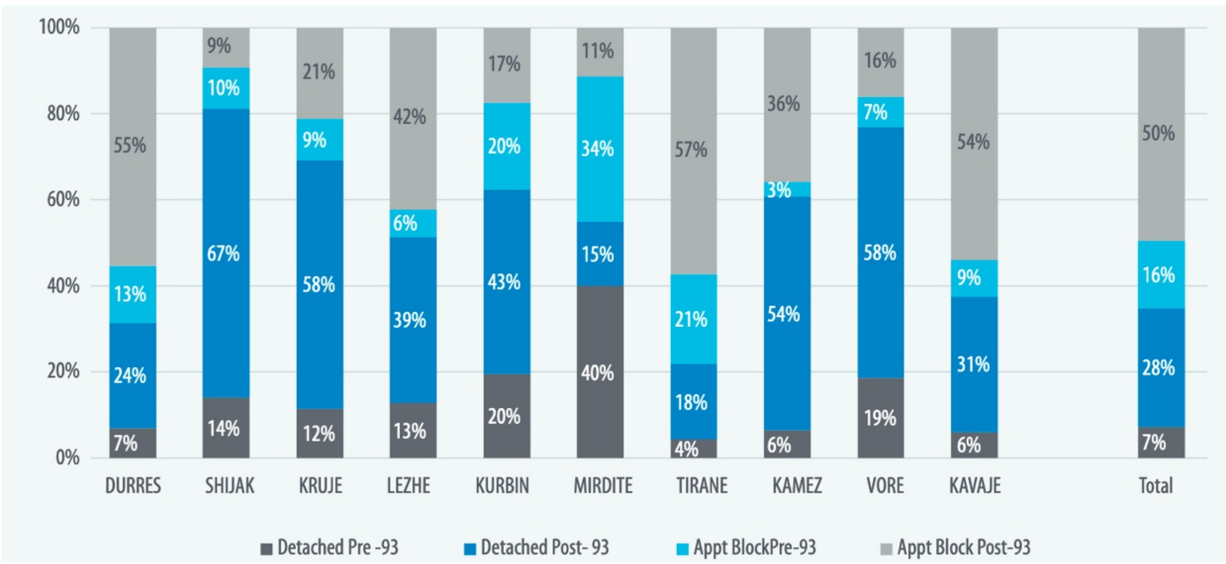



Figure 11. Distribution of housing units of buildings, year of construction and municipality (Republic of Albania et al., 2020).

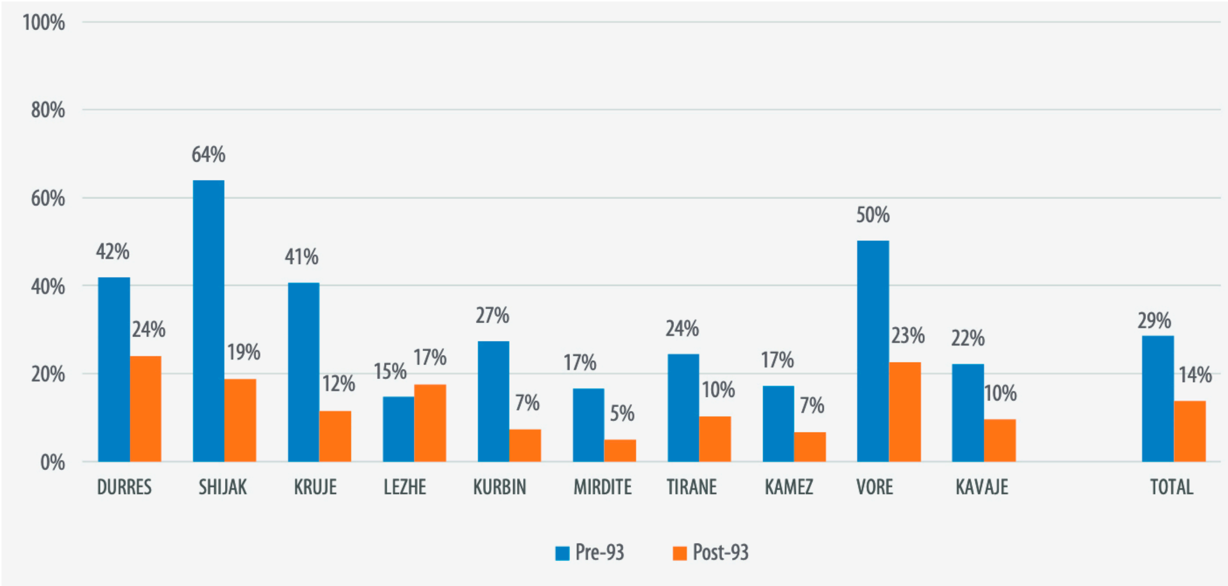



Figure 12. Distribution of damaged housing units per year of construction (Republic of Albania et al., 2020).

Figure 12 presents the percentage of buildings that have experienced a degree of damage in 10 different municipalities in Albania classified per year of construction, with the threshold being in 1993 (Republic of Albania et al., 2020). It is shown that the extent of damage was twice as high (29% for pre-1993 versus 14% for post-1993) for the entire building stock. The same analogy holds for Durrës, where 42% of the pre-1993 buildings and 24% of the post-1993 buildings were damaged.

Overall, the most common damage pattern observed was the out-of-plane failure of infill walls, both external and internal, followed by in-plane diagonal ('X'-shaped) cracking due to diagonal tension, concrete spalling, hoop fracture, buckling of longitudinal reinforcement, concrete core crushing and shear cracking of short columns. At the time of the visit the debris of the collapsed buildings had been removed, while most of the buildings at the onset of collapse had already been demolished. As a result, it was not possible to know if the collapse was total or partial, or to evaluate the failure mechanism.

