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# ASSESSMENT OF DAMAGE TO MODERN REINFORCED CONCRETE BUILDINGS – ENGINEERING ANALYSIS OF THE M6.4 ALBANIA EARTHQUAKE, 26th OF NOV. 2019

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## Abstract

On November 26, 2019, a magnitude $M_w$ = 6.4 earthquake struck Northwestern Albania. It was the strongest to hit Albania in more than 40 years. Cities such as Thumanë, Tirana, and Durrës suffered damage, but Durrës was the hardest hit with several building collapsed [1,2].

A reconnaissance team under the auspices of American Concrete Institute (ACI) visited Durrës, Albania to assess the extent of damage to modern reinforced concrete (RC) buildings (i.e. built after 1990). The team[*1] surveyed buildings during the week of January 12, 2020, with a focus on RC buildings that were infilled with clay block masonry. Over the course of seven days the team documented 55 buildings that had RC frames as their main lateral resisting system. All of the surveyed buildings had unreinforced masonry infills (hollow clay blocks). Most of the buildings had ribbed or waffle slabs. Typical damage observed in these buildings was in-

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plane or out-of-plane failure (dominant) of masonry infill walls throughout the building height. More damage was observed when these masonry walls were not confined well within the RC frame i.e. acting as partitions. In many cases, these masonry walls were not connected to the RC frame at all, having only bed-joints filled with mortar.

This report focuses on the performance of masonry components (infill walls, partitions, etc.) in the buildings in Durrës that were affected by the earthquake. Examples of the damage to the masonry infill, structural details that affected the damage, and its impact on building performance are described.

The paper provides an overview of the earthquake-induced damages in several building types and their variation within different structural systems focusing on RC frames with unreinforced masonry infills in Durrës. Reasons for significant differences in observed damage will be discussed in close relation to the building code development and the preferred design concepts. Besides response phenomena and typical damage patterns which have been observed after other earthquakes worldwide, an attempt is made to investigate parameters with high damage potential according to [3].

## 1 INTRODUCTION

The field reconnaissance missions following natural disasters provide valuable information on the performance of buildings during such events. As part of the American Concrete Institute disaster reconnaissance committee (ACI 133) mission, a team of researchers from the US, Croatia, Albania and Germany surveyed 55 buildings affected by the $M_w$ 6.4 earthquake in Durrës, Albania on November 26, 2019.

The earthquake struck Northwestern parts of Albania, with an epicentral distance of 17 km from Durrës and about 35 km away from the northwest of the capital city of Tirana. Fifty-one people died because of the earthquake and 100,000 were affected. The earthquake caused serious damage to more than 1,400 buildings in Tirana, and about 900 buildings in the city of Durrës and the town of Thumanë with reported cases of collapsed buildings. Besides partial to complete failure due to shaking, a few buildings in the Durrës area were tilted due to liquefaction [4,5].

Events in Albania with a magnitude ($5.0 < M < 7.0$) are considered to be rare [6]. The last large event in the region was the earthquake in Montenegro on April 15, 1979 [7]. It was suggested that the region is going to be at a low seismicity rate interval from the event in Montenegro until the end of the second decade of the 21st century based on the seismic energy release for Albanian earthquakes [8].

The most affected buildings by the earthquake damage were reinforced concrete (RC) frame buildings with infill walls in Durrës. The poor performance of unreinforced masonry infill walls dominated the damage pattern, mostly due to simultaneous in- and out-of-plane dynamic excitation [9]. Thus, the global damage grade is mostly governed by the behavior of the partition/ infill walls. Further, up to two or three grades, larger damages to the infill walls could be observed which makes the assignment of the damage grade according to EMS-98 [11] difficult.

Infill/partition walls are usually treated as non-structural/secondary elements (see Eurocode 8, and EMS-98), whereas past earthquakes have shown that they mainly contribute to the horizontal stiffness and seismic resistance. The herein presented field observation highlight again the need for a proper design to avoid brittle behavior and out-of-plane failure (Eurocode 8).

In this study, the damaged buildings surveyed in Durrës are assessed and key observations are highlighted. Besides, quantitative measurements are used to assign the seismic vulnerability of buildings using the Hassan and Sozen index [10].

## 2 EARTHQUAKE CHARACTERISTICS AND CONSTRUCTION PRACTICE IN ALBANIA

### 2.1 Parameters of the earthquake

The earthquake of Nov. 26, was recorded at seven accelerometric stations of the Albanian network, in the range of epicentral distances from 15 km to 130 km as shown in Figure 1.

