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Structural damages of Durrës (Albania) Earthquake

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Abstract

The moment magnitude 6.4 Albania earthquake which struck the Durrës region on November 26, 2019, caused an extensive damage on a large number of buildings, of nearly all types of construction. Its epicenter was located offshore north western Durrës, about 7 km north of the city and 30 km west from the capital city of Tirana. Officially, 52 died and 3000+ were injured, and thousands left homeless. Approximately, ~80000 buildings were adversely affected. Buildings damaged during this event were representative of construction types in form and structural system to those of the similar vintage found in Europe. This study focuses on the damage suffered by the masonry and RC buildings during this earthquake and explains the reasons of observed failure modes. Examples of several damage types, as observed by the authors during the reconnaissance visit to the stricken area are presented, along with technically substantiated description of reasons for the damages.

1.Introduction

Durrës has been assessed as an area of relatively high seismic hazard [1]. On November 26, 2019, an earthquake hit the central western part of Albania. It was assessed as Mw 6.4 (Figure 1).

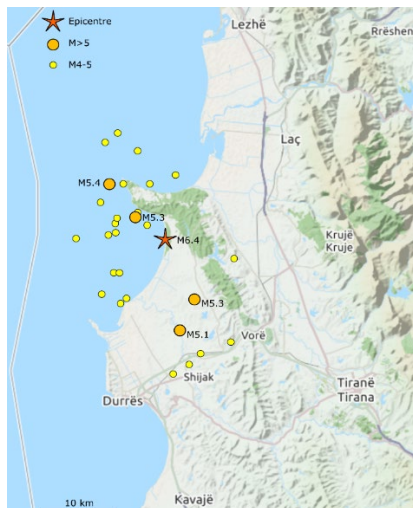


Figure 1. Location of epicenter and aftershocks in the first twenty days of the 26 November Earthquake

Based on a report on historical earthquakes, the region was struck by several earthquakes. The Durrës earthquake was the deadliest in Albania since 1979 Shkoder Earthquake [2]. As regards the impact on the building stock, severe seismic shakings induced damage to buildings in the medieval city of Durrës, Tirana and several settlements of the broader area. The most earthquake-affected areas are the city of Durrës and the town of Thumanë at the central-western Albania. Damage was also observed in Laç town, Fushë-Krujë town,

Kamëz, Vore as well as the capital city, Tirana. Building damage was distributed along two ellipses, whose major axis is oriented in NW-SE (Figure 2).



Figure 2. Earthquake-affected area during the November 26, 2019 Durrës Earthquake

Damages to buildings were serious and widespread. Eventually, 52 people died, with some 3000+ people injured, and thousands left homeless. A large number of structures comprising RC, masonry and historical buildings were heavily damaged or collapsed.

According to recent reports, 80000-100000 buildings were seriously damaged or collapsed [3]. It was observed that URM or RC moment resisting frames with hollow clay tile infill partitions are the most popular structural systems in the region. The main structural materials are unreinforced masonry composed of rubble, stone, brick, and hollow clay tile. Moreover, observations revealed that most of the damages in Durrës were restricted to old masonry and non-ductile RC buildings (Fig 3).



Figure 3: Two types of typical damages from Vore and Durrës; a) Severely damaged URM building; b) Partially collapsed non-ductile RC building

There are many incidents of infill wall damages which experienced either shear failure or out-of-plane failure due to the lack of anchors at the upper and bottom parts of the walls.

This study discusses different types of structural damages that were observed by the authors during reconnaissance visits to the region. The reasons of the structural damages are examined and placed into context with some recommendations.

2. Evaluation of strong ground motion records and response spectra

The earthquake has been recorded by seven stations of the Albanian Seismological Network, located at epicentral distances from 15 to 130 km [4]. Strong ground motions records for the November 26, 2019 Earthquake are given in Figures 4-5 (http://www.geo.edu.al/tirana_record/).

