EVALUATION OF RECENT EARTHQUAKES IN ALBANIA

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ABSTRACT

Earthquakes are natural phenomena that impact the life of inhabitants who live in zones prone to them. It is of great importance to understand the mechanism in order to undertake adequate precautions and design improvements to have a more resistant urban infrastructure. This article takes into consideration the issues related to structural problems caused by the two earthquakes that shook Albania (September 21 and November 26) in 2019. A considerable number of structures suffered a lot of damages and a substantial amount was destroyed. The team of structural engineers did inspection and post assessment immediately after these incidents. This paper shares some of the findings achieved during these inspections. We find it necessary to summarize in a structural engineering point of view the main causes that the buildings suffered through these earthquakes. Moreover, we added some recommendations in order not to repeat the errors of for the future. This study also includes comparisons between Albanian seismic codes of construction and their equivalent Eurocodes and evaluates the adoption of them to nationwide.

KEYWORDS: Earthquake resistant design, rapid screening, attenuation

INTRODUCTION

Albania is located in a seismically active zone. From September 20, 2019 until the end of January 2020, more than 1300 ground shaking events with magnitudes greater than 3.0 were recorded in Albania (geo.edu.al). Within these ground motions, two significant large earthquakes occurred on 21 September 2019 and on 26 November 2019. On November 26, 2019 at 02:54 hours local time an earthquake with Mw 4.4 alerted people of central western part of Albania, and after that at 03:54 hours local time an earthquake with Mw 6.4 hit again causing 51 causalities and around 900-million-euro losses to 10 municipalities including two most urbanized and developed, Tirana and Durres (Freddi et. al. 2021).

There are numerous active fault lines throughout Albania since it is located in the convergent border region between Africa and Eurasia plates. This region has a complex tectonic environment, influenced by the movements of numerous microplates and regional structures, such as the Adriatic plate.

Recent studies made in 2017 in the affected area based on continuous observations made by GPS, stated that there had been observed some vertical ground displacements at speeds greater than 10 mm per year (www.rheticus.eu). This is the region (Durres) hit by two strong

ground motions in Albania in 2019 causing building collapses and damages (Table 1). This study aims to find out the reasons for these losses.

Table 1. Information About 2019 Earthquakes in Albania

Earthquakes	21 September 2019	26 November 2019
Latitude	41.43 N	41.41 N
Longitude	18.71 E	19.54 E
Focal depth	19 km	24 km
Mw	5.6	6.4

Table 2. Loss of Life and Building Collapses in 2019 Earthquakes in Albania (INSTAT, 2020)

City	Population	21 September Earthquake				26 November Earthquake			
		Fatalities	Injured	Collapsed buildings	Damaged buildings	Fatalities	Injured	Collapsed buildings	Damaged buildings
Tirana and Durres	1185044	-	105	-	1500+	51	3000+	9	14000

Civil Engineering in New Normality

As rest of the world, Albania was also impacted by the COVID-19 pandemic while gradually recovering from post-earthquake crisis. New challenge for all of us would be to make a plan on how to manage dual disasters; on one part to recover from the earthquakes of 2019 and to slow down the spread of COVID-19 and develop new policies and approaches to protect human life and vulnerable groups.

With effective responses to two health emergencies occurring only a few months apart, Albania demonstrated that a timely integration of lessons learnt from one crisis could improve response measures to a consecutive crisis. Specifically, it achieved this through proactively adapting broader health system structures and plans based on reflections gained from an ongoing emergency.

It is thus important to account for the possible occurrence of large natural hazards during the pandemic and develop response plans that consider both the constraints due to the pandemic and the additional requirements caused by the natural hazard (WHO, 2020).

Furthermore, some disasters may be unpredictable, but engineers may prevent some of consequences by resilience planning. Nowadays, almost every city is affected by the severity of the Novel Coronavirus or the Covid-19 pandemic. As other industries even civil engineering industry is part of this crisis. We are entering into a new normal epoch with an unknown outcome. The design of buildings and technology probably will forever be changed and there won't be a unique or a standard solution anymore. Almost every sector is seeing great changes. Future buildings may require new designs that facilitate social distancing. Covid-19 has changed our 'normality' in regard to the way of living and working and we as civil engineers known generally as problem solving individuals should adapt fast to this new normality. Furthermore, despite how challenging the pandemic has been on this industry we

