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MOST AFFECTED TYPOLOGIES FROM THE 26 NOVEMBER 2019 EARTHQUAKE

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Abstract

Assessing and finding the causes of damages in buildings belonging to construction typologies severely damaged as a result of the 26 November 2019 earthquake is of significant importance. Not only to better understand the causes of severe damage and the measures that should be taken specifically for these buildings, but also for planning the necessary interventions in these typified buildings typologies not only in the damaged areas but also in non-affected areas. This paper aims to carefully analyse some of the most severely damaged buildings by the earthquake, which have been associated with human casualties. Three construction typologies are considered in this paper, where two of them are design and build before the ‘90s as a typified buildings implemented in different cities, and the third one is a modification of typified RC building, constructed mainly after the ‘90s. One of the buildings build before the 90s is a masonry structure, while the others are reinforced concrete structure. Through damage and collapse mechanism assessment as well as using results of non-linear analysis, the paper attempts to highlight the primary causes of severe damage, compliance with building codes and the necessary measures that are recommended to reduce the vulnerability of these buildings

Keywords: construction typology, brittle failure, soft story, shear resistance, nonlinear analysis, vulnerability

1 Introduction

According to IGJEO on November 26, 2019, 03:54 local time, a Mw 6.4 earthquake occurred 16 km north of Durrës and about 35km from Tirana, in the western region of Albania, at a depth of 38 km. The event was preceded by an Mw 5.6 earthquake with approximately same epicentre which occurred on September 21, 2019, causing considerable damage, mainly non-structural, and affected roughly the same area as the November 2019 earthquake (26Nov ADE); (RPI-Nov.26, 2020).

The 2019 earthquakes were recorded by several IGJEO stations and the data are provided online (IGEO, 2019). Unfortunately, the Durrës station (most important one close to the epicentre), recorded only the first 15 seconds of the main shock due to a technical issue (Duni L, Theodoulidis N, 2019). Some of the elastic response spectra, from Sept. 21 and Nov. 26, 2019 earthquakes records are presented in Fig. 1. The recorded PGA values were 0.114g and 0.194g in the Durrës station for the Sep.21 and Nov.26, 2019 earthquakes, respectively. In contrary, Sep.21, 2019 Earthquake produced higher PGA value in Tirana (0.183g) than Durrës (0.116g). The Nov.26, 2019 earthquake induced high seismic demands in flexible buildings in Durrës and Sep.21, 2019 earthquake induced high seismic demands in stiff buildings in Tirana. It should be noted that the Durrës station is located in very weak soil conditions (IGEO reported $v_{s,30}$ = 202 m/s). Very close to that station (50m away), the measurements shows $v_{s,30}$ less than 170 m/s and shear wave velocity decrease with depth Fig. 2, so, soil category can be classified as S1 according to the EN 1998-1:2004.

The seismic event caused 51 fatalities, more than 913 injuries and up to 17,000 people were displaced. The total effect of the disaster in the three regions Durrës, Tirana and Lezha amounts to 985.1 million EUR, of which 70% belongs to housing sector. It was estimated that 18% of all housing units in the affected area required either reconstruction or rehabilitation (PDNA-A, 2020).

Fatalities have been concentrated in two municipalities, Durrës and Thumana (an administrative unit of Kruja). In addition to the earthquake magnitude, the vicinity to the epicentre and the soil conditions, the fatalities happened in these areas are also closely related to the typified buildings that have suffered heavy damages and collapse from the seismic event.

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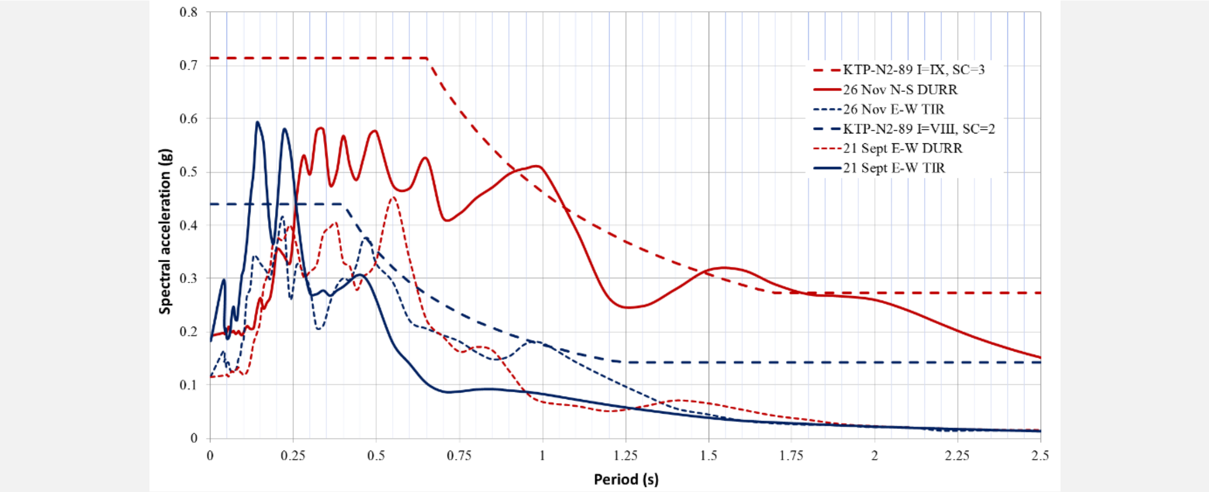

Fig. 1. Elastic response spectra of the ground motion records for Sep. and Nov. 2019 earthquakes at Tirana and Durrës (5% damping ratio) and national seismic design code (KTP-N2-89) elastic response spectra.