Its epicenter was located offshore northwestern Durrës, about 7 km north of the city and 30 km west from the capital city of Tirana. Its focal depth was about 10 km. Based on the focal plane solutions provided by several seismological institutes and observations; the main shock was generated by the activation of a NW-SE striking reverse fault [5]. This was the second earthquake to strike the region after September 21, 2019 earthquake sequences.

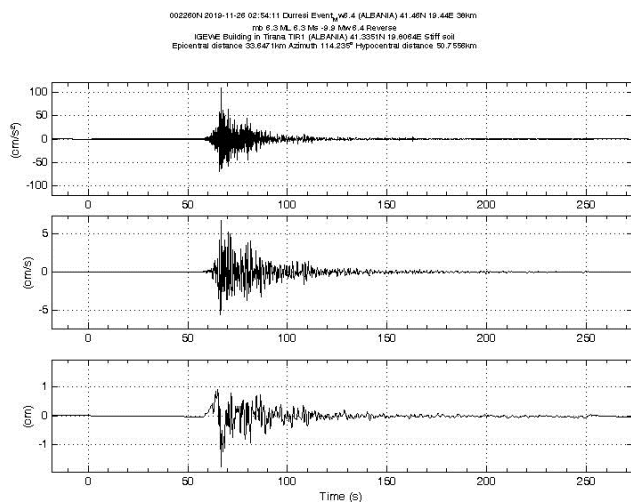


Figure 4: November 26, 2019 Earthquake N-S component

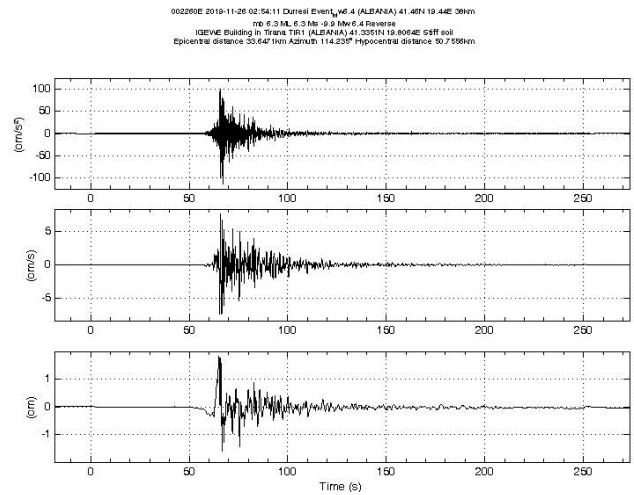


Figure 5: November 26, 2019 Earthquake E-W component

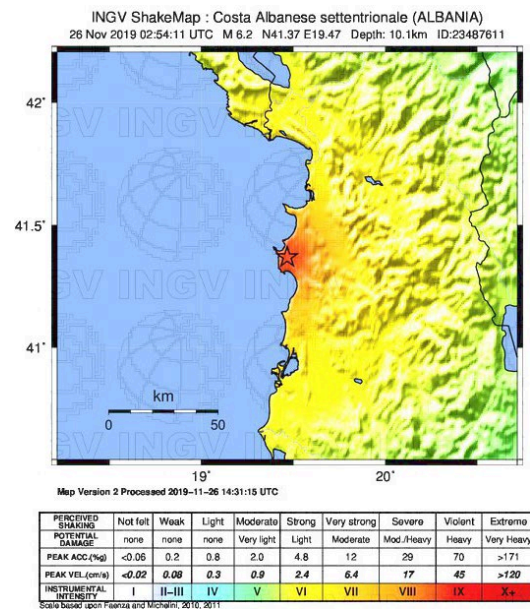


Figure 6: Intensity shake map of the 26 November Albania Earthquake (INGV, 2019)

Intensity Shake map of the 26 November Albania Earthquake (INGV, 2019) is shown in Fig 6. Fig 7 shows the distribution of peak ground acceleration expressed as percent of the acceleration of gravity.