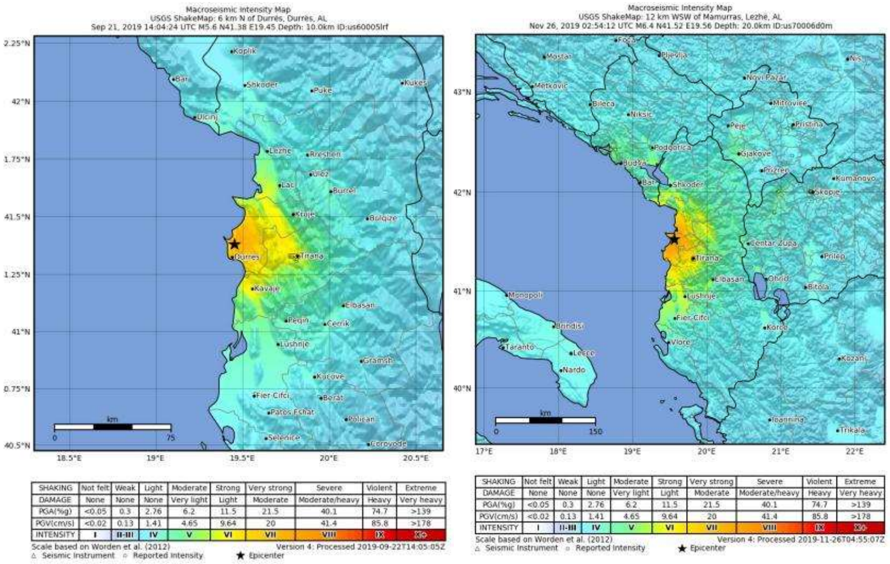
can contribute on the resilient plans for the future of this sector to coming back stronger than before.

SEISMOTECTONIC AND GEOTECHNICAL ASPECTS OF ALBANIA

The region's tectonics are compatible with northwest-southeast striking reverse faults. The African plate converges with the Eurasian plate at a pace of 73 mm/year near the location of this event.

The tectonics of the Mediterranean Sea, which lies on the convergent boundary between Africa and Eurasia, is intricate, including the movement of multiple microplates and structures on a regional scale. The reversal of faulting in Albania on the Adriatic Sea's eastern coast is consistent with the shortening of the mountain belts that amplify from Croatia to Greece.

Large earthquakes are prevalent in this area; seven earthquakes of magnitude M6 or greater have occurred within 150 kilometers of the epicenter of November 26 earthquake in the last 100 years. The most powerful was an M6.9 earthquake on 15 April 1979, 70 kilometers north-northeast of the 26 November quake epicenter, which killed 100 people in Montenegro and 35 in Albania and as a consequence displaced 100,000 people. A magnitude M6.7 earthquake struck 80 kilometers east of the current event on November 30, 1967, killing 19 people and causing severe damage to the surrounding area (Freddi, et. al., 2020).



September 21, 2019 November 26, 2019

Figure 1. Intensity Maps of 21 September and 26 November 2019 Earthquakes in Albania (USGS)

Intensity maps for September 21 and November 26 earthquakes in Albania are presented in Figure 1. The maximum macroseismic intensity estimated by the USGS based on instrument data and witness reports was VIII on the modified Mercalli intensity scale. Four acceleration measurements were made within an epicentral distance of 100 km or less (7 within 130 km). The acceleration closest to the epicenter was recorded at the Institute of Geosciences, Energy, Water and Environment (IGEWE) building in Tirana. Distance of accelerometric stations in Tirana and Durres is 33.7 and 15.6 km from the epicenter of the earthquake of 26 November. Type of ground is type C according to EC8 with shear wave velocity in upper 30

m is around Vs_{30} = 202 m/s at DURR and 312 m/s at TIR1. Due to a power failure during the mainshock a part of the time history (after the first 15sec) was not recorded at the DURR station (geo.edu.al).

Strong motion records for the November 26, 2019 earthquake are shown on Figure 2 and peak ground accelerations (PGA) recorded in Tirana and Durres stations are presented in Table 3. It can be inferred that maximum PGA values for the 21 September earthquake were 5.6 and 5.1 in Durres and Tirana stations. The highest recorded PGA values for 26 November earthquake are 6.4 and 5.4. These values are in the anticipated limits representing the attenuation relation with respect to epicentral distance (Lekkas, et. al., 2019).