### *6.1.1. Residential buildings*

Structural damage patterns, classified as slight, moderate, severe (major) and collapse are depicted in Figures 13 to 22 characterizing the seismic performance of buildings in Durrës. An example of light damage is the multistorey RC building that performed well during the earthquake (Fig.13), with only slight horizontal and diagonal cracking at external infill panels observed. Multistorey RC buildings that performed rather well during the earthquake (Fig.15,16). Figures 14-15 illustrate cases of moderate damage including diagonal cracks at non-structural elements along with flexural cracks at columns. Figure 16 shows an example of a multistorey RC building with poor seismic performance and major damage due to the earthquake, including extensive in-plane and out-of-plane failure of masonry infill panels. The latter is a widespread building practice in southern Europe and usually consist of perforated clay bricks. Their interaction with the encasing RC frame is typically neglected during seismic design calculations and also by the codes as it is perceived as a secondary horizontal load bearing system. When the panels are well-connected to the surrounding frame and are arranged in a regular pattern that does not create stiffness discontinuities, the contribution of the infills can enhance the seismic response of the RC building, a fact that has been long and well-documented in the literature (Dolšek & Fajfar, 2008; Panagiotakos & Fardis, 1996; Ricci et al., 2013; Zarnic & Tomazevic, 1985). On the other hand, poor connection with the frame can lead to premature out-of-plane failure of the infills, at it was observed in several cases in Durrës.

Figure 13. Light damage of an 8-storey RC building

Figure 14. Moderate damage of a 5-storey RC building


Figure 15. Moderate damage of a 7-storey RC building

Figure 16: Major damage of an 8-storey RC building

As seen in Figure 16, masonry infills of the perimeter frames were inadequately confined by the surrounding frames due the lack of columns at the ends, which is in itself a rather unfortunate design choice. As the infill walls tend to follow the inter-storey drifts experienced by the surrounding frame during the earthquake-induced ground motion, they experience shear diagonal cracks; the absence of vertical RC elements at the edges providing some confining contact pressure to the deformed panel, makes the masonry panel extremely susceptible to out-of-plane collapse, due to the inertial forces caused by the component of floor response perpendicular to the infill's plane (Morandi et al., 2014). This type of damage is concentrated to the lower floors of the building, which is anticipated, since RC frames tend to exhibit a shear-type lateral deformation pattern, with greater concentration of inter-storey drifts closer to the ground floor.

Another issue with masonry infills is the irregularity of lateral stiffness along the height of an RC frame, caused by interruption of the infills at the ground floor. This practice is often dictated by commercial use of the building at ground level and can lead to a concentration of flexural deformations at the ground floor columns (Ricci et al., 2011). Evidence of this effect can be seen in Figure 17.

Figure 17: Major damage of 4-storey RC building

In fact, flexural and shear cracks are visible at the external ground floor columns, which can be attributed to the aforementioned effect of stiffness irregularity-in-height. The out-of-plane buckling of a segmented metal-sheet garage door, also attests to the concentration of drift at the ground floor. Furthermore, the spalling of concrete cover, visible at the base of one of the columns, reveals poor detailing of transverse reinforcement; the 20 cm spacing of the stirrups is not up to par with modern seismic code ductility requirements for confinement reinforcement in columns. It should also be noted, that the adjacent building suffered collapse and had already been demolished by the time these pictures were taken; in this light, some of the damage that can be observed the outer-most non-structural elements could have been due to pounding between the two buildings during strong ground motion.

Figure 18: Major damage of 5-storey building.

Another interesting and typical structural typology that suffered extensive damage is that of unreinforced brick masonry buildings with RC slabs (Fig. 18). This typology can be characterized as a template design building, which were used for building development by the Albanian authorities until the end of the communist period in 1990 and nowadays are mainly used as residential buildings (Bilgin & Korini, 2012).

This structural system follows the concept of similar building types developed in Italy and in other areas in the world between 1920's-1930's called "modern" masonry buildings (MMB) (Sandoli & Calderoni, 2018) with the introduction of reinforced concrete elements (especially for the floors) to reduce the seismic vulnerability of buildings (Calderoni et al., 2020). The masonry material was perforated clay blocks. Flexural and shear cracks at structural and non-structural elements were observed externally, mainly around openings. In particular, "X"-shaped cracks due to diagonal tension were observed at both external and internal infill walls, while wider cracks and detachments were also apparent. Severe damage of internal walls (clay bricks) was observed; out-of-plane wall failure and partial collapse. There were also significant out-of-plane displacements of corner walls due to very large diagonal cracking near the building corners. This mechanism has been also observed in private residential masonry buildings in Italy after strong earthquake events such as that of L'Aquila (Calderoni et al., 2020) and can be probably attributed to the decompression of portions of corner walls after cracking, that is, not necessarily due to overturning phenomena of the external facades. The observed damage could also have been developed due to insufficient interlocking between intersecting walls and lack of anchorage between wall and concrete floor slabs along with low-quality masonry materials and mortar, as it is noted also on a work on the performance of masonry buildings in Albania (Kokona & Kokona, 2015).

Figure 19 offers another example of a multistorey RC building exhibiting major seismic damage, where the two defects highlighted above are both present: masonry infill panels not adequately aligned with the perimeter frames and interruption of the infills at the ground floor. In fact, these issues are a recurrent theme also in the following cases examined. In this case too, out-of-plane failure of infill walls was observed in several location around the perimeter. The partial collapse of extruded volumes of unreinforced masonry, provided for aesthetic and architectural reasons, is also visible. This can be attributed to lack of adequate connection to the load-bearing RC frame between floors, as stability was apparently relying exclusively on small portions of the floor slab cantilevering out to accommodate the masonry elements.

Another multistorey RC building with major damage due to the earthquake is illustrated in Figure 20. Flexural cracks and out-of-plane failure of infill walls, partial collapse of infill walls and facades, wide cracks and detachments, were observed. Significant damage was observed at the interior of the building, with wide flexural and shear cracks, mainly at infill walls and "X"-shaped cracks at infill walls around the staircase location. The absence of a RC core at the staircase and the elevator should be commented, along with the severe damage of the staircase. Similar structural pathology is depicted in Figure 21.