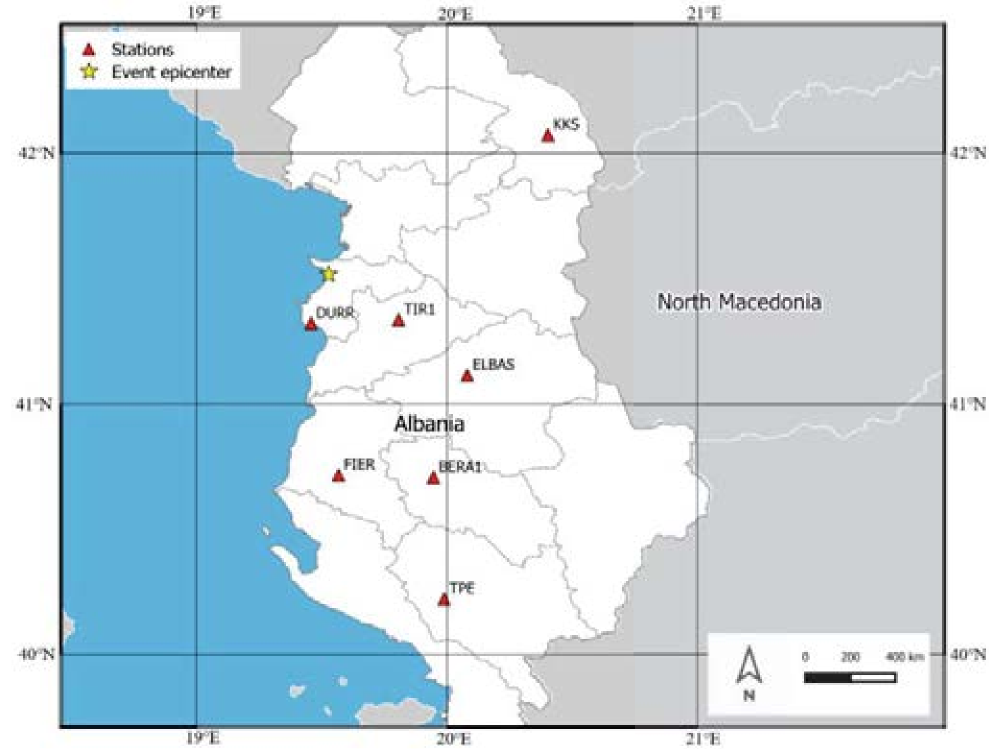


Figure 1: Strong motion stations in Albania that recorded the Nov. 26, 2019 earthquake and its epicenter [2].

The mainshock was followed by multiple aftershocks, two of which have a magnitude $M_w > 5.0$ as shown in Table 1. Figure 2 shows the shakemap of the mainshock calculated using surveyed macroseismic dataset collected through felt reports by the EMSC [11] and combined with expected intensities derived from strong-motion records using the correlation function of Faenza and Michelini, 2010 [12]. Up to intensity $I_{EMS} = VIII$ on the EMS-98 intensity scale [13] was estimated.

DURR station in Durrës, which lays on soft soil recorded only 15 s of the mainshock due to electricity pause [2]. This record has a horizontal peak ground acceleration (PGA) of 0.196g and spectral acceleration of more than 0.5g for 5% damping in a period range of 0.25s to 1s, as shown in Figure 4. This period range could be related to the fundamental period of buildings with five or more stories according to Eurocode 8 (EC8), which lays in the height range of observed damaged and collapsed buildings in the area.

| Date | Time (UTC) | Lat. (°) | Long. (°) | $M_w$ | Depth (km) | Reference name |
|---|---|---|---|---|---|---|
| 26/11/2019 | 02:54:12 | 41.514 | 19.526 | 6.4 | 22 | Mainshock |
| 26/11/2019 | 06:08:21 | 41.571 | 19.424 | 5.5 | 10 | Aftershock (1) |
| 27/11/2019 | 14:45:23 | 41.550 | 19.479 | 5.3 | 10 | Aftershock (2) |

Table 1: Focal parameters of the Nov. 26, 2019 mainshock and following moderate aftershocks (USGS).