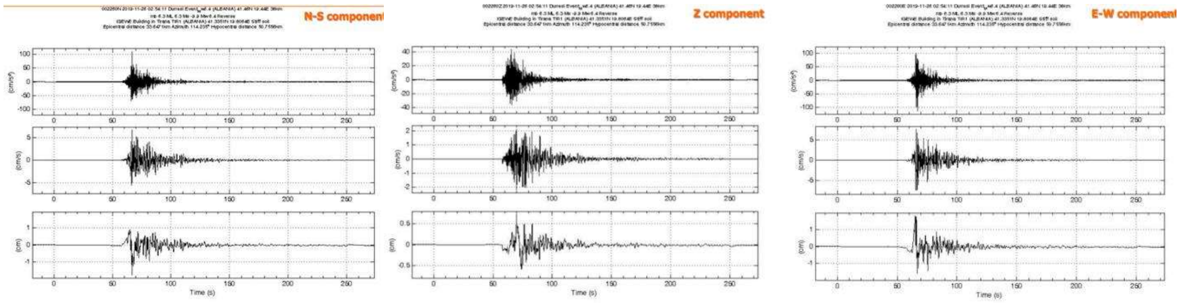


Figure 2. Strong Motion Records for the November 26, 2019, Earthquake (Lekkas et. al., 2019)

Table 3. PGA Values for Durres and Tirana 21/09/2019 and 26/11/2019 Earthquakes (Lekkas et. al., 2019)

Date	Mw	PGA-DURRES	PGA -TIR1
21/09	5.6	0.12	0.18
21/09	5.1	0.10	0.03
26/11	6.4	>0.20	0.12
26/11	5.4	0.04	0.02

RAPID VISUAL MONITORING AFTER-26 NOVEMBER 2019 EARTHQUAKE

The aim of this evaluation was to identify the buildings seriously affected and represent a hazard for the community after a moderate or severe earthquake. This evaluation was based on structural and non-structural damage and geotechnical failure. The method used to make this evaluation immediately after this earthquake is based on Rapid Visual Screening of Buildings (RVS survey) to identify the buildings which are expected to be more vulnerable under an earthquake.

The purpose of the adopted form of RVS which the team used during the inspection was to quickly identify buildings and categorize them using the color codes as; “safe for use” (green), “unsafe for use” (orange), “partly safe for use” (yellow) and also the buildings that are considered as “dangerous for use” (red). The posting “unsafe for use” (orange) has to be used for all the damaged buildings where there is uncertainty about the extent to which they have been weakened by the earthquake.

RVS also intends to identify buildings in need of urgent demolition, local hazards that have to be removed for safety purposes and, in general, safety measures that have to be taken in order to avoid further casualties or injuries. The damage assessment of the structures affected by the November 2019 earthquake was undertaken collecting the information provided in Table 4, which was adopted around the specific needs of this mission, such as accessibility and typology of building stock to assess, time availability, and locations.

The findings of the field engineering group were uploaded to a web portal (Invent. AI) in order to share to the public and beneficiaries (Figure 3). This portal also contains the location of the objects and integrates with ASIG GPS coordinates.

Table 4. List of collected information

COLLECTED INFORMATION

1-General information: Number of storeys and dimensions, year of construction, address, GPS coordinate

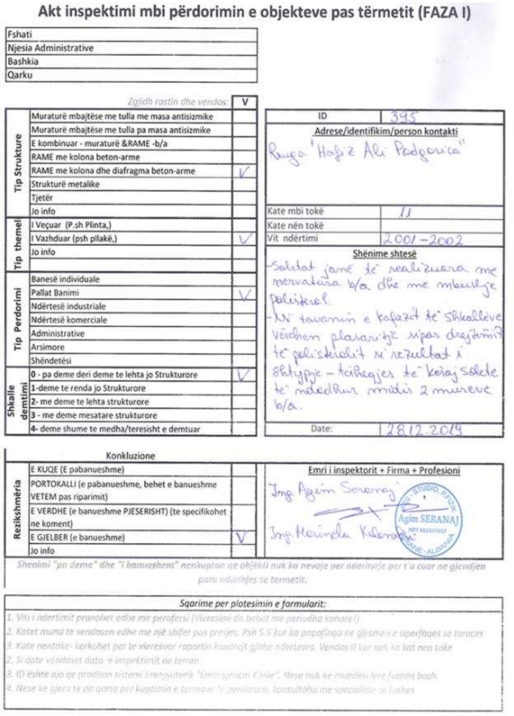
2-Structural system description

3-Basement and foundation system

4-Building type

5-Damage scale

6-Final classification (Red, Orange, Yellow, Green, cannot be specified)



