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The impact of non-compliance with code desings of structures in seismic areas

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Abstract

The Mw = 6.4 November 26, 2019 02:54 UTC earthquake struck near the city of Durrës, Thumanë. Since the earthquake struck on 26 November, resulting in 51 deaths and up to 750 people injured. Many buildings in Durrës and Thumanë were collapsed and many more were seriously damaged. The inspection of the damaged buildings and declared uninhabitable, revealed many problems related to their design. After 1990 and especially after 2000 the construction of multi-storey reinforced concrete buildings (9-12 floors) mainly for residential and service facilities was very intensive.These structures are mainly designed referering to old Albanian design codes KTP-89 and these structures are the ones most damaged by seismic event and are mainly related to bypassing the design codes and specific criterios for structures in seismic areas. But it should be noted that one of the reasons for their non-collapse is that they are designed as very elastic structures so consequently having reduced seismic forces, but not meet the requirements of Eurocode 8 and KTP-89 to other criterias. To illustrate the above problem,we will show the most common avoidances from general rules of design according to EC8. The fundamental periods of of 9-12 floors buildings are much larger that the values that should have these type of structures according to design codes. The factors related to the above are and cousing the damage, colapse of the filling and the partition walls and also creating panic and endangering the lives of residents are the element designs such of hidden beams in the slabs, lack of diaphragms and cores. Inadequate design of foundations cause the differentials settlements and inclination of objects as well. Another problem is incorrect dimensioning of seismic gaps between two structures.

Key words: earthquake, code design, seismic area, periods, settlements, bumping

1 Introduction

Durres as a residential center is one of the oldest cities in Albania with a history of civilization over 2500 years. Named Durachium in ancient times, it was one of the important cities of the Roman Empire and later of that Bizamine. During all this time he has often been hit by strong earthquakes, which have not only severely damaged it from time to time but, in some cases they have forced its inhabitants to leave the city (such as the earthquake of 1273) [1]. The city of Durres is constantly hit by large earthquakes with its epicenter city or near it, such as the earthquakes of 58, 334, 346 and 506 with epicenter intensity 8-9 MSK-64 and the earthquake of 1273 and that of 1926 with intensity 9 MSK-64. The city of Durres was also affected by earthquakes with epicenters in the area around it, such as the earthquake of August 26, 1852 in the Cape of Rodoni, the earthquake of May 16, 1860 in the bridge of Beshir, the earthquake of the 4th February 1934 in Ndroq, the earthquake of 19 August 1970 in Vrap and the earthquake of 9 January 1988 in (Yzberish) Tirana, who were felt in Durres with an intensity of 6 MSK-64.The most significant earthquake of the recent history was the April 15, 1979 Mw = 6.9 "Montenegro" earthquake; that occurred ≈100 km towards the north of Durrës . On November 16, 1982, the Mw = 5.6 earthquake event occurred to the SW of Tirana. The Mw = 6.4 November 26, 2019 02:54 UTC earthquake struck near the city of Durrës, Fig1