Based on the recordings, the horizontal Peak Ground Acceleration in Tirana station was about 0.12 g, whereas this value was approximately 0.20 g in Durrës (closer to epicentre). However, it is worth mentioning that the station in Durrës only recorded the event for the first 15 s due to an electricity cut induced by the earthquake, hence the 0.20 g value could be considered a lower bound of the real peak ground acceleration felt in the site. In order to understand the impact of the earthquake, Fig. 7 shows the response spectra from the recorded ground motion in Durrës versus the elastic response spectra defined according to the EC-8 (Category D) and Albanian code [6] for soil category III.

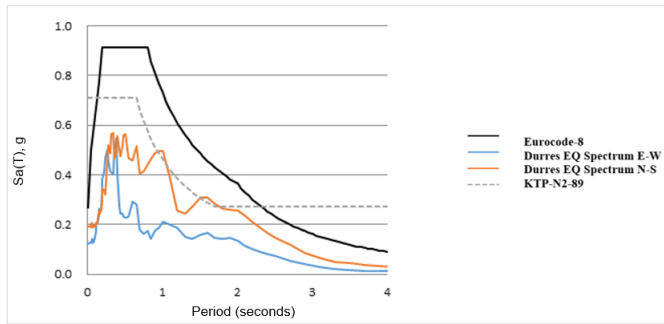


Figure 7: Peak ground acceleration map in (g %)

The Eurocode [7] has greater spectral accelerations with respect to the current code. The elastic design spectrum, shown in Fig. 7, is higher than the response spectra of the recorded ground motions in both directions. The only exemption is for the period range of 1 to 2 seconds, where the spectra of the ground motion for the N-S component is comparable to the code-based elastic response spectrum. This figure clearly shows that buildings were exposed to seismic forces higher than expected design forces in this range. But, as mentioned above, this comparison could not be representative of the actual conditions due to the limited data for the ground motion at the Durrës station. It is certain that a prolonged period of shaking with high accelerations would cause a heavier damage profile for the existing buildings.

3. Structural damages

The types of the construction in the affected area can be classified as follows:

- Older masonry and historical buildings mainly constructed by brick masonry and stone,
- Reinforced concrete (RC) frames with URM infills. This structural form is used for all building heights. URM infill walls had a dominant influence on the seismic performance of the main structural system.
- Prefabricated residential buildings.
- Industrial buildings.

The observed damage is correlated with the construction materials and peak ground acceleration. The structural damages observed during the earthquake varied depending on the location, building typology and the age of construction.

3.1. Structural damages to historical/old masonry buildings

Durrës (Albania) earthquake served as a good open laboratory for damaged masonry buildings. Some of those buildings had historical characteristics. Many of the damaged historical buildings were brick and stone masonry having low construction quality. Similarly, other masonry buildings in several settlement areas of Albania were also constructed by bricks, rubble stone and heavy blocks usually, which can be easily available around settlement areas. Many of these masonry buildings were constructed according to older code requirements and some of them were non-engineered and not earthquake resistant [8,9]. These buildings are forming the significant part of the building stock in the earthquake affected area of Durrës. Since the affected region is one of the potentially earthquake prone zones of the country, old masonry buildings often show typical deficiencies like aging, low material quality and lack of proper detailing which increase their seismic vulnerability [2]. The observed damage patterns of the masonry buildings could be classified as follows:

- In-plane and out-of plane failure modes,
- Diaphragm-related failure modes,
- Anchorage-related failure modes.



Figure 8: Presence of multi-leaf clay brick walls and collapse of the external leaf: detail of collapse in Durrës, Castle of Durrës (left) and partial collapse remains (right)

Unconnected outer and inner wythes are given in Figure 8. These types of deficiencies led to out-of-plane failures as shown above.



Figure 9: Out-of-plane failure of URM walls

In many cases, at corner points of the buildings, masonry units were not properly overlapped to ensure an earthquake-resistant connection. This causes walls to be separated at initial stages of the quake. After that, out-of-plane failures were initiated due to poor restraining conditions. These types of damages are shown in Figure 9.