Akt inspektimi mbi përdorimin e objekteve pas tërmetit (FAZA I)

Fshati
Njesia Administrative
Bashkia
Qarku

	Zgjidh rastin dhe vendos:	V
Tip Strukture	Muraturë mbajtëse me tulla me masa antisizmike	
	Muraturë mbajtëse me tulla pa masa antisizmike	
	E kombinuar - muraturë &RAME -b/a	
	RAME me kolona beton-arme	
	RAME me kolona dhe diafragma beton-arme	V
	Strukturë metalike	
	Tjetër	
	Jo info	
Tip themel	I Veçuar (P.sh Plinta,)	
	I Vazhduar (psh pllakë,)	V
	Jo info	
Tip Perdorimi	Banesë individuale	
	Pallat Banimi	V
	Ndërtesë industriale	
	Ndërtesë komerciale	
	Administrative	
	Arsimore	
	Shëndetësi	
Shkalle demtimi	0 - pa deme deri deme te lehta jo Strukturore	V
	1-deme te renda jo Strukturore	
	2- me deme te lehta strukturore	
	3 - me deme mesatare strukturore	
	4- deme shume te medha/teresisht e demtuar	

ID	395

Adrese/identifikim/person kontakti

Rruga "Hafiz Ali Podgorica"

Kate mbi tokë	11
Kate nën tokë	
Vit ndërtimi	2001 – 2002

Shënime shtesë

-Soletat jane te realizuara me nervatura b/a dhe me mbushje polisterol.
-Në tavanin e kafazit te shkallëve vërehen plasaritje sipas drejtimit te polisterolit si rezultat i shtypje – tërheqjes te kësaj solete te ndodhur midis 2 mureve b/a.

Date: 28.12.2019

Konkluzione

Rezikshmëria	E KUQE (E pabanueshme)	
	PORTOKALLI (e pabanueshme, behet e banueshme VETEM pas riparimit)	
	E VERDHE (e banueshme PJESERISHT) (te specifikohet ne koment)	
	E GJELBER (e banueshme)	V
	Jo info	

Emri i inspektorit + Firma + Profesioni

Ing. Agim Seranaj

Ing. Merinda [illegible]

Agim SERANAJ

Shenimi "pa deme" dhe "i banueshem" nenkupton qe objekti nuk ka nevoje per nderhyrje per t'u cuar ne gjendjen para ndodhjes se termetit.

Sqarime per plotesimin e formularit:

1. Viti i ndertimit pranohet edhe me perafersi (Vleresimi do behet me periudha kohore!)
2. Katet mund te vendosen edhe me një shifer pas presjes. Psh 5.5 kur ka papafingo ne gjysmen e siperfaqes se taraces
3. Kate nentoke- kerkohet per te vleresuar raportin kundrejt gjithe ndertesës. Vendos 0 kur nuk ka kat nen toke
2. Si date vendoset data e inspektimit ne terren
3. ID është ajo qe prodhon sistemi kompjuterik "Emergjencat Civile". Nese nuk ke mundësi lere fushen bosh.
4. Nese ke gjera te pa qarta per kuptimin e termave te perdorura, konsultohu me specialiste te fushes