As already stated, at the time of the reconnaissance mission, the debris of the collapsed buildings had been removed and partially collapsed structures had been demolished. Therefore, it was not possible to evaluate their failure mechanism (Fig. 22). It is noted that the sites of the (fully or partially) collapsed buildings were cleaned in very short time after the earthquake event.

Figure 19: Major damage of a 5-storey RC building. No confinement of the brick masonry walls to the RC frame is observed.

Figure 19 (continued)


Figure 20: Major damage of a 6-storey RC building

Figure 20: Major damage of a 6-storey RC building (continued).

Figure 21: Major damage of a 10-storey RC building.

Figure 22:  Collapsed and/or demolished buildings.

### *6.1.2. Hotels*

Severe damage was observed at several hotels in Durrës. Hotel Ljubljana, Hotel MiraMare and Hotel Villa Verde are some examples. As with the residential buildings, at the time of the visit the debris of the collapsed buildings had been removed (Figure 23). Light damage was observed at several hotels in the close proximity of the collapsed hotels. Flexural and shear cracks were observed, mainly at infill walls, as depicted in Fig. 24.


Figure 23: Vila Verde Hotel (left) and Lubjana Hotel (right).

Figure 24: Photos at the location MiraMare Hotel.

Figure 25: Light damage at hotels in Durrës

### 6.2. Building performance in Thumanë

Most buildings in Thumanë are single or two-storey (rarely three-storey) buildings built after 1950 until recently. Regarding the structural system, the most popular is RC frames with infills and masonry with timber roofs. In most cases the buildings were constructed by the owners themselves, therefore, without necessarily following structural design code prescriptions. Unreinforced masonry buildings (URM) are also common. It is noted that many buildings were constructed in stages using different materials and structural systems, being extended in plan and/or elevation years after their initial construction, using RC frames and infill walls.

The most common damage patterns observed were the in-plane diagonal ('X'-shaped) cracking and out-of-plane failure of infill or masonry walls, both external and internal. Other damage patterns observed were concrete spalling, hoop fracture, buckling of longitudinal reinforcement and concrete core crushing and shear cracking. Unreinforced masonry buildings (low-middle rise) presented extended damages, as it is very common during strong earthquakes due to poor quality of construction, poor workmanship, aging and the lack of maintenance.

### *6.2.1. Religious establishments*

Slight to moderate damage was observed at the mosque of Thumanë (Fig. 26-27). The structural system of the mosque is mainly masonry with RC frames at the interior. The horizontal and vertical joints are irregular (in terms of shape and thickness), while the mortar thickness varies. Wide "X"-shaped cracks due to diagonal tension were observed at the exterior infill walls together with cover spalling at the interior. Small cracks were also observed at the dome as well as along the dome ring due to excessive horizontal stresses. No significant damage was observed on the interior RC frame elements. This is the result of their small stiffness compared to the stiffness of the masonry walls at the perimeter of the structure that provided the main seismic resistance. The minaret appears to have suffered moderate damage. Minarets in general exhibit seismic behavior not similar to other known structures, because of their unique characteristics in terms of slenderness and shape. The minaret has a hexagonal cross-section and it is constructed with RC columns of approximately 10x10 cm2 at every vertice of the hexagon and tie-beams every 3m along its height. Extended cracking and spalling were observed, at the base and along the shaft. Cracks are also present at the connection of the minaret to the main mosque structure. These cracks are very common when minarets are contiguous and integral with the main mosque structure. They come as result of the out-of-phase vibration of the two parts of the structure due to the difference of their dynamic properties.

Figure 26: Damage of the mosque in Thumanë

Figure 27: Damage of the mosque in Thumanë

### *6.2.2. Residential buildings*

Most buildings in Thumanë developed moderate to major damage, if they did not collapse either partially or totally. An example of light-to-moderate damage is the single-storey masonry building with clay bricks shown in Figure 28. "X"-shaped, wide cracks due to diagonal tension at masonry walls were observed, along with cracking and spalling at the base of slender vertical load bearing elements. The in-plane diagonal cracking is related to the shear failure of the masonry piers and spandrels due to excessive stresses induced by in-plane vertical and horizontal forces. Similar extent of damage is presented in Figure 29 followed by a three-storey RC building irregular in elevation in Figure 30. Figures 31-33 illustrate a three-storey, irregular in elevation, masonry building with RC slabs and confined masonry walls that was heavily damaged. The walls were thick enough, but masonry was constructed using low-strength clay bricks (partially fired or unfired). A detachment of the external staircase, wide cracks and failure at the corner and partial collapse of the timber roof were also observed. In addition, the vertical concrete members were constructed with an attempt to follow an Italian and South American practice from the 1970s for concrete beams utilizing a welded steel-truss type reinforcement (Colajanni et al., 2017) instead of a regular arrangement of longitudinal reinforcement bars and transverse. Regarding poor concrete quality, rounded large-size gravel aggregates were observed in the concrete mixture.

One-storey masonry building with RC slabs and masonry columns is also shown in Figure 34, with major damage and complete collapse of the masonry-RC frame porch in front of the house. The collapse of the masonry columns at the entrance resulted in the collapse of the RC roof slab. Apparently, this part was built at another construction phase and was not properly connected to the building in order to transfer loads safely. Wide diagonal tension cracks at masonry external and internal walls and "X"-shaped cracks between openings were observed, along with the partial collapse of the timber roof.

A two-storey masonry building with stone bricks, extended in plan with R/C frames, with severe moderate damage of the older masonry part of the structure is shown in Figure 35. The new RC frame part of the structures suffered no damage at all. It should be pointed herein, that the owner built the RC frame section on his own, falling back to his experience working in the construction industry abroad, without any structural design and supervision by licensed professional engineers. Diagonal tension cracks mainly at masonry walls, partial failures of bricks, wide cracks and detachments, were observed, as well as partial failure of mortar and bricks at the base of masonry walls.