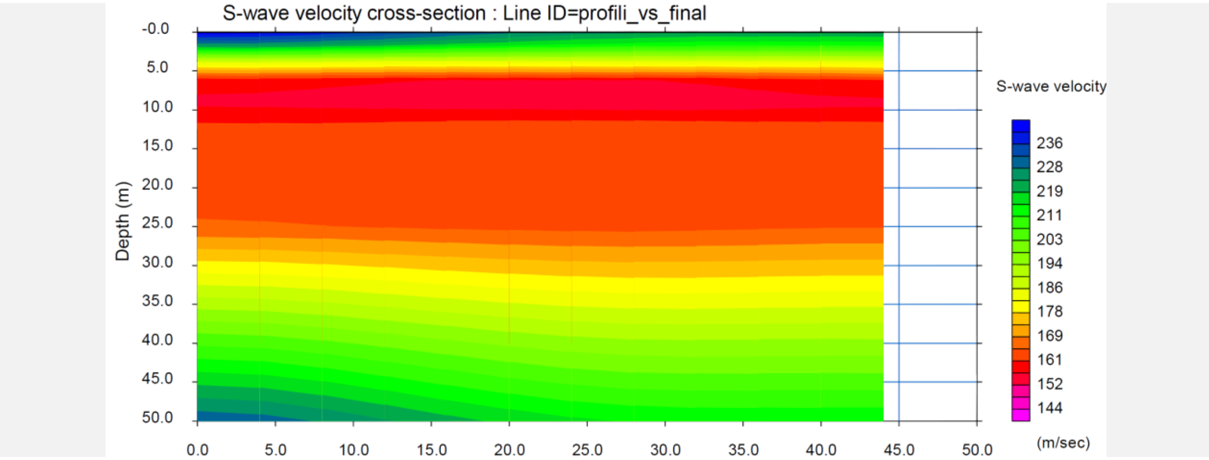

Fig. 2.Shear wave velocity, very near to the Durrës station (A. G. Consulting, UTS-01, 2022)

In Table 1 are presented the building places, their typology and collapse mechanism as well as number of fatalities for each of them [see also (EEFIT Report, 2020)]. From the 51 fatalities, 3 persons that lose their life in other circumstances, rather than related to the building collapse are not presented in this table. If some associations to the total number of fatalities presented in Table 1 can be done, 33 fatalities occurred in typified buildings having a construction permit and build previous or around ’90 and 13 fatalities in buildings without construction permit of with a violated permit in the period 1990-2005.

Table 1 – Fatalities and their connection with location and building model and typology

No.	Municipality	Admin Unit	Coordinate	Typology	Model	Floors	Fatalities	Comments
1	Kruja	Thumana	41.5499; 19.6791	URM	Model 77/5	5	**17**	Partially collapsed
2	Kruja	Thumana	41.5495; 19.6797	URM	Model 77/5	5	**7**	Partially collapsed
3	Durrës	Lagje 18, Durrës	41.3275; 19.4529	RC	Model 82/2	6	**7**	Total collapse
4	Durrës	Këneta, Durrës	41.3281; 19.4591	RC	Informal	4	**8**	Total collapse
5	Durrës	Lagje 6, Durrës	41.3214; 19.4468	RC	Model 82/2	6	**2**	Soft story
6	Durrës	Plazh, Durrës	41.3092; 19.4871	RC	Informal	6	**2**	Total collapse
7	Durrës	Plazh, Durrës	41.3131; 19.4777	RC	Informal	5	**2**	Total collapse
8	Durrës	Plazh, Durrës	41.2728; 19.5169	RC	Informal	8	**1**	Total collapse
8	Durrës	Plazh, Durrës	41.2728; 19.5169	RC	Not typified	5	**1**	Soft story
9	Tirana	Kombinat, NJA 6	41.3129; 19.7701	URM	Not typified	5	**1**	Parapet felt down
			Total fatalities due to building collapse =				**48**	

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This paper will be focused analysing the performance of the typified buildings with fatalities, highlighting the primary cause for their heavy damages/collapse and giving recommendations to reduce the vulnerability of these typified buildings.

2 Description of the typologies considered

In the following chapters three main typified buildings, causing most of fatalities during November 26, 2019 earthquake will be analysed in more details. The analysis will be focused on:

1. Typified URM building, Model 77/5 – Two buildings caused 24 fatalities;
2. Typified RC building, Model 82/2, original and modified – Two buildings caused 9 fatalities;

Table 2 summarizes important structural characteristics of selected buildings, related to general geometry and dimensions as well as material properties and structural details. Structural analysis and respective results are based on these data.

2.1 Typified URM building - Model 77/5

The Typified URM 77/5 Model was designed and started to construct in 1972 (the 72/5 Model). Later, in 1977 it was introduced with some architectural and functional improvements and was presented as Model 77/5. Only few changes can be found between these models, and the most important, its structural regularity – it is increased. Although the Seismic Code KT-63 (Goverment of Albania, 1963), Point 25, doesn't allow such layouts without dividing them into simple shapes by seismic joints for areas with seismic intensity 7 or higher, this model is found in many areas which suffer higher intensity due to September 21, and November 26, 2019 Earthquakes.

The general data of the URM model 77/5 are given in Table 2. The masonry wall are constructed with thickness 38cm in the first three floors and 25cm in remaining two. Masonry wall are composed with brick strength 7.5 Mpa (clay or silicate bricks) and mortar strength 1.5Mpa. Foundation are stone masonry embedded not less than 1.3m. Slabs are composed with prefabricated panels, placed in one direction, supported directly to masonry walls and without any additional concrete layer on top.