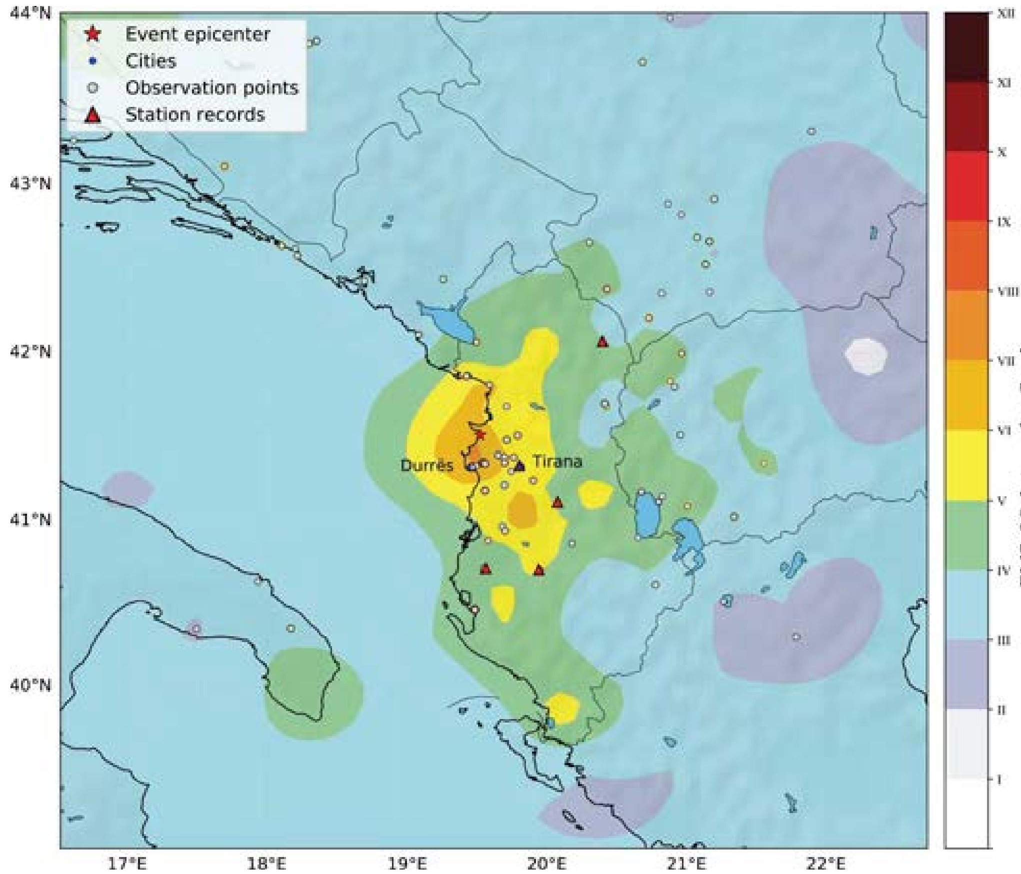


Figure 2: Macroseismic shakemap with EMS-98 intensity for the mainshock.

To evaluate the spectral acceleration obtained from the mainshock, response spectra from EC8 and the Albanian code (KTP-89) are calculated as shown in Figure 3. EC8 spectra are calculated with a PGA of 0.24g obtained from a probabilistic seismic hazard map with a 475-year return period proposed by [6] for Albania. The KTP-89 spectra are calculated based on the seismic code map with intensity $I_{MSK\text{-}64} = VIII$ for Durrës. By comparing the code spectra with the recorded mainshock spectra, the mainshock spectrum from the DURR station exceeded the KTP-89 spectra for periods higher than 0.2s for all soil types. However, the EC8 spectrum with soil type D (soft-soil) covered the recorded spectra. The aftershock records showed similar period ranges to the mainshock (0.2 to 1s) as shown in Figure 4.

It can be concluded that buildings designed according to the KTP-89 spectra were affected by higher ground motion, whereas the design forces according to EC8 and a PGA equal or greater than 0.2g covered the ground motion of the 2019 Albania EQ.

## 2.2 Design and construction standards

The current officially enforced earthquake design code in Albania is the 1989 KTP-89 code [14]. This code uses the seismic zoning map with expected intensities based on MSK-64 scale for the next 100 years and zones from $I_{MSK\text{-}64} = VI$ to $IX$ developed by [15]. Multiple studies highlighted the need for increasing the seismic coefficients used in the code as they show a low return period when compared with the probabilistic assessment of seismic hazard studies [6,16]. In particular, the city of Tirana, assigned to $I_{MSK\text{-}64} = VII$ with of 0.08g seismic coefficient according to KTP-89, has a return period of approximately 50 years for a rock soil (category I) [16].

There were recent efforts to translate and implement the Eurocodes in Albania. Drafts of national annexes were prepared with updated seismic hazard maps [17]. However, the Albanian legislation still requires following the KTP-89 code and allow using Eurocodes voluntarily [18].

In addition, local engineers reported that building regulations were not properly enforced during the 1990s and early 2000s. That resulted in problems as buildings without a permit and improper addition of stories to existing buildings, which were reported in some of the collapsed buildings in Durrës [19].

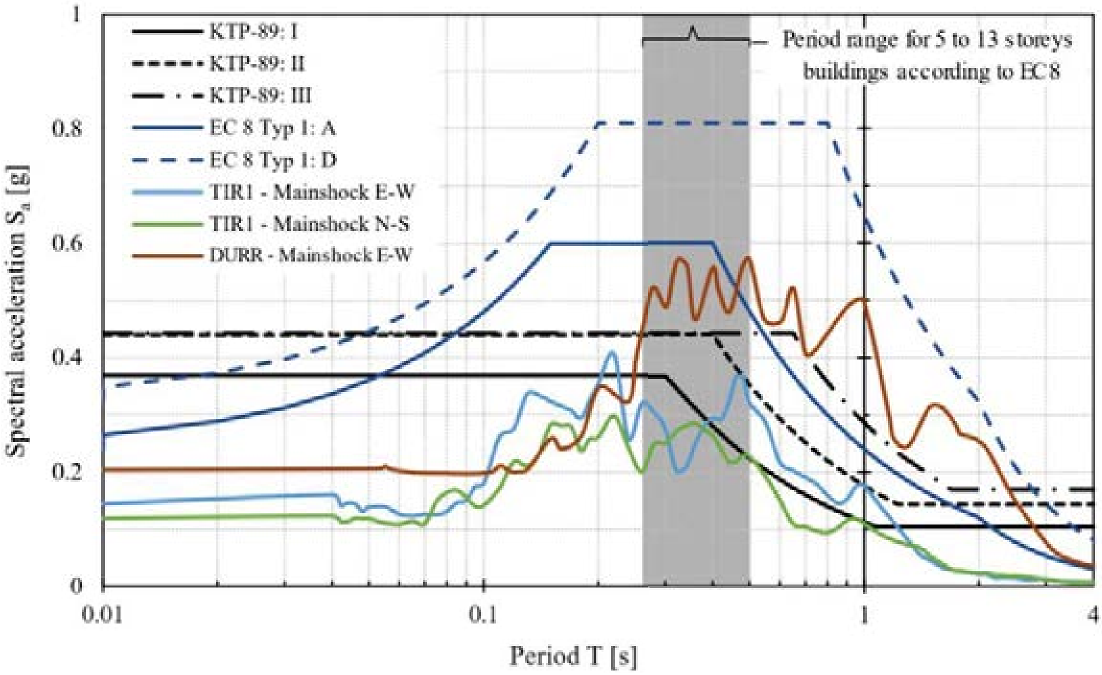


Figure 3: Response spectra of mainshock (5% damping) with KTP-89 and EC8 spectra.