In-plane, failure mechanisms are commonly observed near the openings as shown in Figure 10.



Figure 10: Typical diagonal shear cracks of piers on a multistory masonry building

Poor connection between walls - walls and roof, the lack of bond beams leads usually to the failure of corners of masonry buildings. Some

patterns of this failure are shown from the images below during the observations done after November 26 earthquake (Fig. 11).

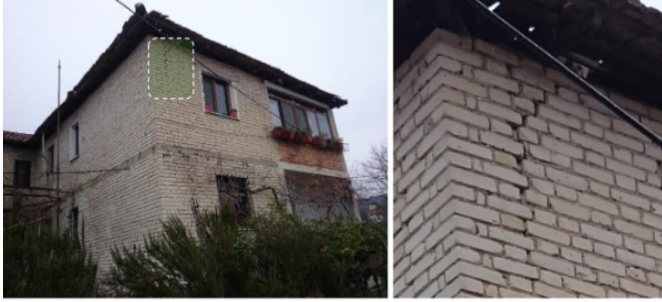


Figure 11: Anchorage-related corner failure of a masonry building

Restraining effect of crossing walls was reduced by wall openings placed too close to the building corner. Window and door openings weaken the connection of crossing walls. The failure mode involving separation of the front facade and return walls was commonly seen due to poor interconnection of return walls, as can be observed in the multiple examples shown in Figure 11.

4. Structural damages to RC buildings

The prevalent structural system used for buildings in Albania consist of URM structure until 1990s and RC frames with unreinforced masonry infills after 1990s. This structural form has been used for all building heights and occupancy. Dual systems are also used in relatively new buildings. Industrial buildings are either pre-cast/conventional RC or rarely steel framed structures. A typical RC frame building in Albania consist of a regular symmetric floor plan with rectangular or square columns and connecting beams. The exterior enclosure as well as interior partition walls are formed by non-load bearing unreinforced hollow clay tiles. These partition walls contributed substantially to the lateral stiffness of the building during the earthquake and, in many cases, controlled the lateral deformation and resisted seismically induced forces. The observed damaged patterns to the RC buildings are discussed in this part.

Poor concrete quality, insufficient reinforcement detailing in structural elements, steel corrosion due to insufficient concrete cover were a few of the deficiencies that led to heavy damages in the RC buildings hit by 6.4 Mw earthquake in Albania.

The observed failure patterns during the investigation of RC buildings in the effected cities are categorized as shown below:

- Short column,
- Insufficient reinforcement in columns and beams,
- Poor concrete quality and corrosion,
- Inadequate gaps between adjacent buildings,
- In-plane/out of plane failures.



Figure 12: Typical shear failure of short columns in RC buildings

Short column mechanism developed as a reason of continuous openings located at the top or bottom of infill walls between columns as shown in Figure 12.



Figure 13: Inadequate detailing caused buckling of longitudinal reinforcement in plastic hinge regions (spacing of transverse reinforcement)

Based on most of the observations during the November 26, 2019 earthquake, a number of detailing flaws were observed in damaged buildings (Fig 13.).

Concrete quality plays a significant role on the structural performance against earthquakes. In Albania there are many cases where hand-made concrete is used, especially in the old buildings. Moreover, workmanship service was not at the desired level resulting thus in a very low material quality. All these factors including corroded rebars together with the poor-quality material of the building led to poor performance during this earthquake (Fig 14.).



Figure 14: Column failure due to the corroded rebars and poor concrete quality



Figure 15: Pounding failure due to lack of enough space b/w adjacent buildings

Another damage pattern was observed in many nearby buildings due to hammering effect. The building seen in Figure 15 can be considered as one of the typical examples of the hammering effect damage seen during the investigations.