Table 2 – Main characteristics of the case study buildings

No	Item	5-Story building, 77/5 URM Model	RC and M-RC 82/2 Model, Durrës
1	Seismic design code	KT-1963	Improved KTP-N.2-78
2	Year of construction	1977-1982	1982-1996
3	Interventions	Openings in ground floor walls (not confirmed)	Added one floor
4	Soil category	III (KTP-N.2-89), D (Eurocode 8)	III (Improved KTP-N.2-78 and KTP-N.2-89), D (Eurocode 8)
5	Structural system	Unreiforced Masonry	RC moment frame
6	Structural regularity	Irregular in plan and regular in elevation	Regular in plan and irregular in elevation
7	Building height	5x2.8=14.0m	RC 4.06+4x3.06=15.3m or M-RC (3.8+5x2.8=17.8m)
8	Storey height	All floors 2.8m	Ground floor 4.06/3.8m, others 3.06/2.8m
9	Plan dimensions and area	18.8x14.21m (same layout); Area=225m2	RC = 10.0x20.7m, Area=220m2; M-RC = 13.7x20.7m, Area=279m2
10	Building mass (ton)	URM = 2000 ton	RC = 1100 ton; M-RC = 1600 ton
11	Foundations	Continues T shape stone masonry foundations, 0.7x1.5m+1.0x0.5m thick, depth at least 1.5m	Footings 2.5(2.8)x2.5(2.8)x1.0m connected with tie beam bxh=0.3x0.4m only outside (inner foots dim, PL2); depth at least 1.5m
12	Basement available	No (exists only in some specific cases)	No (exists only in some specific cases)
13	Slabs and Beams	One-way prefabricated ribbed slabs with brick infill 15cm or RC hollow pannels, 11cm thick. No tie beams on top of the wall	One-way prefabricated RC hollow pannels, 11cm thick. Beams bxh: transversal 30x40cm, longitudinal 40x30cm* (* differ in some M-RC buildings)
14	Materials (based on design and tests)	Design: Mortar 1.5Mpa, Bricks 7.5Mpa, Tests: Mortar 1.6Mpa, Bricks 8.6Mpa	Design: Concrete C16/20, Steel yield strength 210 MPa; Tests: Concrete cubic strength 20-23Mpa; Steel yield strength 320 MPa (plain rebar)
15	Column/Wall spacing	Max walls spacing: Transversal direction 10.7m*, Longitudinal direction 4.35m	Transversal direction 3.6m, Longitudinal direction 4.2-5.4m
16	Column/Wall cross-sectional dimensions	Walls: Three floors - 38cm thick and two other floors 25cm thick.	bxh = 30x40cm
17	Column reinforcement	NA	K1 GF: 2.4%; Other floors: 1.4%; K2 GF: 2.9%; Other floors: 1.9%; Single hoops: Ø8 at 10/20/10cm spacing
18	Beam reinforcement	NA	Long. rebar ratio approx. 1.8%, with 80cm critical regions and stirrups Ø8 at 10/20/10cm spacing (spacing differ in some M-RC buildings)

The April 15, 1979 earthquake provided valuable information on: used materials (mortar and weak bound between silicate bricks and mortar) and the building layout (Stermasi F, Premti K, Meka K, 1980) (Pistoli, 1980). In year 1982, in accordance the 77/5 model was reviewed and improved Fig. 3 for use

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in seismic areas with intensity VII and VIII by adding columns (K1) to the corners of the building; by increasing the mortar strength from 1.5Mpa to 2.5Mpa for walls with clay bricks and 5.0Mpa for walls with silicate bricks; by adding RC horizontal tie beam 15x38(25)cm on the top of the masonry wall at each floor. Slight improvements are done also for out-of-plane behaviour (AQTN).

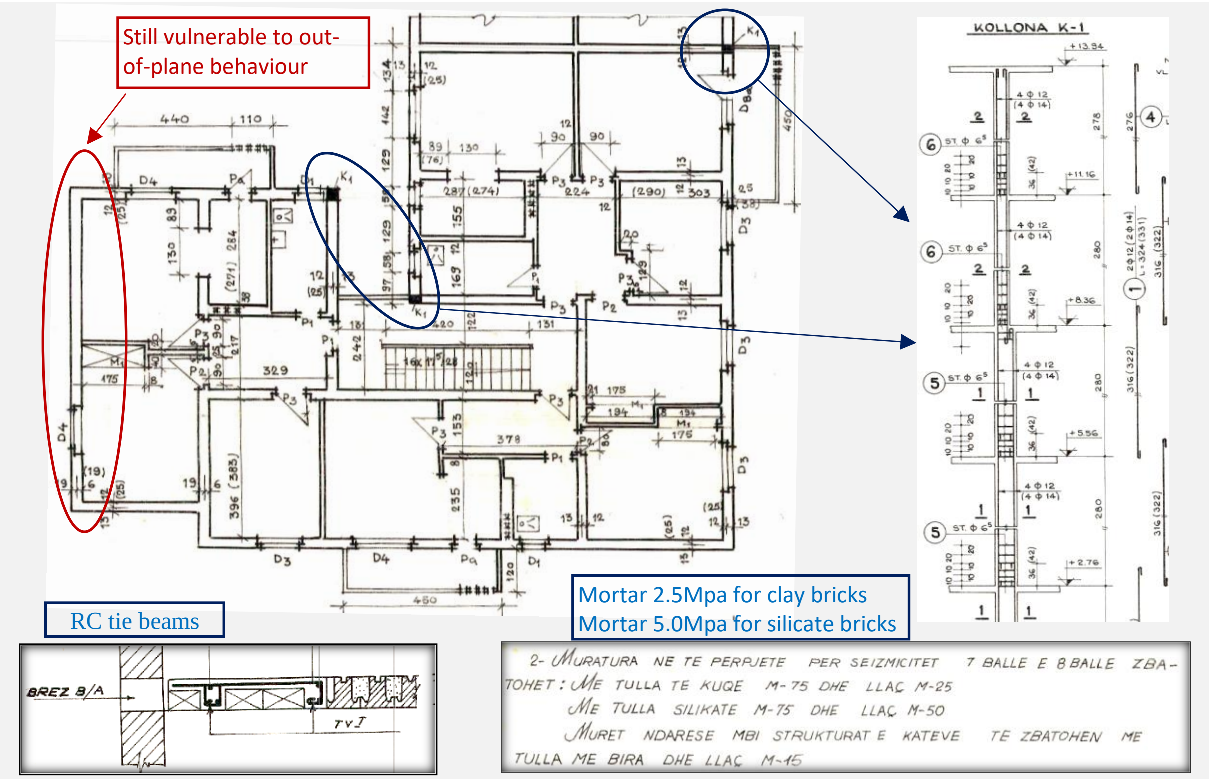

Fig. 3. Improved 77/5 Model, by adding at least 3 RC columns at the corners; improving the mortar strength; reinforced concrete tie beams were also added at the floor levels