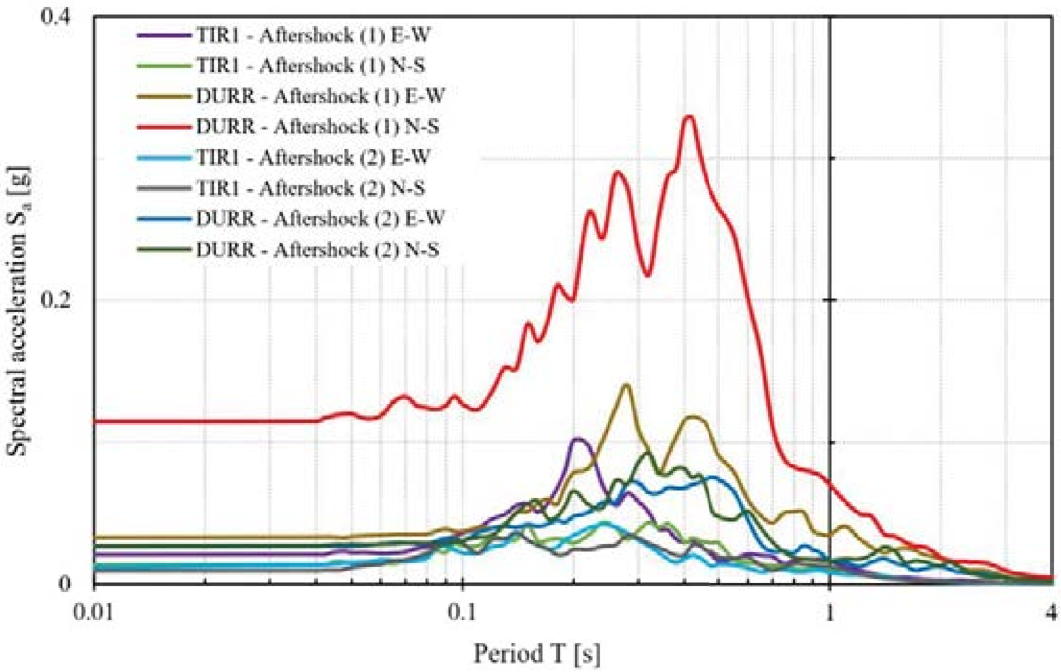


Figure 4: Response spectra of aftershocks (5% damping).

# 3 PERFORMANCE OF THE MAJOR BUILDING TYPES

## 3.1 Surveyed buildings

During the reconnaissance mission in Durrës city, totally 55 buildings were surveyed with a focus on modern multi-story RC buildings (i.e. built after 1990). Figure 5 shows the location of the surveyed buildings (all in the area of $I_{EMS}$ = *VII*), in addition to 4 out of 7 reported collapsed buildings in Durrës [19]. Data was collected from the surveyed buildings in the form of building type, dimensions, structural characteristics, and damage observations if exist. Table 2 shows the damage levels description used in the survey for RC elements and masonry infill walls. The damage level is linked to the EMS-98 damage classification [13].

The team focused on mid to high-rise buildings (see Figure 6 for sampled surveyed buildings). Figure 7 (a) and (b) shows the height distribution and damage levels for the infills and structural elements respectively in the surveyed buildings.

| **Material** | **Damage level** | **EMS-98 damage classification** | **Definition** |
|---|---|---|---|
| RC (Structural) | Light | Grade 2 | Hairline inclined cracks and/or flexural cracks |
| | Moderate | Grade 3 | Spalling of concrete cover |
| | Severe | Grade 4 | Local structural failures |
| Masonry (Non-structural) | Light | Grade 1 | Hairline cracks. Flaking of plaster |
| | Moderate | Grade 2 | Cracks in walls and joints between panels. Flaking of large pieces of plaster |
| | Severe | Grade 3 | Wide and through cracks in walls and joints between panels |

Table 2: Definition of damage levels used in the survey forms and in compliance with [20]