Figure 28: Moderate damage of single-storey building in Thumanë

Figure 29: Moderate damage of two-storey building in Thumanë

Figure 30: Moderate damage of three-storey building in Thumanë

Figure 31: Major damage of three-storey confined masonry building in Thumanë.

Figure 37 illustrates a two-storey RC building that suffered significant damage in the infill. Shear cracks due to diagonal tension are observed around the openings, as well as out-of-plane failure, partial collapse of infill walls, wide cracks and detachments. Concrete spalling is observed at external columns along with corrosion of longitudinal reinforcement. Despite being built rather recently the lack of quality control during the construction of the building (or the lack of compliance with up-to-date standard provisions during the design) is evident from the large and irregular spacing of the hoops in the RC columns revealed after spalling.

It is worth mentioning that with the exception of the heavy damage observed in the RC building presented in Fig. 39, very few RC buildings performed poorly in Thumanë. The latter is either due to the small number of RC buildings that exist in Thumanë (a rural area with a building inventory dating back to the 1950s) or due to the superior performance of the RC buildings in the seismic event. It is recalled that in old buildings with extensions of RC systems, damage was only observed in the older part of the building, whereas the RC part remained undamaged.

Figure 32: Major damage of three-storey confined masonry building in Thumanë.

Figure 33: Major damage of three-storey confined masonry building in Thumanë.

Figure 34: Major damage of single-storey building in Thumanë

Figure 35: Moderate damage of two-storey masonry building with stone bricks, extended in plan with RC frames in Thumanë.

Figure 36: Major damage of two-storey RC building in Thumanë

Figure 37: Major damage of two-storey building in Thumanë

Figure 38: Major damage of single-storey building in Thumanë

Figure 39: Major damage in the infill brick walls of a two-storey building in Thumanë.

### 6.3. Post-Quake Rapid Visual Inspection Aggregated Data

During the field mission, the data (Listed in Table 5) were combined with those collected by the Earthquake Engineering Field Investigation Team (EEFIT, UK) and resulted into inspection surveys for **75** buildings mainly in Durrës and Thumanë (Figure 40). The structural typology of the inspected buildings are depicted in Fig. 41; the categories of structural systems considered are similar to the ones prescribed in FEMA 154 ((FEMA P-154, 2015). The majority of the 75 buildings inspected were reinforced concrete (RC) buildings and the most common structural systems were RC4 (RC-MRF - Modern Code-24%) and URM2 (Unreinforced Brick Masonry with RC slabs-19%). When the classification considers the height of the buildings, the most common structural typologies of low-rise (i.e., less than 5 stories) buildings is URM1 (Unreinforced Brick Masonry -29%) and URM2 (Unreinforced Brick Masonry with RC slabs-23%). For higher buildings with more than (or equal to) 5 stories, the most common structural typology was that of RC4 (RC-MRF - Modern Code-38%) and RC2 (RC-MRF - Old Code -19%). It should be noted that the buildings' sample inspected during the field mission mostly referred to damaged buildings, therefore the statistical distribution and conclusions should be evaluated considering that the sample was not unbiased in terms of seismic performance. A summary of building tagging for the entire portfolio of the city of Tirana and Durres/Kruja/Shijak is given in Tables 5 and 6, respectively.

The distribution of damage level per structural typology of the inspected sample of buildings is depicted in Fig. 42. Most RC buildings designed with old codes (RC2) and unreinforced brick masonry (URM1) suffered severe damage. Buildings with designed to modern codes (RC4) and unreinforced (confined) masonry with RC slabs (URM2), perform better, yet there were cases where they experienced light-to-moderate damage. When building height (number of storeys *n*) is introduced as a classification criterion, with a threshold of n=5), it is evident that for low- to mid-rise buildings (n<5) the damage extend is higher for URM buildings with the majority of URM1 and URM2 developing major damage or collapse. The latter were mainly unreinforced brick masonry (URM1) and RC buildings designed with old codes (RC2), whereas RC buildings designed with modern codes (RC4) experienced a lower level of damage. For the case of mid- to-high-rise buildings (n ≥5), the majority of RC buildings designed with modern codes (RC4) experienced only minor to moderate damage, with most of the older RC buildings (RC2) and unreinforced brick masonry with RC slabs (URM2), suffering moderate to major. Based on the same figure, the damage extend is higher for lower buildings (n <5 , T~0.5sec) in accordance with the response spectra presented in Fig. 5, where for both cases (i.e., earthquake records at the Tirana (TIR) and Durres (DURR) station), the spectral amplification is higher for a period range T=0,2~0,5sec.

The above damage statistics on the limited sample of 75 characteristic buildings inspected are in good agreement with the comprehensive post-earthquake inspection campaign in Tirana (Table 6) (World Bank, 2019) and the qualitative results are in since the majority of buildings with severe damage (i.e., tagged as red) were low rise buildings, designed with old (pre 1992) codes. It is also noted that the distribution of tagging (i.e., green, yellow, red) between Tirana (Table 6) and the municipality of Durrës was also similar (approximately 60% deemed as 'safe'). Figure 43 illustrates the frequency of damage patterns observed in the building sample inspected. The most frequent damage type for both low-to-mid height (H<5m), URM (unreinforced masonry) and mid-to-high RC buildings (H>=5m) was in-plane and out-of-plane wall failure. As anticipated, beam and column, flexural and shear damage was more frequent for buildings designed with old codes (RC2). Finally, Figure 44 relates the inspected damage per building height. It is seen that both low- to mid-height and mid- to high- rise buildings develop in and out-of-plane failure of infill panels, while in plane failure is more frequent for low-rise buildings, which can be expected given the flexibility of high rise buildings. Moreover, RC column flexure failure is more frequent in mid- to high-rise buildings, while shear and short column failure are more frequent for low- to mid-rise ones, as anticipated. Overall, the damage level developed can be characterized as disproportionate to the seismic intensity.

However, the damage patterns developed are similar to observed cases after strong earthquake events in other parts of the world where poor construction quality was also reported.