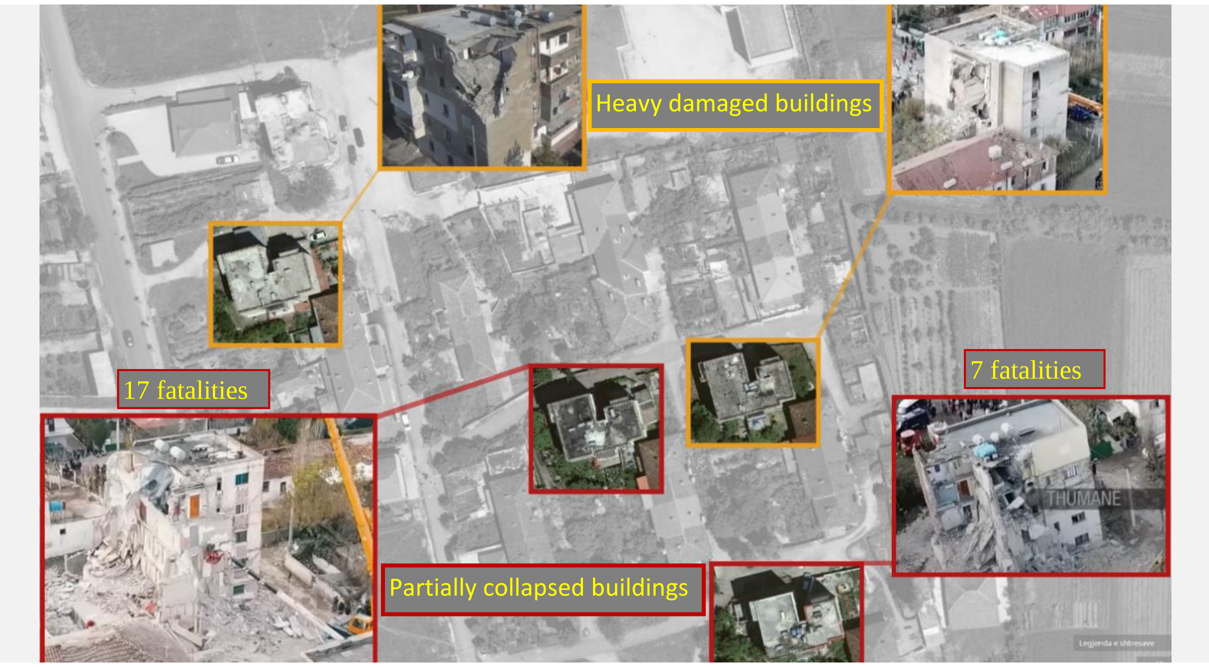

Fig. 4. Location of URM Model 77/5 in Thumana and their damage degree

Unfortunately, many buildings with URM 77/5 models has been constructed since its release and the improved 77/5 model in 1982 wasn't use to retrofit the existing building stock. During the 2019 Earthquakes many buildings belonging to this model suffer moderate-heavy damages. Four partially

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collapsed buildings in Thumana belonged to this model as well and 24 people lost their lives in two of them Fig. 4.

From the structural point of view, URM 77/5 Model can be considered composed of two "separate" structural units having a weak "connection unit" Fig. 5, comprising: low percentage of transversal walls and high potential of out-of-plane failure of longitudinal walls; stairs; longitudinal walls weakened by the presence of doors and windows. The prefabricated slab panels, placed in one direction and without tie beam connecting to the wall also affect the joint work of the units A and B.

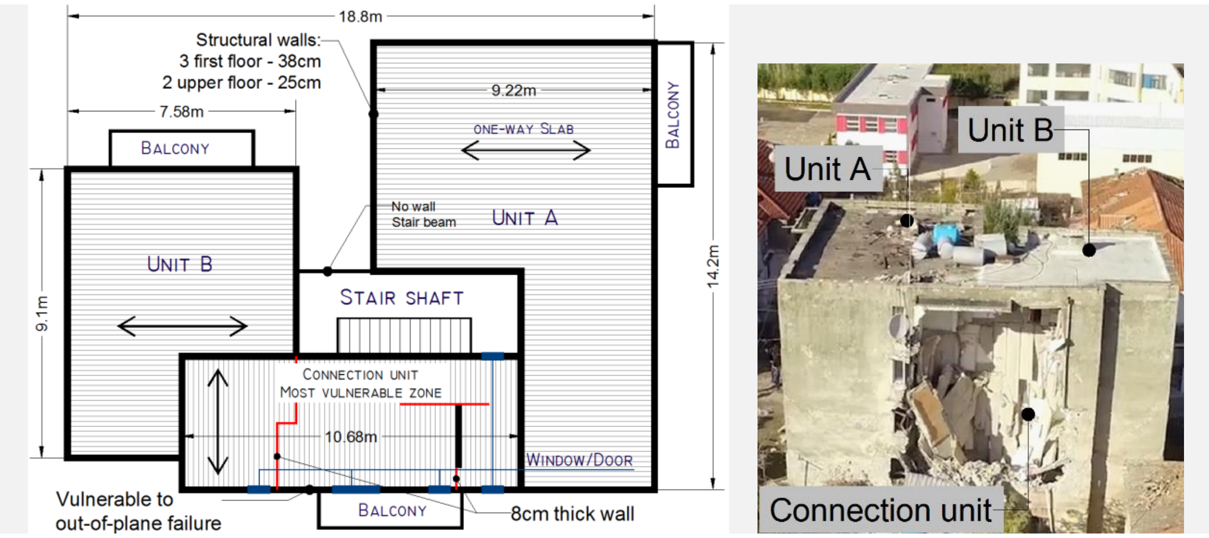

Fig. 5. Structural unit composition of 77/5 URM Model

Due to the layout geometry, the weak "connection unit" and the distribution of the masonry walls and their openings, the torsion and the interaction of the structural units A and B increase the seismic effect to each other. The interaction may have contributed to the heavy damages and falling parts of the "connection unit" as well as to the collapse of the small unit B in two cases, during 26 November earthquake. The photos of the heavily damaged buildings clearly show the collapse of small units in two buildings and damage to the connecting area in the two others.