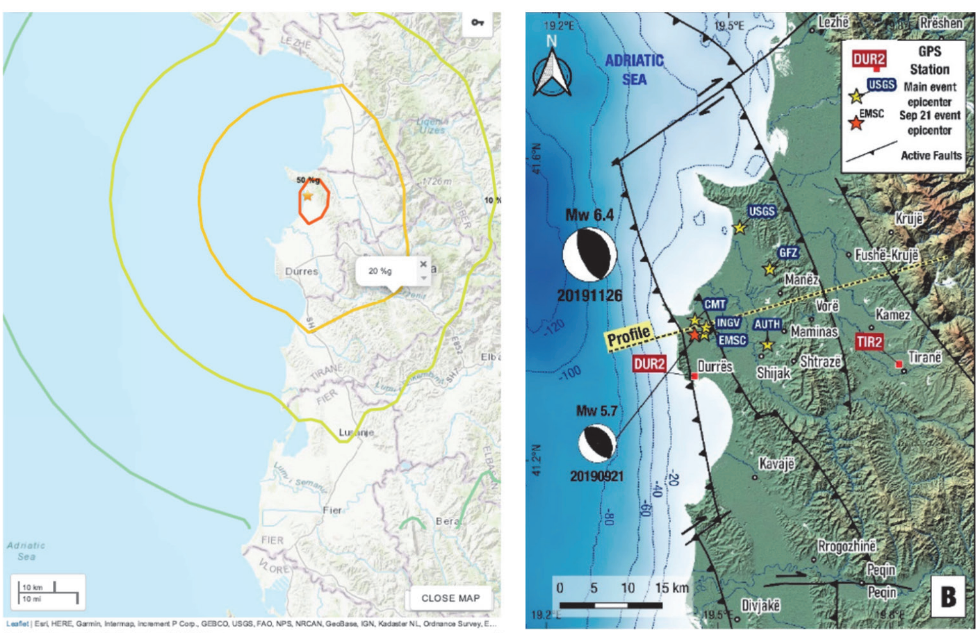

Figure 1. a) Location of epicenter and Pga contours of the 26 November Earthquake; b) Geological stuctures (thrust faults,epicenter,station that recorded earthquakes) [2]

Its hipocenter was determined in the range 6–26 km Table 1. The magnitude of the main aftershock (occurred on 06:08 UTC on the same day) was Mw = 5.4 according to EMSC. Since the earthquake struck on 26 November, resulting in 51 deaths and up to 750 people injured. Many buildings in Durrës and Thumanë were collapsed and many more were dangerously damaged. As of 14 December, up to 12,181 people were reported to be living in temporary accommodation (excluding those hosted by relatives or friends): 7,383 in tents (a majority of them in spotted tents in rural areas, close to their individual houses), 4,149 in hotels, 395 in community centres and 254 in gymnasiums. As of 17 December, all tent camps have been closed.

Table 1. Determination of the parametric data of the Nov. 26, 2019 02:54 UTC earthquake by different Sources [3]

Institute	Longitude	Latitude	M_w	Depth (km)	Source
GFZ	19.580	41.460	6.4	26	1
GCMT	19.578	41.390	6.4	24.1	2
USGS	19.526	41.514	6.4	19.5	3
CPPT	19.360	41.380	6.4	15	4
INGV	19.467	41.371	6.2	21	5
AUTH	19.578	41.359	6.1	6	6
EMSC	19.470	41.380	6.4	10	7

2 Identification of problems

One of the groups that inspected the damaged buildings by the earthquake was that of the Faculty of Civil Engineering at the Polytechnic University of Tirana. The inspected buildings were mainly in the most affected areas such as Durres, Thumane, Manze, Fushe Kruje, Lac and Lezhe. Expertise was performed more accurately for damaged buildings in the city of Durres, Tirana and Fushe Kruje. In this material we will refer to some of the structures that were inspected in Durres and mainly those buildings with a height of 9-12 floors.

The area where the buildings are located belongs to a mostly flat relief with a small difference in quotas. From the point of view of geological formation there are alluvial, aleo-proluvial Quaternary and Neogene deposits. Quaternar deposits are represented by dusty sands, silt, dust mites and clay. Quaternary deposits according to the study of seismic microzoning of the city of Durres have thickness about 130 m. Neogene deposits are represented by clays and sandstones, are poorly up to average cemented. The upper part of this formation in contact with the cover deposits is aerated. (Kociu et al, 1985). Referring to KTP-79 seismic intensity in this area according to the seismic microzone Durres aria is IX scale MSK - 64.

The buildings from the point of view of time of construction can be classified before 1990 and those after 1990. Buildings before 90 are up to 5 floors with brick supporting masonry structures with antiseismic reinforcing columns after 1979 but without

antiseismic columns before 1979. Also there are prefabricated buildings (frame system) with filling masonry and lightweight partitions.
These structures are designed according to the Albanian design codes KTP-79 and KTP-89 which include rules for Sismic design [4]. After 1990 and especially after 2000 we have the construction of multi-storey reinforced concrete structures mainly for residential and service facilities. These are frame reinforced concrete structures or frame combined with diaphragm and cores mostly supported in raft foundations and in some cases supported on piles and raft foundations.