Figure 3. Adopted RVS Evaluation Form

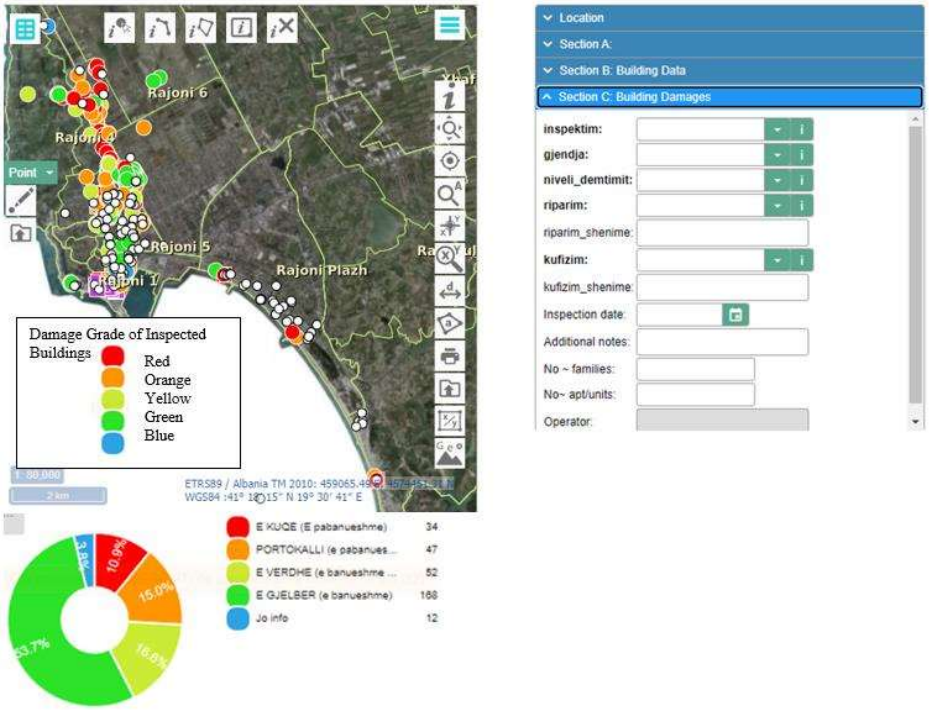


Figure 4. Invent. Al portal where all information of building evaluation was filled in real time.

A total of 313 buildings were evaluated during the field inspections. From the inspections, it results those 34 buildings are classified as Red (unhabitable), 47 buildings Orange (habitable only after retrofit), 52 buildings yellow (partly habitable), 168 Green (safe for use) and 12 did not have enough information to be classified into these groups.

DAMAGES OBSERVED

Multiple building typologies during the inspection. Structural and non-structural damages that were observed during the inspection are presented in Tables 5, 6 and 7.

Table 5. Damage Scale of Inspected Buildings According to Their Typology

Nr of Building according to Typology	Damage Scale						Total
	0	DS1	DS2	DS3	DS4	No Info	
Unreinforced masonry (URM) load bearing walls	20	5	8	7	4	1	45
Reinforced masonry (RM) load bearing walls	9	0	4	1	0	0	14
Reinforced concrete (RC) frame type	97	4	16	16	24	3	160
Reinforced concrete frame with diaphragm shear walls (RCS)	11	4	2	2	0	1	20
Masonry with combined Reinforced concrete (MRC) frames	26	1	1	2	2	1	33

Table 6. Damage Scale of Inspected Buildings vs Timeline of Evolution of Albanian Seismic Design Codes

Before 1952	-	-	3	2	-	5
1952-1963	1	1	3	-	-	5
1963-1978	5	1	1	2	2	11
1978-1989	3	1	2	-	1	7
After 1989	180	14	34	24	32	281

Table 7. Damage Scale of Inspected Buildings vs Building Usage Type

Building Classification	DS0	DS1	DS2	DS3	DS4	Total
Administrative	2	-	-	-	-	2
Educational	13	1	5	2	1	22
Individual	122	8	13	19	23	187
Industrial	-	-	-	-	-	1
Commercial	7	-	2	3	-	9
Residential	23	8	17	8	7	65
Others	9	-	5	1	4	27

Main Causes of building damages in 2019 Earthquakes

Albania's residential and public construction portfolio contains a wide range of structural types. These structures were constructed at different dates and with distinct seismic parameters. The majority of them were constructed under challenging conditions, such as a lack of knowledge, technical oversight, the use of often low-quality materials, and a lack of the essential research and design. Alterations in the use of buildings, as well as incorrect additions or changes in the original design, result in structural changes.

The underlying cause of damage in many situations is due to the local site conditions where the structures were constructed. Thus, the problem of groundwater in Durres, the construction on a historic and buried stream bed in Tirana, or on poor soils in Tirana each caused significant damage. Geotechnical investigations, as well as constructive solutions, have been insufficient in many circumstances. In Durres, the liquefaction phenomenon became a defining feature, becoming one of the disaster's key causes. Another factor contributing to the high level of damage was the construction materials employed. Their influence was particularly strong in several of the buildings built between 1980 and 1990.

Different behavior based on the object's type

The majority of the investigated buildings for Tirana and Durres are mainly RC structures, and load bearing masonry structures. The URM buildings are up to five stories and most of those buildings were engineered before the 1990. Regarding four of the inspected URM buildings were appointed to damage scale 4 because of the intense structural failure determined on the masonry walls and slabs. The main reasons of failure for this typology of building are associated with irregularities in elevations that in most cases are unauthorized such as the closure and creation of new window/door openings, different physical-mechanical properties of the materials, degradation over time because of bad maintenance, additional unauthorized new floors, and since they do not have steel reinforcing bars embedded in the structure, it is susceptible to severe damage and collapse during an earthquake.