The damage pattern appear in this building typology are: 1-) diagonal cracks in masonry walls, especially in the weak pears and spandrels; 2-) disconnection of the slab panels from the masonry walls due to lacking of the tie beams and inadequate or missing connection between slab panels; 3-) moderate to heavy damages at the masonry walls in the upper floors due to low normal stresses; 4-) Out-of-plane failure; 5-) parapet failure in many cases, especially when masonry buildings are situated in areas without or with low seismicity and the parapets are not strengthened. In the "Kombinat" area near Tirana, as a result of their vulnerability, a lot of parapets felt down and one of them caused a fatality, a girl loss her life. Summarising, the factors increasing the damageability of the 77/5 URM model are:

- The mortar quality and the bound connection between silicate bricks and the mortar;
- In-plane irregularities with an added vulnerable member "connection unit" between two main structural units;
- Some masonry wall are vulnerable to out-of-plane failure – max wall length 10.68m;
- The absence of tie beams on the top of the masonry wall at each floor as well as one direction prefabricated slabs without any additional RC top layer;
- Workmanship quality and competence – many buildings previous to '90 have been constructed by voluntary workers;
- Environmental factors, especially humidity, which has deteriorated the quality of mortar as well as the lack of building maintenance;
- Possible interventions to these buildings, without verifying the existing capacity. The intervention can be both in openings in the ground floor and adding floor or lateral areas.

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Based on the structural assessment carried out through pushover analysis, using two-dimensional masonry elements (Baballëku, 2014), obtaining mortar properties directly from laboratory tests (Mortar strength = 1.6 Mpa and Bricks strength = 8.6 Mpa) and comparing the structural capacity of the building with the seismic demand, the following main conclusions are drawn and highlighted:

1-) Using as demand, the fitting response spectrum of all 2019 earthquakes recorded at Tirana station (Fig. 6-a), the URM 77/5 model suffer significant damages, but no collapse (Fig. 6-b). The buildings with URM 77/5 model situated in "Kombinat" area, periphery of Tirana have suffer moderate-heavy damages and fit quite well with analysis results;
2-) Other factors i.e.: damages from previous earthquakes (July 2018 Mw=5.2 and 21 September 2019 Mw=5.6), lower mortar quality, out-of-plane failure or unknown interventions, may have increase the damages, leading to the building collapse in Thumana.

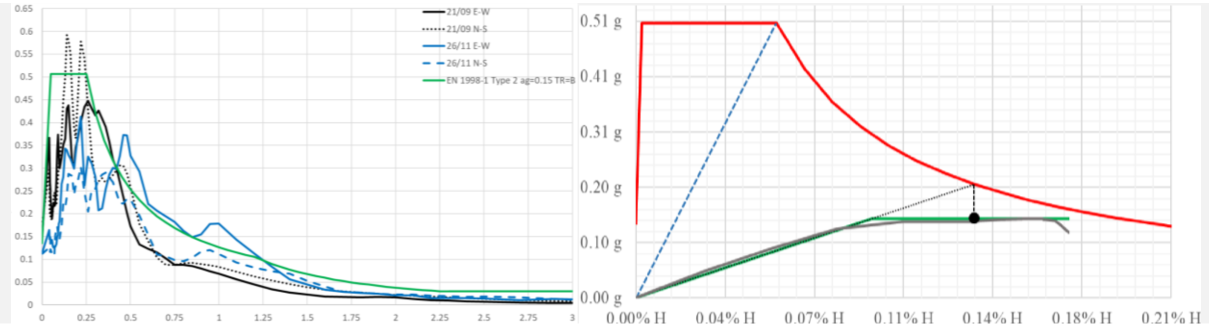

Fig. 6. Target displacement in ADRS format: a-) demand spectra fitting all 2019 earthquakes records in Tirana station (Type2, SC B and ag=0.15g); b-) target displacement (performance point) of the URM model 77/5

Another analysis - using as demand the Eurocode design response spectrum with seismic characteristics: Type1 Spectra, Soil Category C and ag = 0.248g (SZMA-ASH, 2010) – shows that the URM 77/5 model collapse. The fitting demand spectrum (Fig. 6-a) gives another important hint: Stiff structures (including URM 77/5 and other similar models) may have suffer more during Sep.21 than Nov.26, 2019 Earthquake.

2.2 Model 82/2 – Cast in place RC Model

From an architectural perspective, the RC 82/2 model was used even before 1982, but in most of cases with masonry structure. In 1982, this model was introduced initially as prefabricated RC moment frame, to be used for areas with seismic intensity 9 and in accordance with improved KTP-N2-78 code (ktp-n2-78-r, Janar 1982). The main building properties can be found in Table 2 and in the Fig. 7 is given the structural layout of original RC 82/2 Model (prefabricated or cast-in-place).