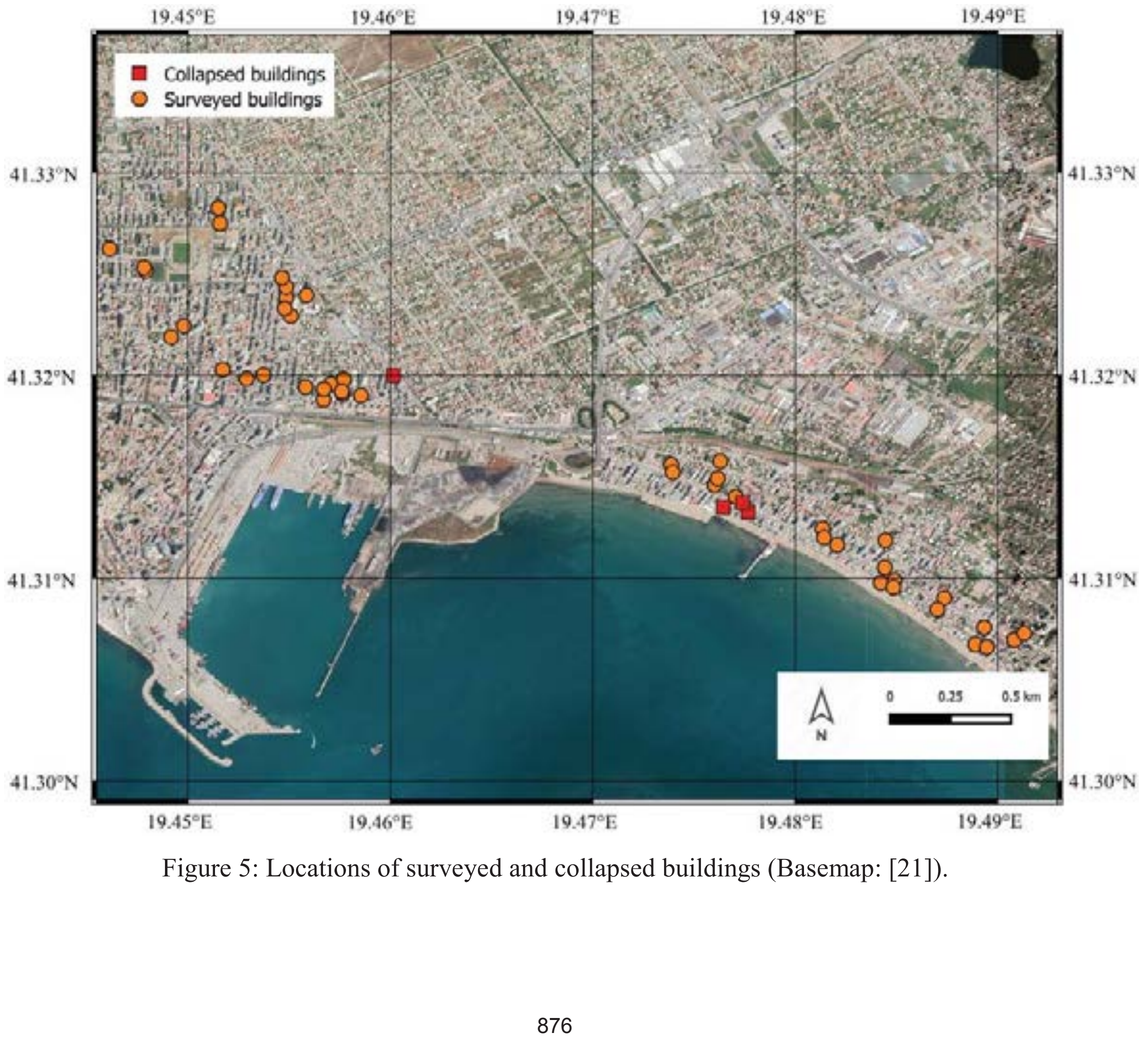


Figure 5: Locations of surveyed and collapsed buildings (Basemap: [21]).

Figure 6: Samples of the surveyed building with 8, 12, and 13 stories.

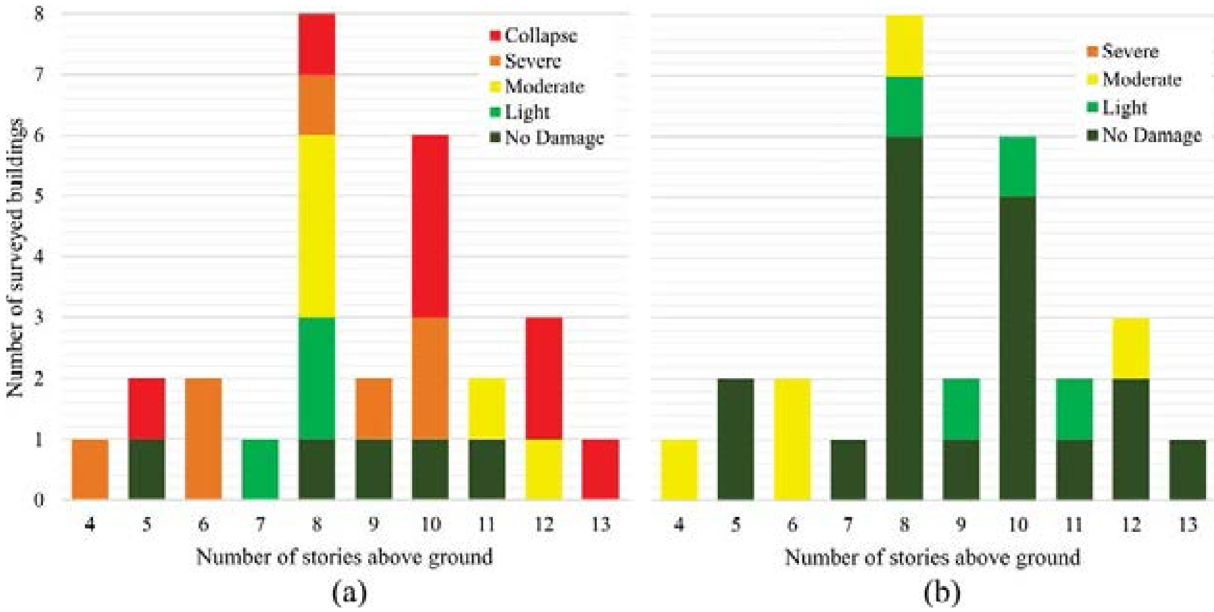


Figure 7: Distribution of the number of stories for surveyed buildings with (a) masonry infill damage levels, (b) RC element damage levels.