1-2 Story Buildings with Load Bearing Walls

Figure 4 presents examples from the field that represent the failure due to insufficient or lack of bonding between masonry and RC beams and slabs. This resulted damage of walls and also possibility of falling parts from ceiling and roof.

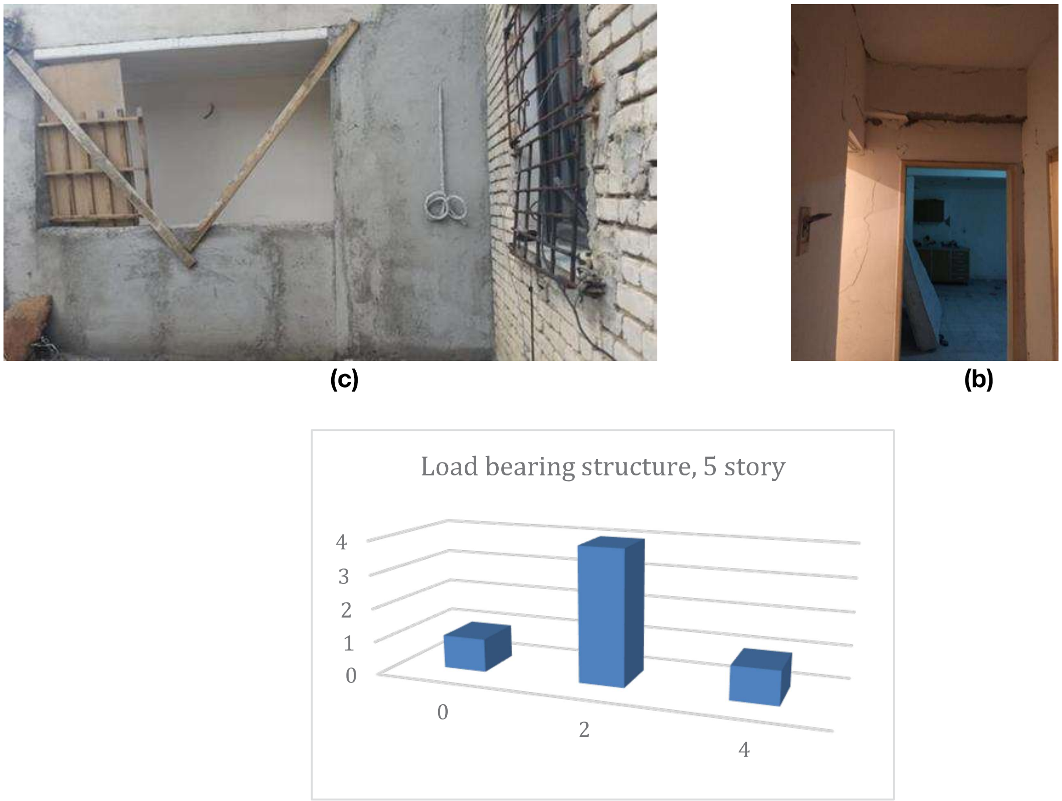
(a) **(b)** **(c)**

Figure 4. 1-2 Story Buildings with load bearing walls

5 Story Buildings with load bearing walls

Unengineered and unauthorized additions to the existing building causes severe structural damage during earthquakes. Figure 5 shows examples of this type of additions resulting various levels of damages.

(a) **(b)**



(c) (b)

Figure 5. Un-engineered and Un-authorized Additions

Buildings with reinforced concrete frame and infill walls (RC)

RC buildings are the ones being the foremost frequent among those inspected. It is valuable mentioning that none to very little structural damage was observed in RC structural elements. 97 buildings are evaluated as safe with damage scale 0, 4 buildings with damage scale 1, 16 buildings with damage scale 2, 16 buildings with damage scale 3, and 24 buildings with damage scale 4.

The damages are focused mainly cracking of the plaster, cracks in the infill walls, staircases, and the upper part of elevator openings (Figures 6-10). There are also structural damages detected. The main reason for these kinds of structural damages was failure in realization of the detailing of reinforcement according to technical rules such as minimum dimensions of supporting columns and the absence of seismic walls. Improper connections of the infill walls to the RC frame were observed. In some cases, this connection is entirely absent. This is the main reason why large pieces of walls were dislocated and even fallen out of plane.