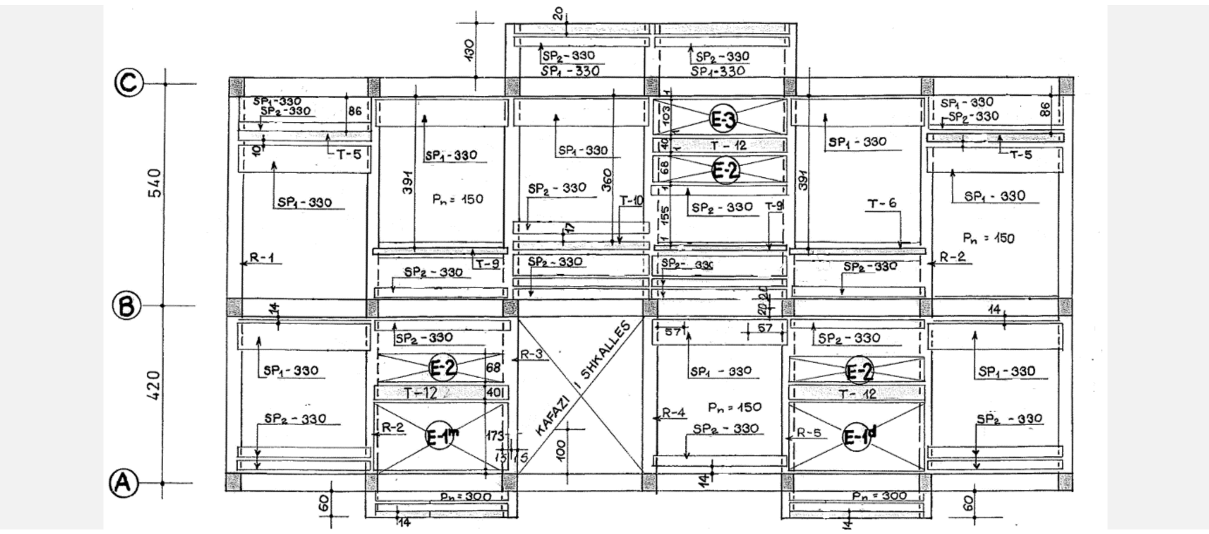

Fig. 7. Structural layout of original RC 82/2 Model (AQTN)

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From local technical office this model was proposed to be constructed as cast-in-place RC 82/2 Model in Durrës area, initially without any change in layout, number of storeys and element dimensions. The main change was related to concrete strength and the reinforcement percentage, Fig. 8. This model is regular in plan but with irregularities in elevation due to: a-) ground floor at least 1m higher than the other floors (masonry wall under +0.00 and tie beam at top of it is not uniform and doesn't have adequate stiffness); b-) immediately reduction of columns rebar percentage (Fig. 8-b.), and, c-) often infill walls exists only partially in the ground floor – often this floor is used for services. Moreover, in some cases infill walls distributed asymmetrically in ground floor affect also the plan regularity.

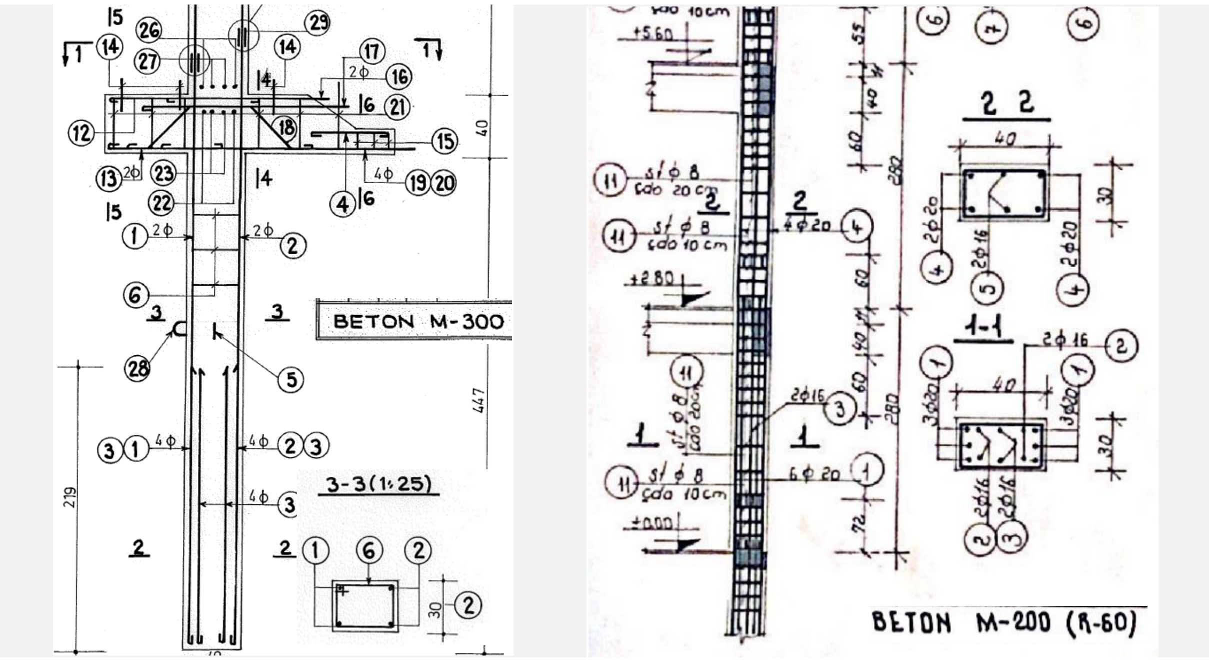

Fig. 8. Column material and details: a-) Prefabricated RC Model 82/2: Concrete C25/30; Rebar 4Ø18 (less than 1%); Single hoop Ø6.5/20cm; b-) Cast-in-place RC Model 82/2: Concrete C16/20; Rebar 6Ø20+4 Ø16 (2.2%); Single hoop Ø8/10/20cm

In different periods, previous and after '90, designs with several changes (in layout and/or number of stories) of cast-in-place RC Model 82/2 are proposed and constructed until year 2000. Hereunder, these modified cast-in-place models will be named M-RC 82/2 Model.