Figure 2. a) Inspected aria in City of Durres ; b) Location of some of the inspected 9-12 stories buildings in the same geological conditions

These structures are mainly designed according to the old Albanian design codes but in some cases the Eurocodes [5] have been used through engineering softwares such as etabs, sap, or softwares that are also used in Italy or Greece. However in Albania until 2018 KTP-89 has been the legal design code for the design of structures.

Figure 3. a) Filling walls completely destroyed; b) partitions walls completely destroyed; c) Inclintion and short roblem

The inspectied structures, in general were with large damages and declared uninhabitable. The most frequent damages are in the filling and partition walls destructied or exit from their plane, meanwhile the primary structural elements such as columns, beams, diaphragms or reinforced
concrete cores do not show signs of destruction. Another serious roblema is the inclination up to 2% of some of the 6-12 stories buildings due to the differential settlement of soil. Fig. 3.

3 Specific cases

Let discuss some of the factors that have led to the damage of these structures. We think that mainly the main factors of damage for most of these objects can be as follows

3.1 The impact of fundametntal period of soil

The own fundamental period according to seismic and geological studies in these sites fluctuates in a very wide interval 0.30-2.0 sec.[6]. The conception and design of these structures as very elastic one placed in the soil with these characteristics leads to the major problems for the structure in terms of the resonance phenomenon. For the inspected damages buildings placed mainly in this area, from geological-seismic studies, the own fundamental period of the soil resulted in values between 1.0-2.0 sec, so in the range of the fundamental period of 8-12 floors structures.
For the completion of the act of expertise of the damaged buildings, we used the simplified analyzes for finding the fundamental characteristics of structures related to the seismic action of the earthquake such as the fundamental period of vibration, the base shear force and the maximum displacement of the structure.
According to EC 8 base shear force can be calculated as

$$F_b = S_d(T_1) \cdot m \cdot \lambda \qquad (1)$$

where $S_d(T_1)$ is taken from the design specter for the fundamental period of the structure for buildings up to 40 m high and the value T_1 (in sec) can be calculated approximately through the following expression:

$$T_1 = C_t \cdot H^{3/4} \qquad (2)$$

So according to the above formula for 8-14 floors buildings these values of fundamental periods will vary between (0.8 sec ≤T1≤ 1.24 sec).
In cases where the results from the simplified formulas seemed with very large deviations we also done more exact calculations by modeling some of the structures with FEM. From the numerical controls performed for the damaged structures, their respec-

tive fundamental period is at least 70% greater than that referred to by the Euro codes Table 2.
We have used the simplified formulas by Miranda [7] accepting as the calculated height 0.6h-0.7h of the building depending on the type of structure (simple frame, frame with hiden beams in slab or frame with diaphragms). From the calculations we see that objects are quite elastic with the exception of object 3.

Table 2. Fundamental Period of the structures

	Fundamental period T_1 (sek)						Miranda (1999)	SAP	EC8
	Type of Structures	Nr. floors	h(m)	ΣA (m^2)	ΣI_X (m^4)	Plan (LxB)	Period T1 (sek)	T1 (sek) SAP	Period EC8 T1 (sek)
Objekti 1	Frame beams in slab	9	27	6.54	0.577	11x26	2.40	2.19	**0.592**
Objekti 2	Frame beams in slab	12	35	8	0.311	16x18	2.75	Na	**0.719**
Objekti 3	Frame Walls	12	39	22.16	11.419	22.5x32	1.30	1.13	**0.780**
Objekti 4	Frame beams in slab	12	36	0.96	0.0512	13x6* Single frame	2.18	2.70	**0.735**
Objekti 5	Frame beams in slab	12	37	0.8	0.01667	12.5x5* Single frame	2.03	2.30	**0.750**

3.2 Differentiated settlements

A hould buildings due to irregularity in the plan and predominantly in their height and due to seismic action have caused extremely large inclinations of the structures Figura 3.a.