Another problem observed is on the combination of flexible structural system and rigid infills. Albanian code KTP does not provide story drift limitations for Ultimate Limit States so there might be a need to review of the current seismic code in order to reduce the seismic risk in the future.

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h) (i)

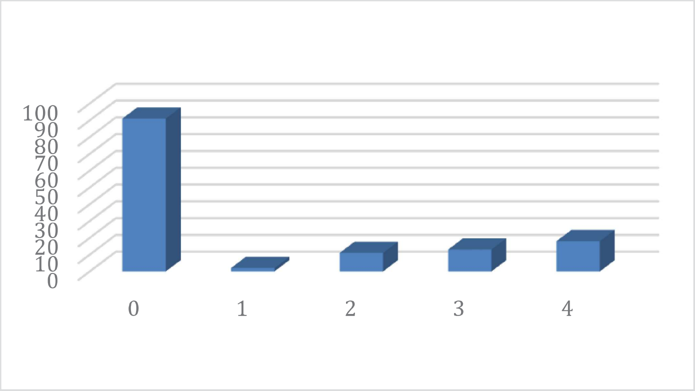


Figure 6. Damages in 1-5 storey Buildings with RC frame and infill walls

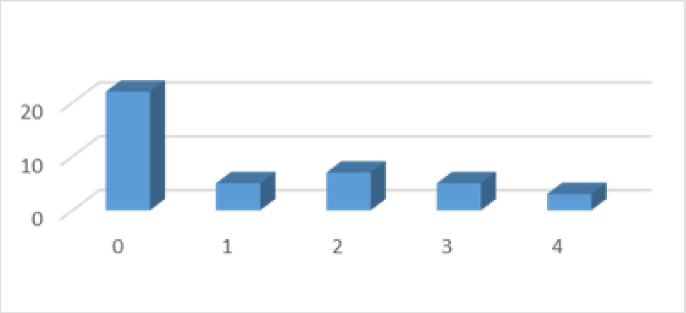


Figure 7. Damages in Buildings with RC frame and infill walls with more than 5 storeys.

Figure 8. Damages in Buildings with RC frame and infill walls with more than 5 storeys (Vila Verde, Durres)

Figure 9. Damages in Buildings of more than 5 storeys with RC frame and infill walls (Gostivari Building, Durres)

Figure 10. Damages in Buildings with more than 5 storeys with RC frame and infill walls (Hotel Tropikal, Durres) (before and after earthquake)

Material Quality

Low material quality is one of the main reasons which increase seismic vulnerability, from the inspection (Figure 11). We can say that in URM buildings fired bricks were used in the construction of walls. 3 structures of this typology had heavy structural failures and one of the main causes of collapse is the poor mechanical properties of the bricks and the lack of connections between the slabs and walls. Some of the RC structures had problems with concrete quality and also there are many cases where handmade concrete is used, especially in old buildings, the workmanship was not at the desired level, resulting in a very low quality of material. All these factors, including corroded reinforcing bars, together with the low-quality material of the building, resulted in poor performance during this earthquake.

Figure 11. Problems related to poor material quality

Failure to realize details

During the inspection we found that the minimum depth of required concrete cover was not respected and the details of the reinforcement were not carried out according to the technical conditions (Figure 12). In the old buildings there were cracks in the plaster due to thick layers of plaster, displacement of bricks and damage to the joints between them. Partition walls had out of plane failures and one of the main reasons for this problem is that these walls did not have a good restrain to the RC frames. The detail of stair connection with the floor slab or beam had problems also in some of buildings. There were also frequently observed problems with detailing of beam-column joints, and the diaphragm failures because of problematic connection between the walls and slabs.

Figure 12. Problems related to poor constructive detailing

Known phenomena (soft story, short columns, rigidity changes)

In some inspections we observed that the lower story, 1 or 2 stories, had large openings that created the effect of soft stories (Figure 13). Vertical irregularity that affects the load path for seismic loads from the upper stories to the ground. The mechanism of the short columns developed because of the continuous openings located at the top or bottom of the infill walls between the columns.

Figure13. Known phenomena illustrations

Scatterplot of Epicentral distance with respect to damage levels

It is searched how the attenuation relation to be demonstrated in terms of damage levels. Higher damage levels were concentrated especially within the epicentral distance with radius of 6 km (Figure 14). However, there is not a good correlation of epicentral distance

with damage level beyond this distance. This can be interpreted as an indication of local soil conditions effects. Moreover, a poor geotechnical investigation or evaluation followed by poor structural design without anti-seismic detailing would also be counted.