Table 5: List of collected data using Post-Quake RVI (SAFER)

| | |
|---|---|
| **Location** | GPS latitude/longitude, Country |
| **Building Information** | Structural System, Extend of damage, Number of Stories, Soil Conditions, Regularity in plan and elevation |
| **Type of Damage** | Settlement (S) Infill panel cracking in plane, Infill panel cracking out of plane, 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 storey, Pounding |
| **Other Information** | Notes, Date/time, Username |

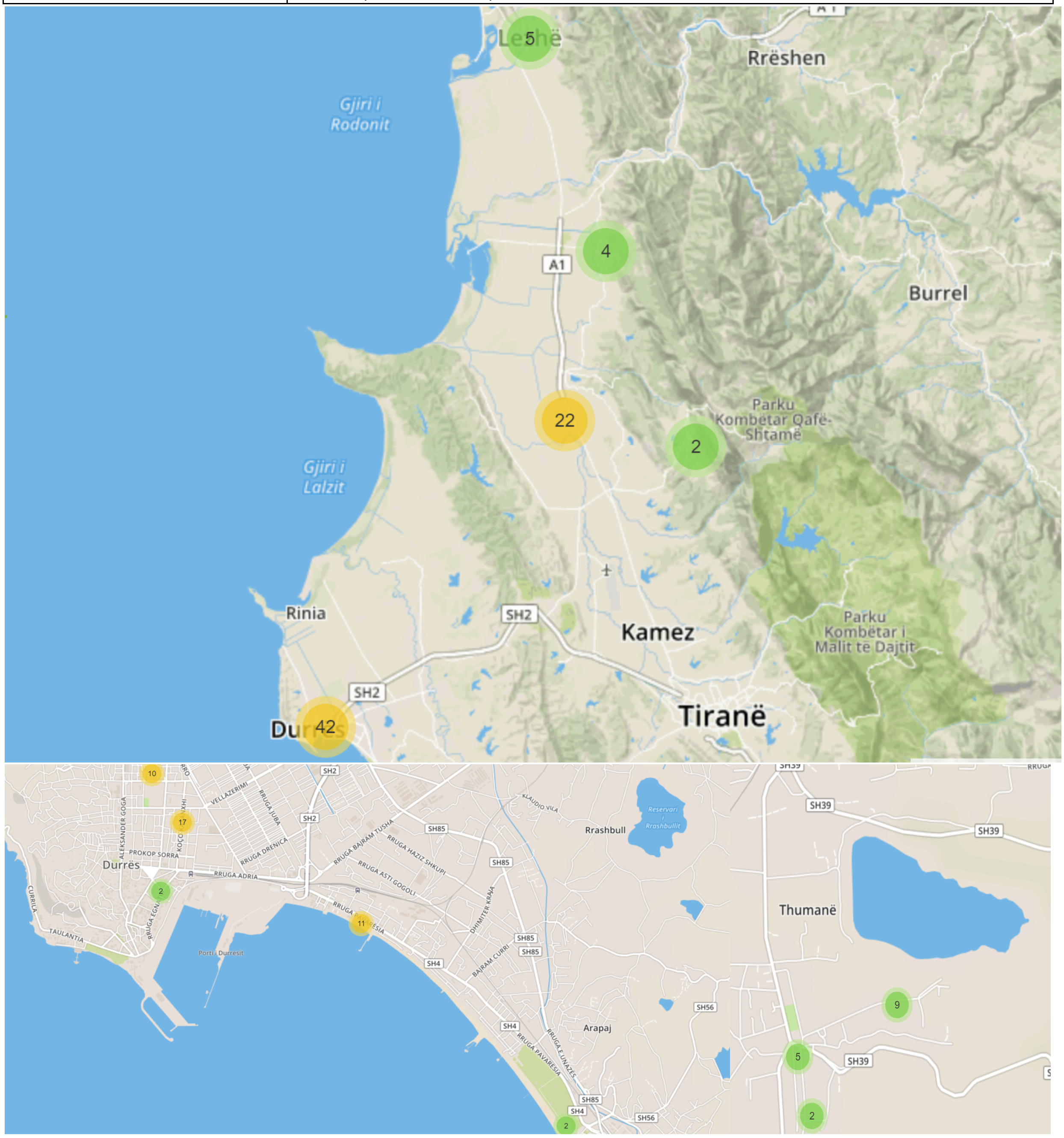
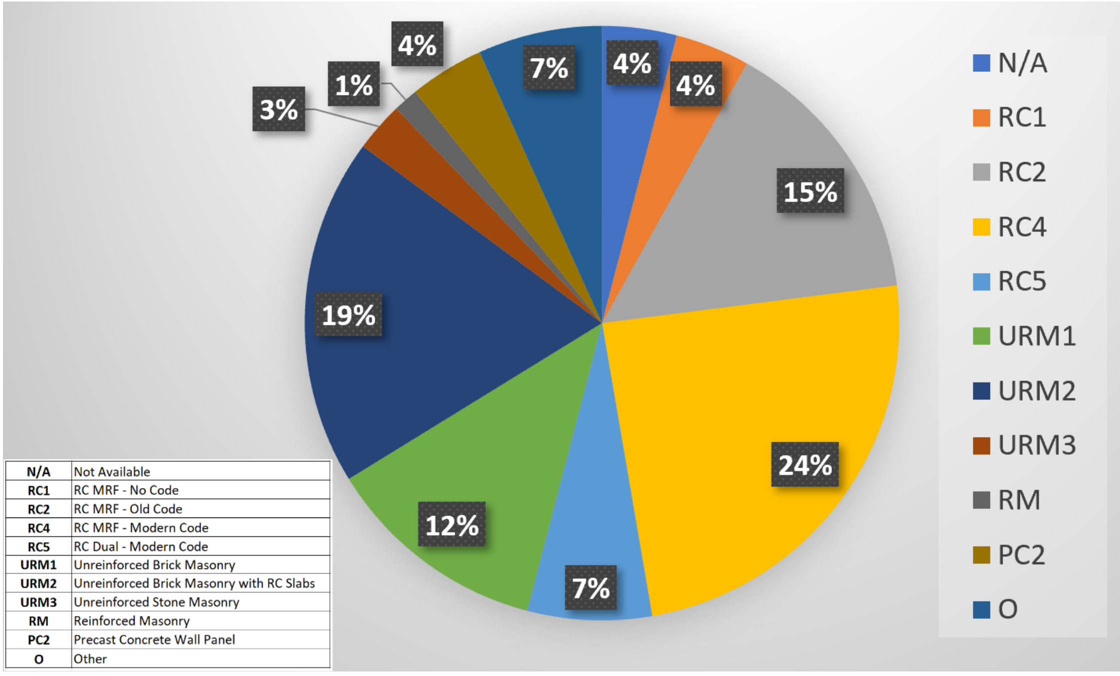
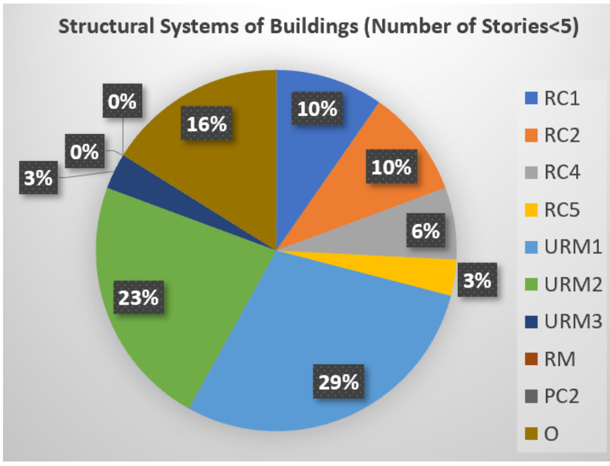