Figure 8: Undamaged multi-story masonry structures in Durrës.

It is worth mentioning that no significant structural damage to low-rise multi-story unreinforced masonry structures was observed in the surveyed city areas during the reconnaissance mission (see Figure 8).

### 3.2 Observed damage to RC buildings

The inspected buildings were scattered among the two most affected areas of the earthquake; the inner part of the city and the coastal (beach) area (see Figure 5). Those buildings were mostly built after the year 2000. Based on the field observations, the RC frame with infill walls was the dominant structural system in the inspected area. The presence of a dual system (RC frame + shear wall) was less common. Shear walls, if present, were mainly used for elevator core shafts.

The structural plans of the buildings were diverse. Buildings with soft-story and vertical irregularity were observed. Nevertheless, in most buildings, light or no structural damage was observed in the load-bearing RC elements, as it seems that the structural systems dissipated the seismic shock properly.

#### *3.2.1 Damages on infill walls*

Even though the structural safety in many of the observed buildings was met, the serviceability conditions of the observed buildings were poor. Considerable damage was observed in the infill walls, (see Figure 9 for in-plane failure samples). Usually, the damage was proportional to the number of stories. As expected, the ground floors were the most heavily damaged. The damage level was reduced with increased height. One of the most dominant characteristics of the damaged infill walls was observed to be poor workmanship and the lack of a proper connection between the masonry units. In all the cases, standard clay blocks with high volume horizontal voids were used (Group 4 in compliance with EC6).

It was observed that there was a lack of head joints in some of the inspected buildings. The brick-laying practice mainly consisted of the application of a bed joint and leaving the bricks unconnected with mortar vertically as shown in Figure 10 (a). Lack of vertical confinement at walls intersections was also observed, as in Figure 10 (b and c).

Another problem was the arrangement of the hollow bricks. In some of the observed buildings, the hollow bricks (even though horizontally perforated) were purely placed with voids horizontally (perpendicular to the direction of gravity). There is a lack of interlocking force of the bricks that is achieved through alternating their positions.

Extensively damaged infill walls are also considered to be a consequence of a ductile design of the buildings. The absence of the shear walls and RC cores has made the structure more flexible and was more susceptible to drifts. The path of load transfer of the lateral seismic loads through columns goes through the infills in the form of compression struts (only not in case of dominant bed joint sliding). The shear-force induced inside the infills (which seem to not have been designed to carry any shear load) has caused the damage of the infills. The extent of cracking is closely related to the workmanship quality, area of the infill, and opening presence. There were cases where the outer walls showed slight cracks only, but the interior walls were heavily damaged.

Another important observation related to the infill walls, was the improper connection of the wall to the frame, as well as in many cases, the lack of that connection. This phenomenon caused large pieces of the walls (sometimes the whole infill panels) to be dislocated and fall out of the plane (Figure 11). Lack of confining beams that are cast inside the infill walls was observed.

Figure 9: Infill in-plane failure.

(a) (b) (c)

Figure 10: Poor workmanship for infill walls (a) Lack of head-joints (b) and (c) Lack of vertical confinement at walls intersection.

Figure 11: Infill out-of-plane failure.

The summarized damage observations show the challenges in making vulnerability and damage grade assignments according to EMS-98 [13], especially with respect to the relation between structural and non-structural damage. From Figure 12, it can be observed that moderate and severe structural (RC frame) damage co-existed with severely damaged and collapsed infill walls. However, non-structurally damaged buildings experienced different levels of infill damage. Thus, the behavior of non-structural components can heavily influence the global damage grade. Therefore, the vulnerability affecting factors like the number of stories and the properties of non-structural elements should be considered as important attributes of a building typology and the corresponding vulnerability table/matrix [22]. The damage observations lead to the conclusion and confirm that the quality of construction and material of the infill walls may have a strong influence on the interaction with the primary (structural) load-bearing system [23,24].

At the same time, many out-of-plane damages could also be observed on the upper and lower floors (see also [25,26]), caused by the influence of bi-directional loading and IP damage, where the two components of a floor movement are of similar importance. The magnitude of the loads in-plane decreases at the upper floors, while the forces acting perpendicular to the plane increase due to the increase in acceleration over the height of the building.