Probably the differential settlements of soil may have occurred over time due to the weak characteristics of soil, the irregularity in the plan and in the height of the structures and as well as the P-Δ effect, but we think that the determining cause to lead to almost catastrophic situations have been seismic actions and especially the earthquake of November 26, 2019.
The question of allowable settlements and the influence on the performance and serviceability of structures has received little attention. In order to solve the problem of allowable settlements and criteria of damage successfully it is necessary to define the types of movements and deformations experienced by foundations. The ground hould be treated by some suitable technique to provide appropriate stiffness and strength. [8]

3.3 Inadequate structural solution

The most of damaged buildings are designed as simple spatial or planar frames not combined with reinforced concrete diaphragms or cores. The use of hidden beams in the slabs is widely used due to its ease during the implementation process, but it causes significant reduction of the stiffness of the structure under the horizontal forces actions. This leads to large displacements of the slabs of inter stories without fulfilling the condition of permitted drifts and leading to the damage or illema of the filling and the partition walls, creating panic and endangering the lives of residents.
According to EC 8 permitted drifts should fulfill the condition:

$$d_r \cdot \nu \leq 0.005 \cdot h \quad (3)$$

where ν = 0,4 for these type of building and according to KTP-89

$$d_r \leq 0.002 \cdot h \quad (4)$$

To illustrate the above illema,we ill show the calculations for some of 9-12 floors structures Table 3.

Table 3. Maximum Roof Displacements and Average value of drift for the structure

		Average value of drift for the structure					
	Type of Structures	Cv.Elas. Max (cm)	q*Cv.Elas . Max (cm)	Cv.Elas. Max (cm) SAP	q*Cv.Elas . Max (cm) **SAP**	ν *0,005	dr/h ≤ 0,002
Objekti 1	Frame beams in slab	22.33	78.155	13.32	**46.62**	0.0125	0.0173
Objekti 2	Frame beams in slab	21.7	**75.95**	Na	Na	0.0125	0.0217
Objekti 3	Frame Walls	14.9	52.15	13.06	**45.71**	0.0125	0.0117
Objekti 4	Frame beams in slab	15.28	53.48	20	**70**	0.0125	0.0194
Objekti 5	Frame beams in slab	15.13	52.955	17.18	**60.13**	0.0125	0.0163

It is quite clear that the condition for permissible drifts. Although not treated for each floor but referring to the total high of the building is not satisfied in any of the above cases with the exception of building 3, which is a frame structure with diaphragms and core.

3.4 Seismic joints and short columns

In many buildings which are composed of several sections on the same loset on slab or buildings that are loset o other buildings seismic joints are incorrectly designed or are not taken into account at all causing the effect of the collusion and bumping of the structures. This is a very dangerous phenomenon that often leads to major damages and collapse of buildings. Figura 4.b.
Designing the stairs incorrectly by halving the height of the vertical structural element (columns) and causing the "short column" effect.

Figure 4. a) Differentiated settlements 1.6% inclination of building. B) Collusion between two buildings different high. C) Bumping effect

4 Conclusions

The inspection of the damaged buildings and declared uninhabitable, revealed many problems related to their design especially of multi-storey reinforced concrete buildings (9-14 floors) mainly for residential and service facilities was very intensive.
These structures are mainly designed refered to old Albanian design codes KTP-89 and these structures are the ones most damaged by seismic event and are mainly related to bypassing the design codes and specific criterias for structures in seismic areas.
We mention some of the reasons that led to these damage to buildings from the seismic action. Deviation from the design codes in general, both in terms of structural conception and details and neglect of the geological conditions of the soil, have resulted the main factors of damage to the structures. Also the untimely adaptation and improvement of the code design causes big problems for the structural engineers. But, on the other hand, many damages were not avoided even if the technical conditions of the Albanian design code were followed, although old in time and not improved. But with the entry into force of Eurocodes in Albania in 2018 and the strengthening of legislation regarding design, supervising and implementation of works procedures, we are confident that many mistakes will not be made. We are confident for increasing safety,quality of design of structures and avoiding catastrophes from seismic events.

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