In-plane and out-of-plane failure of masonry infill wall are widely observed in the RC buildings damaged during November 26 earthquake. Especially for low and mid-rise buildings it is likely that the infill walls of the ground story in the RC frames will fail earlier. This happens as the fact that infill walls found in the ground story, obtain higher in-plane demands during an earthquake. As the in-plane demand reduces at the upper floor, the out-plane forces increase due to acceleration increases. Figures 16 show the in-plane and out-plane damage patterns of the investigated RC buildings.

Moment frames require careful detailing and excellent construction practice to achieve the intended level of performance during earthquakes. In Albania earthquake, it was observed that detailing of many RC buildings was very poor.



Figure 16: Heavily damaged partition walls; a) In-plane failure, b) Out of plane failure

5. Results

Although the magnitude of the event (Mw 6.4) with respect to its peak ground acceleration values is quite low, it has caused widespread damages to many RC and masonry buildings. The amplitudes of the ground shaking affecting Albanian settlements range between 0.16g - 0.58g. As indicated by the response spectra, the frequency content of the recorded motions was in the range 0.1 - 1.5 s, which have resemblance to the range of fundamental frequencies of the most buildings in the affected area. The experience provided by the Albania earthquake revealed that there is a significant gap between the requirements established by modern seismic codes and construction practice especially in rural areas. Besides poor construction practices and the use of non-ductile seismic detailing, higher spectral accelerations were the other reasons of the reinforced concrete building failures. Further reasons are as follows;

- It has been observed that the concrete quality is low in many RC buildings and a important percentage of these buildings with limited ductility and insufficient strength do not have the lateral load bearing capacity to withstand ground shaking without damaging it.
- No SWs were seen in many of the damaged RC buildings. Lateral stiffness of multi-storey reinforced concrete buildings was not sufficient. Due to the presence of slender columns with brittle seismic behavior, such buildings have suffered significant damage.

- Poor detailing in beam-column joints was also frequently observed. Stirrups spacings and the amount of the transverse reinforcement was not detailed properly in most of the damaged columns.

- Partition walls of RC buildings were not properly restrained to the frames, and hence out-of-plane failures of those walls were inevitable.

The URM structures with the load-bearing masonry walls suffered the most by the Durrës Earthquake due to the following reasons; aging, poor construction quality and workmanship, interventions made by people, the design code of the time. Many of these masonry buildings were constructed as brick masonry and stone masonry. Materials and construction techniques of these masonry buildings did not provide earthquake resistance to these buildings. Considering construction techniques of these buildings, the most important defects are listed;

- The lack of interlocking elements between external and internal units of the wall section and lack of connection between crossing walls.
- The wall thickness and the floors were too thick. This increased the weight of the structure and therefore resulted in higher earthquake forces in older historical buildings.
- The percentage of the openings in many masonry buildings was high and led the formation damage patterns near the corners.
- Due to lack of proper connection between the walls and roof, diaphragm related failures were observed.

6. Conclusions

Generally, the structural performance of the buildings in the Durrës city center was not satisfactory. The main structural materials are URM composed of brick, stone, and hollow clay tile. Masonry units suffered the worst damage. Several modern, non-ductile concrete frame buildings experienced moderate-heavy damage. In reinforced concrete structures, many structural deficiencies such as non-ductile detailing, poor concrete quality, strong beams-weak columns were commonly observed.

The main conclusions drawn from this study are given below;

- In the cities under similar earthquake risk, the necessary precautions must be taken into consideration. In an anticipated tremor, the potential for damage of masonry buildings seems high. A new retrofitting approach must be suggested, which will not influence the functionality and will not disturb normal usage by the inhabitants for such buildings.
- The RC buildings without SWs can be retrofitted by adding external shear walls.
- To prevent the out of-plane failure of the external partition walls, intending isolation, a connection with the remaining inner wall must be provided as well as anchoring to the structural elements in order to prevent damages.

To sum up, thousands of existing buildings designed and constructed in accordance with older or no seismic codes at all, are present in seismically active areas of the region. These buildings must be properly rehabilitated as soon as possible to prevent future loss of lives.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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