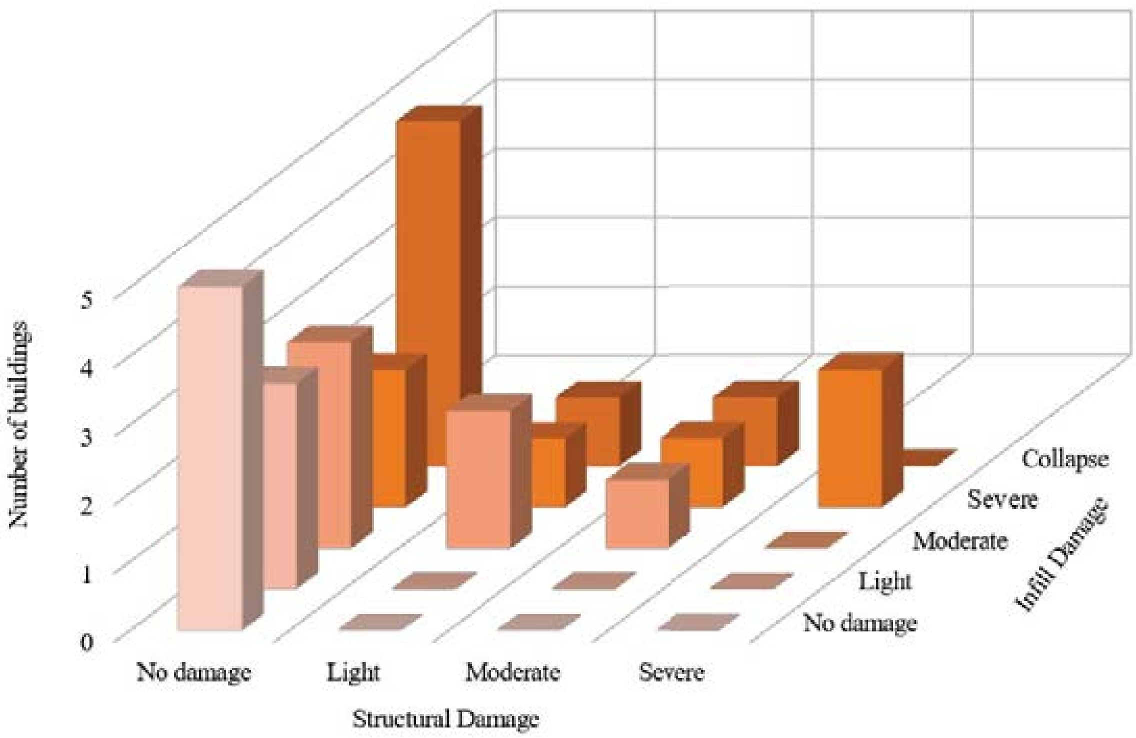


Figure 12: Observed infill damage level linked to observed structural damage level.

### *3.2.2 Damaged RC frame elements*

Besides the surveyed buildings, it was reported that 7 buildings collapsed in Durrës due to the earthquake [19]. Figure 13 and Figure 14 show collapsed 4-story and soft-story buildings respectively. The collapse of these buildings could be attributed to the high shaking effects, poor construction practice, and the insufficient respect of the building code requirements.

Figure 13: 4-story collapsed building in Durrës (Left photo: [27], Right photo: courtesy of C. McKenney [28]).


Figure 14: Collapsed Lubjana Hotel in Durrës (Left photo: [29], Right photo: courtesy of C. McKenney [28]).

Figure 15: Soil settlement in buildings.

### *3.2.3 Damage due to the ground conditions*

The ground conditions in the near coastal part were susceptible to liquefaction, which was observed during the survey in few buildings as shown in Figure 15. It was reported that extensive soil liquefaction was observed along the coastal side of Durrës city [30]. This settlement caused tilting of buildings, which could be visually observed.

## 4 ASSESSMENT OF SURVEYED BUILDINGS

To evaluate the surveyed buildings quantitatively, the two indices method proposed by Hassan and Sozen [10] is used. This method is based on wall index (*WI*) and column index (*CI*), calculated as follows:

$$WI=(\Sigma A_w+0.1\Sigma A_m)/\ \Sigma A_f \qquad (1)$$
$$CI=(0.5\Sigma A_c)/\ \Sigma A_f \qquad (2)$$

where $\Sigma A_w$, $\Sigma A_m$, $\Sigma A_c$ and $\Sigma A_f$ are the sum of: RC walls area at ground floor in the direction of smallest RC wall area, masonry walls at ground floor in the direction of smallest RC wall area, columns area at ground floor, and total floor area above the ground floor respectively. Figure 16 shows the column and wall indices for the surveyed buildings, where floor plans were sketched or obtained.

