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Damage observed in structures of different types during the inspection after the Durrës earthquake of 26.11.2019 and proposals for their repair

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Abstract: During the inspection of various construction structures such as: school buildings, houses, multi-storey buildings, etc. of different structural systems after the Durrës earthquake of 26.11.2019, various damages were observed in structural and non-structural elements. Damages were of various natures such as: defects during the implementation of structures, defects in the quality of materials, construction of additional floors on existing ones, use of structures with poor ductility such as massive masonry systems, negligence of supervision or construction without supervision, etc. In reinforced concrete structures, damage to the ground floor columns (mainly in plastic hinge regions), damage to the protective layers of the reinforcement and the presence of corrosion in the reinforcement, collapse of the masonry fillings, etc.; in massive masonry structures, diagonal cracks in the walls, partition in the corners at the connections between the walls, and at the connection of the wall with the ceiling tile have been observed. Some of the retrofit and repair methods that can be used to strengthen existing structures are: reinforced concrete jacketing, steel confinement, FRP wraps, FRP rebars, etc.

***Keywords**: Structure, damage, reinforced concrete, masonry, retrofit*

Introduction

On November 26, 2019 in Durrës, Albania, a strong earthquake with magnitude 6.4 occurred with an epicenter 16 kilometers southwest of Mamurras. After the earthquake, several days of visits were made to the areas affected by the earthquake to assist in the preliminary assessment of damage to construction structures. The inspected areas were the area of Lushnja and Divjaka to inspect school buildings, the area of Thumana for inspection of residential houses, the area of Sukthi i ri for inspection of residential houses, and the zone-IV of Durrës for inspection of residential buildings, as well as some structures in coastal areas. During the visit, about 7 school buildings were inspected, where most of them were built with a masonry structure, except for one that had a flexible structure made of reinforced concrete; about 54 residential houses with different construction systems such as those with masonry structures, reinforced concrete combined structure with brick masonry and flexible reinforced concrete structure; as well as some buildings with flexible structure in some areas of Durrës. During the inspection, various damages were noticed in both constructive and non-constructive elements. The damages observed in the rigid masonry structures were: cracks in the joints at the corners of the masonry walls, cracks between the openings of masonry walls, out-of plane of masonry wall, detachment between the ceiling and the masonry as well as diagonal cracking in the plane of the masonry walls; in combined systems, diagonal cracks in the walls, removal of the wall from its plane, demolitions in concrete pillars, etc.; In flexible systems are mainly observed damages to the lower and upper joints of the ground floor columns (mainly in plastic hinge zones), removal of the reinforcing protective layer, etc.; also major damages to non-structural elements has also been observed, especially in masonry infillings of flexible structural systems.

Overview of structures of different types damaged by the earthquake

Inspected schools structures in the area of Lushnja and Divjaka were built in old times and mainly with construction systems known for that time, such as rigid system with masonry walls. As it is known at the time when these structures were built the seismic design code was not considered or little considered, also these building systems are structures with low ductility and not suitable for seismic areas. Some of the damages observed during the inspection of these structures were: diagonal cracks in the openings, cracks in the corners where the walls are connected to each other and disconnection between the ceiling structure and the masonry walls.

Figure 1. Damages to the school of Karbunare and Hysgjokaj of Lushnja

During the inspection in the village of Bushnesh in the area of Thumana, Thuks i ri, IV zone of Durrës and some coastal areas, various structural construction systems were encountered, such as those with rigid masonry wall structures, systems combined with reinforced concrete and masonry walls, as well as flexible reinforced concrete systems. The height of these inspected residential buildings was from those with only ground floor to those with B + P + 4 storeys. The structure of the single-storey houses was built of stone foundations, masonry of bricks, ceilings of wooden elements and plank fillings, as well as the roof of the wooden structure; while the tiles in the buildings with masonry structure with larger floors were made of reinforced concrete reinforced concrete. Some of type of damages observed in these types of structures were: large diagonal cracks in the masonry walls mainly at the corner connections, in-plane diagonal shear cracks of spandrel panels, vertical overturning due to lack of roof-to-wall connection, etc. These damages are mainly due to the construction system which does not withstand the earthquakes loads taking into account the characteristics of the material used as well as the construction method. Figure 2 shows some of the damage observed during inspections.