Figure 40: Location and density of inspected buildings (each number indicates the number of inspected buildings in the respective area).




**Number of Stories < 5** **Number of Stories ≥5**



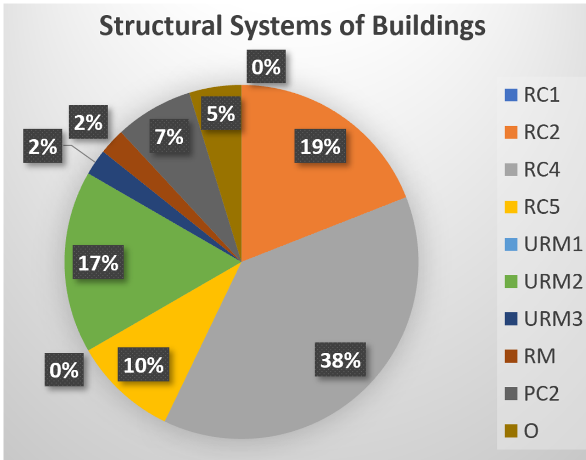
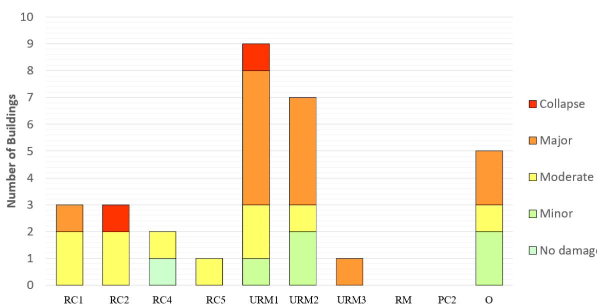




Figure 41: Structural typologies of inspected buildings

**Number of Stories < 5** **Number of Stories ≥5**



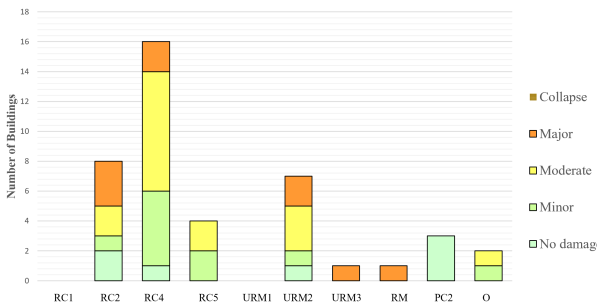




Figure 42: Structural typologies of inspected buildings classified by damage level.

Table 6: Analysis of building damage statistics in Tirana from the Tirana Municipality by period of construction, number of floors, type of structure and 3-colour scheme damage levels (World Bank, 2019).

| Building characteristics | Green (safe) | Yellow (review) | Red (evaluate) |
|---|---|---|---|
| Pre-1992 | 56.3% | 23.6% | 20.0% |
| Post-1991 | 71.6% | 15.3% | 13.1% |
| Unclassified | 47.0% | 16.6% | 36.5% |
| | | | |
| 1-2 floors | 29.8% | 22.2% | 48.0% |
| 3-5 floors | 60.6% | 23.5% | 16.1% |
| 6+ floors | 78.0% | 14.0% | 8.1% |
| Unclassified | 66.3% | 12.5% | 21.2% |
| | | | |
| Adobe walls | 17.4% | 17.4% | 65.2% |
| Brick Masonry | 56.1% | 20.9% | 23.0% |
| Concrete Block Masonry | 9.1% | 9.1% | 81.8% |
| Prefabricated | 86.2% | 10.3% | 3.4% |
| Reinforced concrete | 71.7% | 16.0% | 12.3% |
| Structural Masonry | 62.8% | 21.8% | 15.4% |
| Unclassified | 4.0% | 36.0% | 60.0% |
| **TOTAL** | **60.6%** | **19.2%** | **20.2%** |

Table 7: Table 3: Building damage statistics from the Office of Natural Disaster Management Operations in three municipalities in the epicentral region (as of Dec. 10, 2019) (World Bank, 2019).