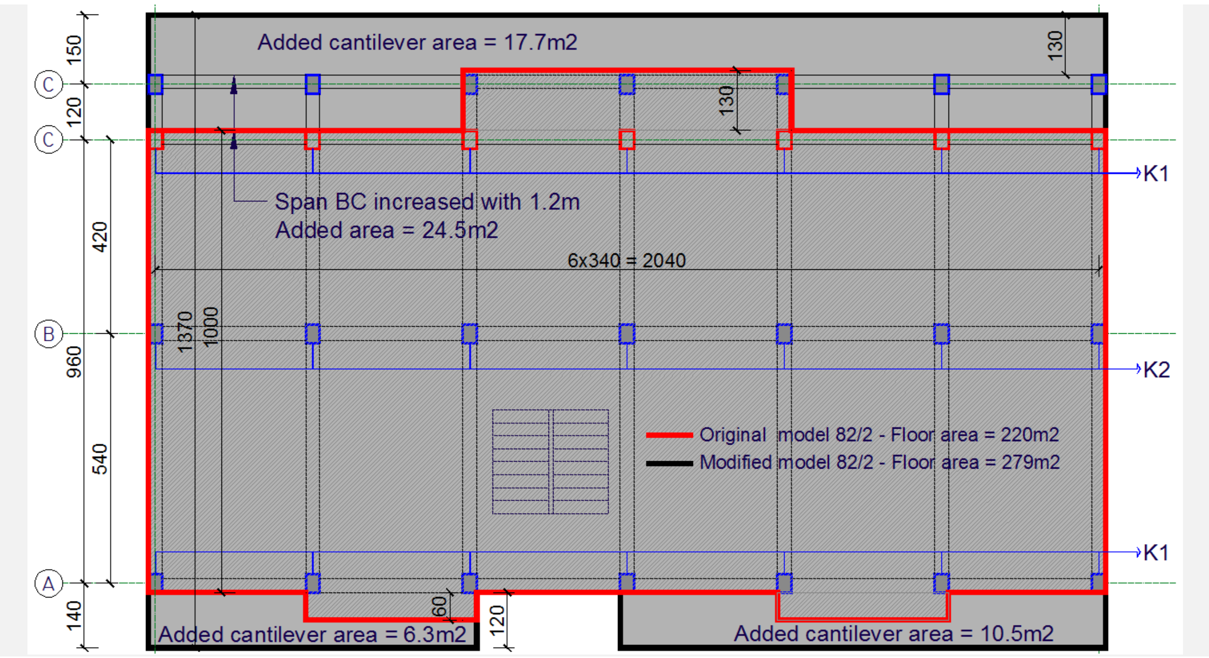

Fig. 9. Structural layout of RC Model 82/2: a-) Original model; b-) Modified model

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In Fig. 9 are given layouts of two cast-in place models: Original RC 82/2 and M-RC 82/2 with the extensive changes in layout, by increasing plan area with 26.8% and in elevation by adding generally one floor. In some cases these adding volumes are followed by increasing rebar percentage (generally in beams), but in most of them the columns reinforcement remain unchanged towards original cast-in-place RC Model 82/2.

In Durrës, two buildings with the M-RC 82/2 Model collapsed, both with "soft story" mechanism. One of them subsequently develop also pancake collapse. Heavy damages suffer most of cast-in-place RC Models 82/2, original and modified ones in Durrës area.

Fig. 10. Two cast-in-place M-RC 82/2 Model collapsed buildings: a-) pancake mechanism; b-) "soft story" mechanism

The damage patterns appears in cast-in-place 82/2 model are mainly concentrated on the ground floor: 1-) joint crush at the top of the ground floor; 2-) shear crack in columns and beams; 3-) columns buckling; 4-) failure due to high normal forces; 5-) diagonal cracks in the filling walls.

Damages and collapses on RC and M-RC 82/2 Model are connected with different issues:

1-) Cast-in-place RC Buildings for residential purposes just started massively in the beginning of '80 and the experience regarding their seismic behaviour have not been comprehensive. Most of damaged buildings during the earthquake of April 15, 1979 have been with masonry structure;

2-) KTP-N2-78 (1978) gives only few criteria for seismic details. Moreover, the cast-in-place concrete quality and the RC elements detail accuracy didn't results as required in design. Even in those cases when the design has foreseen seismic details beyond the KTP-N2-78 (or in accordance with KTP-N2-89) requirements, they have not been implemented;

3-) Both stiffness and resistance in longitudinal direction results smaller than in the transverse direction and "soft story" mechanisms are dominant in the longitudinal direction. This is also confirmed by calculations.

Summarising, the factors that have caused or increased the damages in the cast-in-place RC and M-RC 88/2 Model are:

- Poor concrete quality and inappropriate detailing's: a-) low concrete strength; insufficient dimensions for primary structural element; b-) low percentage of the longitudinal reinforcement

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and low volume ratio of the transversal reinforcement; c-) inappropriate reinforcement details: absence/deficiency of hoops in critical regions, deficiency in bar anchorage and lap-splicing, hoops bent not more than 90° and insufficient anchorage length into the concrete core; d-) inadequate stirrup/hoops amount and detailing in beam-column joints; e-) plain rebars;

- The severe reduction of the columns resistance above the ground floor – abrupt change in rebar percentage above ground floor;
- Insufficient stiffness and resistance in the longitudinal direction of the building;
- Prefabricated slab panels placed in one direction and without cast-in-place any top RC layer – no rigid diaphragm behaviour;
- Added floors and/or increased floor area without making appropriate structural verifications and design adaptions;
- Environmental factors deteriorating the qualities of the materials - is evident in the columns base. Lack of maintenance and possible interventions during the design working life.

Fig. 11. Columns damaged in six different cast in place RC and M-RC 82/2 Model

Based on the structural assessment carried out through pushover analysis, using material properties based on tests (checking also with those given in design) and comparing the structural capacity of the building with the seismic demand, the following main conclusions are noted and highlighted:

1-) Using as demand, the fitting demand spectrum comprising the 2019 earthquakes recorded at the Durrës station (Fig. 12-a), the RC 82/2 model suffer near-collapse (Fig. 12-b). The failure mechanism result soft story.

2-) The same demand is used also for the M-RC 82/2 model and the structure collapsed (Fig. 12-c). The failure mechanism is still soft story.

In both analysis the soft story mechanism is developed in longitudinal direction. Exist high possibility that the “soft story” mechanism to be developed in the first floor rather than ground floor, in those cases

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were columns rebar amount is immediately reduced above ground floor. In fact, one of the two collapsed RC Model 82/2 has developed soft story in first floor.