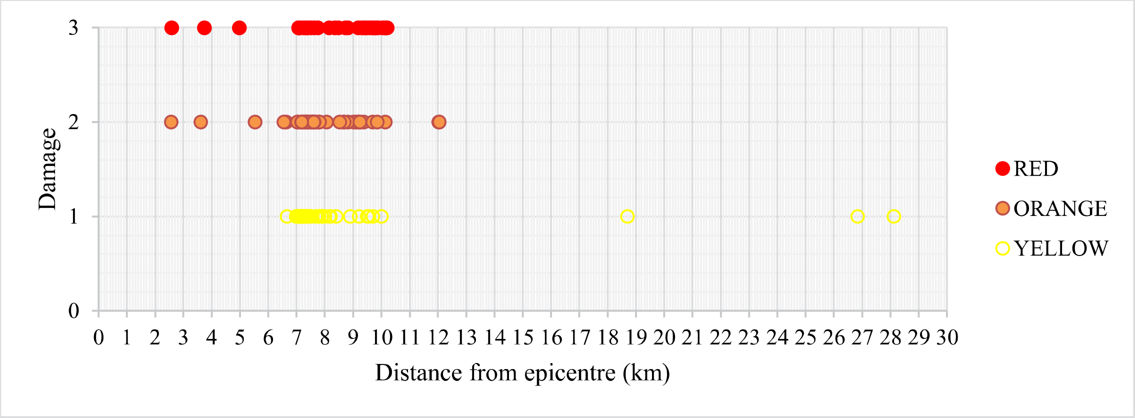


Figure 14. Scatterplot of Epicentral distance with respect to damage levels.

Seismic analysis in Eurocode 8 and KTP

It would be considered beneficial to express the structural engineering point of view of the usage of technical codes. Albanian Technical Codes (KTPs) in the field of construction are still in force in the Republic of Albania. Technical Design Condition KTP N2-89 which is based on ultimate limit state is the basis of design in seismicity. Eurocodes or other international standards can also be used voluntarily by designers by adoption of national parameters according to these standards (Aliaj et. al., 2010). EC 8 takes into account more factors in calculation of forces and displacements than KTP N2-89. Previous studies such as Bilgin (2021) include comparison of factors such as design working life, parameters related to the structural scheme, local parameters, calculation of modal mass, design spectra, shear forces, displacements etc.

The general differences between the two codes can be summarized as:

- EC 8 has more specific calculations depending on the structural system, ductility classes and structure irregularity.
- KTP N2-89 gives lower values of maximum acceleration at floor levels than EC 8.
- The seismic force that the structure can withstand in the case of design according to KTP N2-89 would be less than EC 8 in the case of comparison of Category III with types C, D, E soils.
- Displacements would be larger when the structure is analyzed according to EC 8.

CONCLUSIONS AND RECOMMENDATIONS

Structural engineering in seismic zones is a procedure with unique design and implementation considerations. The remedies provided in these circumstances necessitate a thorough examination not just of the entire, but also of the detailing, which must be thoroughly examined. This is due to the fact that the entire structure is subject to seismic forces. The earthquakes of 2019 demonstrated that we had flaws in our design methodologies and standards, project implementation, material quality, and other areas. This study pronounced some of the major parameters that increased the higher loss in the two major earthquakes that hit Albania in 2019. The area experienced similar destructive earthquakes in the historical past and will probably experience more in the future.

Below are the recommendations that are proposed to minimize losses in the future earthquakes;
- The earthquakes in Albania in 2019 highlighted the need for enhanced seismic engineering training for engineers. There is a growing consensus that certified and licensed engineers should be employed in the design of high-rise buildings in seismically challenging areas.
- It is seen that there is a need to apply and adopt Eurocode norms with all the parameters included in the national framework.
- Seismic assessment is recommended to determine the vulnerability of the buildings in areas with high seismicity. These assessments should prioritize densely populated public buildings such schools, hospitals, etc. For special constructions due to their importance or the risk they may pose, even more advanced analysis can be performed.
- Geotechnical investigations should be carried out before construction to determine the suitable foundation type for the structures. In poor soil conditions it is recommended to avoid designing superficial foundations unless improving the soil properties or to choose better systems (pile foundations, caissons, etc.).
- The materials used in constructions as well as their implementation should be within the related standards and qualities should be assured through the whole construction process.

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