| | Durrës | Kruja | Shilak | Combined |
|---|---|---|---|---|
| Inspected | 2112 | 2499 | 1670 | 6281 |
| Safe | 1368 (64.8%) | 1533 (61.3%) | 346 (20.7%) | 3247 (51.7%) |
| Uninhabitable | 651 (30.8%) | 921 (36.9%) | 900 (53.9%) | 2472 (39.4%) |
| Demolition | 93 (4.4%) | 45 (1.8%) | 424 (25.4%) | 562 (8.9%) |
| Demolished | 34 | 12 | 0 | 46 |

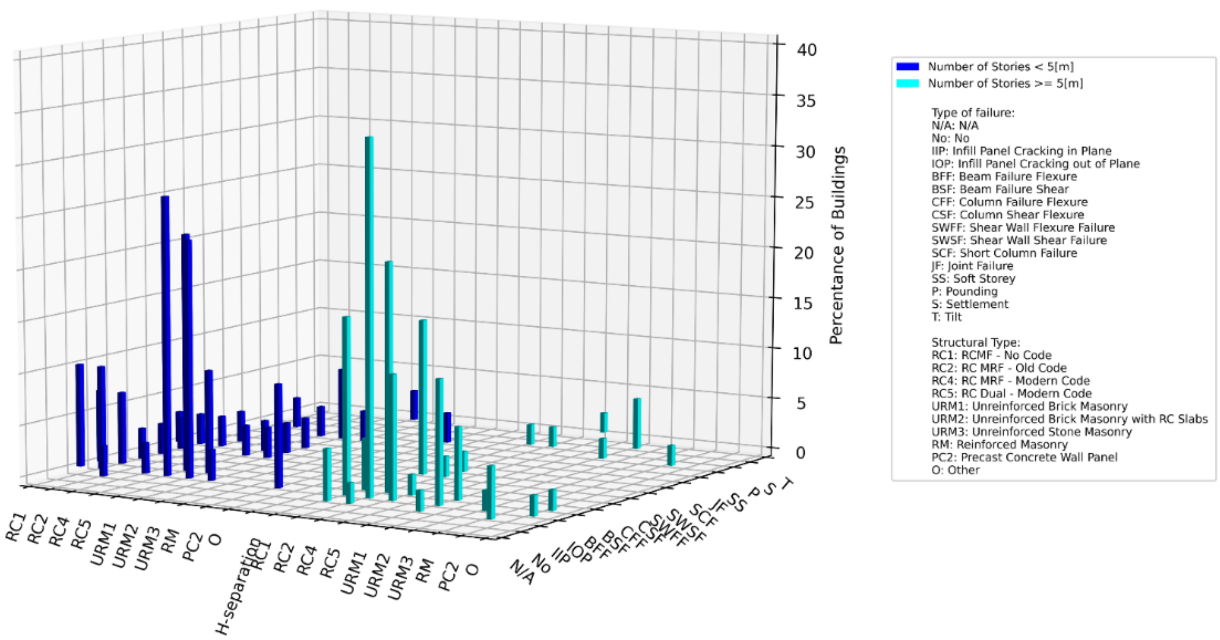



Figure 43: Structural pathology of inspected buildings per number of storeys and typology.

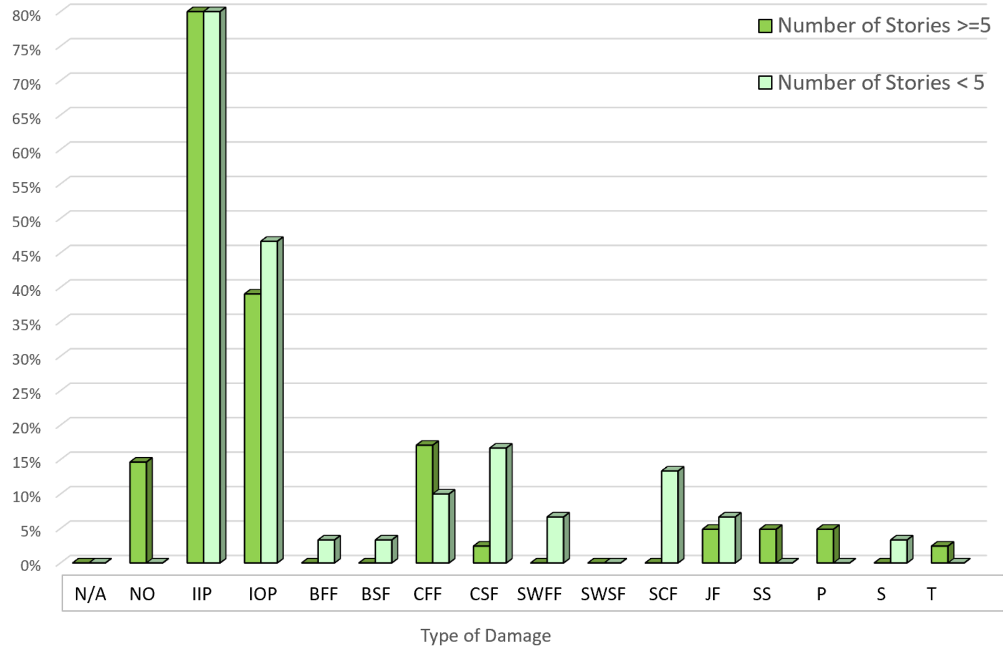



Figure 44: Structural pathology of inspected buildings per number of storeys.

## 7. GEOTECHNICAL DAMAGE

Based on field observations, the M6.4 earthquake that struck Albania on 26 November 2019, resulted mainly in structural damage, whereas geotechnical damage was not explicitly reported. However, there are areas in Durrës, known for their soft soil conditions, which might have contributed to the observed extent and localization of building damage. The main types of geotechnical phenomena observed, were soil liquefaction, settlements and permanent ground displacements. They developed at the coastal area of Durrës, where a number of damaged hotels are located. The map in Fig. 45 (left) shows the liquefaction potential map of the city (Kociu, 2004) with numbers 1, 2 and 3 denoting areas highly, moderately and high susceptibility to liquefaction, respectively. On the right, it is evident the location of the hotel buildings that suffered extensive settlement and titling.