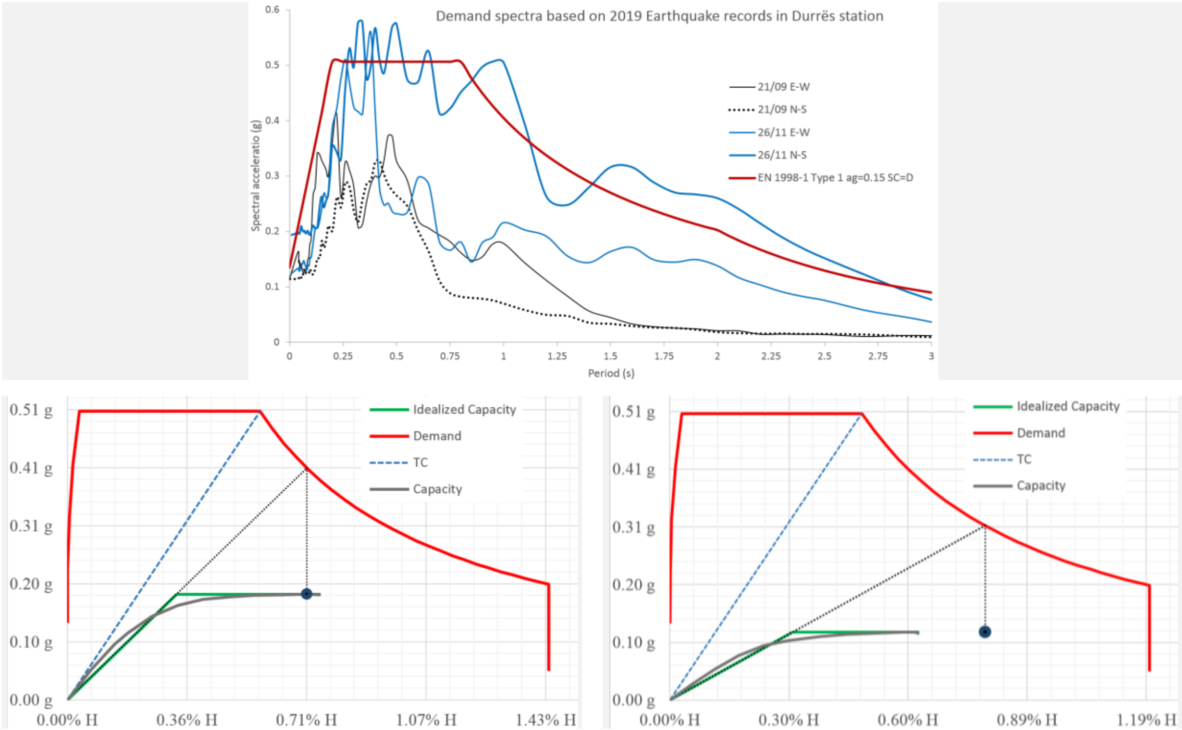

Fig. 12. Target displacement in ADRS format: a-) demand spectra fitting all 2019 earthquakes records in Durrës station (Type1, SC D and ag=0.15g); b-) target displacement RC 82/2 Model; c-) target displacement M-RC 82/2 Model

3 Findings and recommendations

The following findings and recommendations are based on the observation of damages after the 2019 earthquakes and on the assessment carried out, analysing each building as well as other similars.

3.1 Findings

Buildings heavily damaged and/or near-collapsed by November 26, 2019 Earthquake are the result of one or more of the following factors:

1-) Are located in areas where the seismic action has been higher than that foreseen in the seismic code. There are buildings in Tirana, Thumana and other areas which have been designed and constructed with low seismic action or without (areas with seismic intensity VII or lower previous to 1979) than what results from the 2019 earthquakes;

2-) Although significant previous earthquakes (especially those of April 15, 1979 and January 8, 1988) have taught valuable lessons, producing instantly recommendations for new design and construction processes, there are no clear evidences demonstrating that these findings have been used for retrofitting of the existing building stock;

3-) Due to their fundamental vibration period, URMs were moderately damaged during the September 21, 2019 Earthquake. Further, during the 26 November 2019 earthquake, their damages increased and in some cases these buildings collapsed;

4-) Different typologies of the building stock, URM or RC, show limited seismic capacity as a result of the combination of the following factors:

- Structural irregularity in plan and/or height;
- Low materials quality (concrete for RC and mortar for URM);

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- Unsuitable construction details for buildings situated in areas resulting with moderate to high seismicity: for URM – weak pears and spandrels, one direction slabs panels and lack of connecting ties beams; for RC - inadequate element dimensions and critical regions confinement and inadequate shear resistance for columns, beams and beam-column joints;

5-) Building interventions performed without taking the necessary structural verifications (and eventual retrofitting). The most common interventions: a-) adding floors; b-) lateral extensions and opening in structural masonry walls, especially in the ground floor in case of URM buildings;

6-) An essential factor have been also the workmanship and their competence during the execution process, since many buildings are constructed based on voluntary work. Adequate execution of details affect directly the seismic building capacity.

3.2 Recommendations

Based on three building typologies analysed above and findings, some recommendations are summarized and listed following:

1-) Typified building (models URM 77/5 and RC 82/2 or M-RC 82/2) – located in the earthquake-affected areas and in other areas with high seismic risk – need to be fully assessed and after a unified retrofitting strategy is necessary to prepare for each model. The retrofitting interventions should be comprehensive: unified solution for typified buildings and special instructions for those cases where buildings are constructed with some differences from "prototype" and where quality of materials, maintenance, environmental or soil conditions, etc. induced extra effects;

2-) An improved typified design has been drafted for the model 77/5 after the April 15, 1979 Earthquake. The performance of buildings with improved model 77/5 during the 2019 Earthquakes should be assessed carefully in order to check the effectiveness of the improvements and to considered them during retrofitting strategy for buildings with unimproved model;

3-) The following vulnerable elements should be remember for retrofitting of the 77/5 model: the low quality of the mortar (when documented); connection unit with high damage potential; low resistance of piers and spandrels; the missing diaphragm behaviour of the slabs and their connections to the masonry walls; large spacing and lack of uniformity of some transversal walls;

4-) For the assessment of the RC 82/2 models it is recommended to follow also these steps: a-) Verify the compatibility of the in-situ building with the typified model, since in many cases are present additional area, cantilever in each floor or added storey on the top of the building; b-) checking material strength and the condition of RC elements, especially the concrete deterioration and rebar corrosion; c-) assessing the existing capacity, paying special attention to: the longitudinal direction capacity, shear capacity, soft story mechanisms in ground and first floor, infill walls and one direction panel slabs.

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