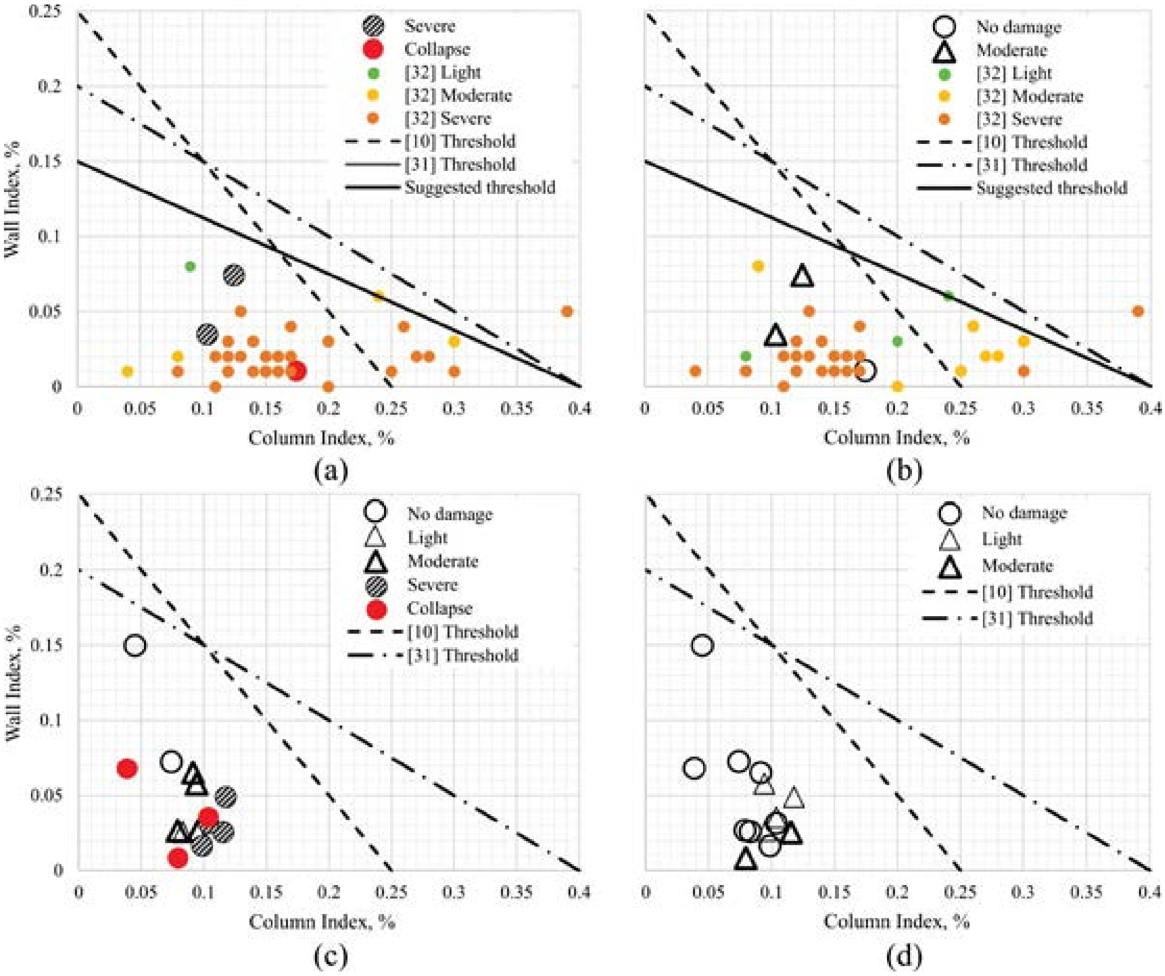


Figure 16: Calculated wall and column indices for surveyed buildings (a) Infill damage (4-6 stories) (b) Structural damage (4-6 stories) (c) Infill damage (≥7 stories) (d) Structural damage (≥7 stories).

Since more damage was observed in the infill walls, the indices are separately related to infill damage and structural damage states. In addition, the buildings were separated into two groups (mid-rise: 4-6 stories and high-rise: ≥7 stories). Especially, to consider that the originally proposed relation is not valid for buildings with more than 7 stories.

Figure 16 (b) and (d) show that all buildings lay beyond the thresholds suggested by [10,31]. These thresholds are suggested for low-rise [10] and low to mid-rise [31] structures to identify the most vulnerable to damage and may not be suitable for medium and high-rise buildings. A reduction in the limits by reducing the wall index limit is suggested to better fit the data with ($WI + 0.375CI$=0.15%) for midrise structures similar to [31]. In addition it is suggested to further adapt the wall and column indices for high-rise structures, because of the rather large margin/distance between the derived data points and the thresholds by [10,31]. This decrease in the wall index and might be also in the column index could be related to the "nonlinear" ratio of the wall area at the ground floor and the total floor area above the ground floor. Whereas, more data need to be elaborated towards structural and non-structural damage to define an appropriate threshold for high-rise buildings.

Figure 16 (a) and (c) show the infill wall damage grades related to the wall and column indices of each building, separately. The data sets are extended by the field study of the 2016 earthquake in Ecuador [32] for further justification of the very limited Albania data set for mid-rise buildings. It highlights the need for column indices larger than 0.4 to also limit infill wall damages. Whereas, it is clear that further data need to be elaborated for justification.

## 5 CONCLUSION

A reconnaissance mission was conducted after the $M_w$ = 6.4 earthquake that struck Albania on November 26, 2019. The damage to RC frame buildings with masonry infill walls built in compliance with contemporary building codes, i.e. after 1990's, was assessed by surveying 55 buildings. The observed performance of RC buildings in Durrës to the earthquake – less damage to RC elements (except in case of highly irregular construction); heavy in- and out-of-plane damage to the unreinforced masonry infill/partition walls – is the result of one or more of these aspects:

1) Improper construction practice, as the building code is not appropriately updated and enforced, especially towards the infill/partition walls.
2) Lack of proper shear walls in mid to high rise building to increase the stiffness and reduce drifts.
3) Poor workmanship of masonry infills, as they were built without head joints and confining elements, and not restrained against out-of-plane failure.

The seismic wall and column indices were calculated using the collected data and related to RC frame (or wall) and masonry infill wall damage. Thresholds for mid to high-rise RC buildings are suggested.

The survey and observation confirm that non-structurally damaged buildings (un- or slight-damaged RC elements) may experience different levels – up to grade 4 and 5 – of infill damage. Thus, the behavior of non-structural components can heavily influence the global damage grade and therefore need to be properly designed or build.

The gained experience and damage observations confirm the principle results of recent analytical and experimental studies [3,33,34]. As a next step, the previously experimentally validated models will be applied to the detailed surveyed Albanian buildings for further real-world validation by the comparison of a damage prognosis with the observation. A number of useful data sets could be collected as part of the reconnaissance mission for further analytical studies.

## 6 ACKNOWLEDGMENT

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