/

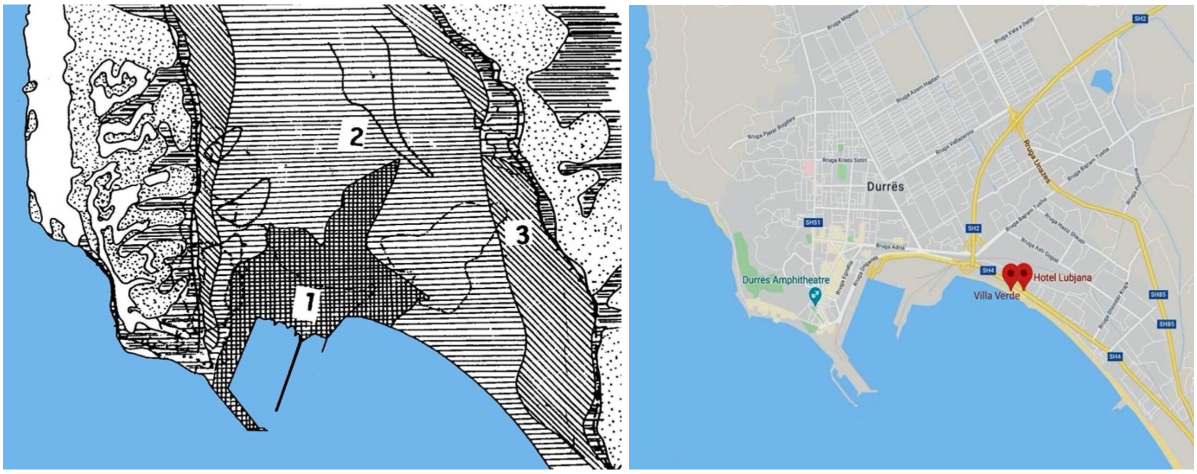



Figure 45: Liquefaction potential map of Durrës (Kociu, 2004) and map showing the location of Hotels Lubjana and Villa Verde Beach.

The Hotel Lubjana situated at the seafront of Durrës, was one of the structures that experienced such extensive tilt due to soil liquefaction as shown in Fig. 46. The damage was beyond repair and it was demolished during the first weeks after the seismic event. The Villa Verde Beach Hotel was also located in the high risk for liquefaction area. Although the main cause of its collapse seems to be the development of a soft-storey mechanism, the soil conditions may have contributed to the failure.

Figure 46: Tilting of Hotel Lubjana due to soil liquefaction and resulting settlement (left). Collapse of the Villa Verde Beach Hotel (photos courtesy of J. Psaropoulos)

Figure 47: Permanent ground displacements.

Soil liquefaction, resulting in the ejection of the liquefied material through cracks, due to increased pore water pressure, affects loose saturated cohesionless soils especially if the cyclic loading has a large intensity and long duration. Large parts of the coast line of Albania from Vlora to Velipoja are susceptible to liquefaction (Daja et al., 2016). An example of such liquefaction phenomena observed in the bay of Porto Romano (10km from Durrës) is shown in Figure 48 with several sand boils and craters extending across a large area.

Figure 48: Sand boils and craters due to soil liquefaction in the bay of Porto Romano.

For the visual inspection of liquefied soils at Porto Romano Bay, two flying drones were used and the relevant photos were saved and evaluated (Fig. 49). It should be outlined, that despite the fact that liquefaction phenomena were evident at the Port, no damage was reported.


Figure 48: Drone images of liquefied soils (top). Field mission of the Hellenic Association for Earthquake Engineering (bottom).

## 8. SUMMARY AND CONCLUSIONS

The most critical findings of the field mission of HAEE/EPPO team and the rapid visual inspection performed, are summarised below:

In terms of **structural** damage:

In *Durrës*

- The majority of the buildings in Durrës are masonry infilled RC frame structures with 4 to 10 storeys, built after 1990. Unreinforced confined masonry buildings are also common.
- Moderate and major damage was observed in many buildings, even some recently constructed, since they were not designed according to the code provisions.
- The most common damage pattern observed was the out-of-plane failure of infill walls (both external and internal) and the collapse of facades. It was observed that the common construction practice does not connect and confine properly the brick masonry walls to the

surrounding RC frame, thus leading to out-of-plane failure of infill walls. The vulnerability of unreinforced, unconfined masonry is particularly highlighted.

- Other damage patterns involved in-plane, shear diagonal cracking of infill panels and load bearing masonry walls, as well as concrete spalling, hoop fracture, buckling of longitudinal reinforcement, concrete core crushing and shear cracking at short-span beams and columns in RC buildings.
- The absence of RC concrete cores around the staircase and the elevator of multi-storey buildings should be outlined. Soft storey mechanisms have also played a detrimental role and have lead several buildings to collapse.
- Insufficient quality control and low-quality materials clearly undermined the structural integrity of buildings, especially of those constructed prior to the enforcement of the latest KTP-89 seismic code.

In Thumanë

- Most buildings in Thumanë are single or two-storey (rarely three-storey) structures built after 1950. They are mainly RC frames with brick infills or masonry structures with timber roofs.
- In most cases, the buildings were constructed by the owners without any structural design and supervision by licenced professional engineers. Furthermore, most buildings were constructed in different eras (sometimes more than 30 years apart), using different materials and structural systems. This unauthorized addition of floors or horizontal expansions, together with removal of load-bearing elements has contributed to the observed poor seismic performance in several cases.
- Most buildings in Thumanë suffered moderate to major damage, and in some cases partial or total collapse was observed.
- Structural damage modes are similar to those observed in Durrës.
- Major damage was also observed at the mosque located in Thumanë. Extended cracking and spalling at the masonry minaret, at the base and along its height.

G**eotechnical** damage:

Soil liquefaction, settlements and permanent ground displacements were observed along the coast of Durrës, leading to or amplifying structural damage. Extensive liquefaction was also evidenced at Porto Romano Bay.

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