Figure 2. Damages of residential buildings with masonry walls structural system

The structures of the inspected houses in the area of the Thuks i ri of Durrës zone were built with rigid masonry construction systems (stone foundations, brick masonry walls, wooden ceilings or concrete slabs), combined structure from reinforced concrete and brick masonry, and flexible reinforced concrete structure. The storeys of these houses were different, such as: ground floor only (GF + 0), GF + 1, GF + 2, B + GF + 1 and B + GF + 2 storeys. Some of the damages observed in the rigid masonry wall systems were large cracks in the masonry walls, mainly at the connections walls at the corners, at the door and window openings, as well as a detachment of the ceiling structure with the vertical masonry wall structure. Some of the damages observed in flexible systems were cracks in the ground columns and removal of the protective layer of the reinforcement, diagonal cracking in the masonry fills between the openings, out-of plane of masonry infill walls, etc. Figure 3 below shows some cases of damages of residential buildings with flexible structural system, especially damages in ground floor.

Figure 3. Damages of residential buildings with flexible structural system in IV zone of Durrës

In addition to structural defects, during inspections in the mentioned areas, large damages were observed in the non-structural elements of residential buildings. Masonry wall fillings in many of the structures have cracked a lot and many of them have fallen from the buildings. These major damages have occurred as a result of poor execution of these walls, such as: non-application of reinforced concrete rings due to their height, poor connection of walls at their corners, or in certain cases non-application of tie columns, etc. Figure 4 below shows some cases of large cracks in the masonry fills as well as their falling from the building structure.

Figure 4. Failure of infill walls of residential structures.

Reconstruction and repair methods that can be used to reinforce existing structures

Some of the retrofit and repair methods that can be used to strengthen existing structures damaged from earthquake are: reinforced concrete jacketing and steel confinement for flexible structure systems; reinforced concrete rings, reinforced concrete layer, FRP wraps and FRP rebars for masonry wall structures, etc. Reinforced concrete jacketing is considered as the most common technique for repairing and strengthening of deficient and/or damaged RC columns (Figure 5). In general, this technique is a practical solution to recover and improve the load-carrying capacity and stiffness of reinforced concrete columns in earthquake-prone countries. It is a simple method that can be applied to any column cross section for rehabilitating structural elements by encasing the old member in a stiff jacket. The steel jacket retrofit is also a method that can be used to enhance the shear strength and ductility of square reinforced concrete (RC) columns in existing buildings (Figure 6). For the masonry wall structures applying of reinforced concrete rings and tie columns for strengthening of them is more difficult, so easiest method is to use FRP wraps or FRP rebars (Figure 7, 8 and 9). They are ease of applications and corrosion resistance, as well as enhances out-of-plane flexural capacity of the wall, strength and ductility.

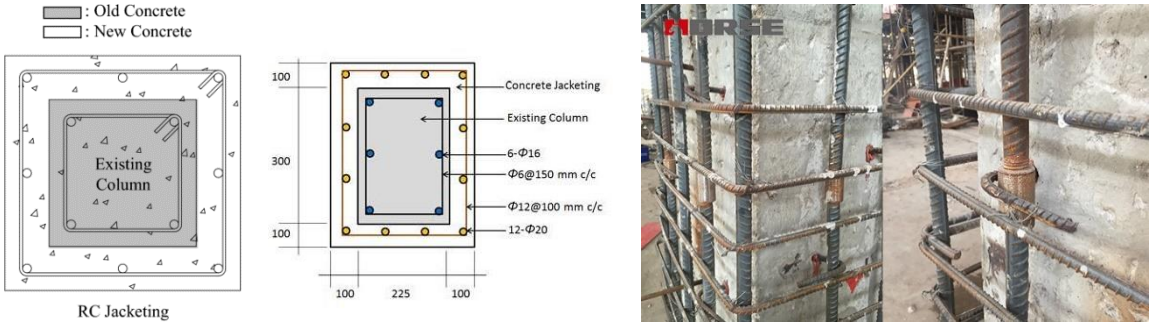

Figure 5. Concrete jacketing strengthening method

Figure 6. Steel jacketing strengthening method

Figure 7. Placement of FRP wraps strengthening method for masonry wall structures

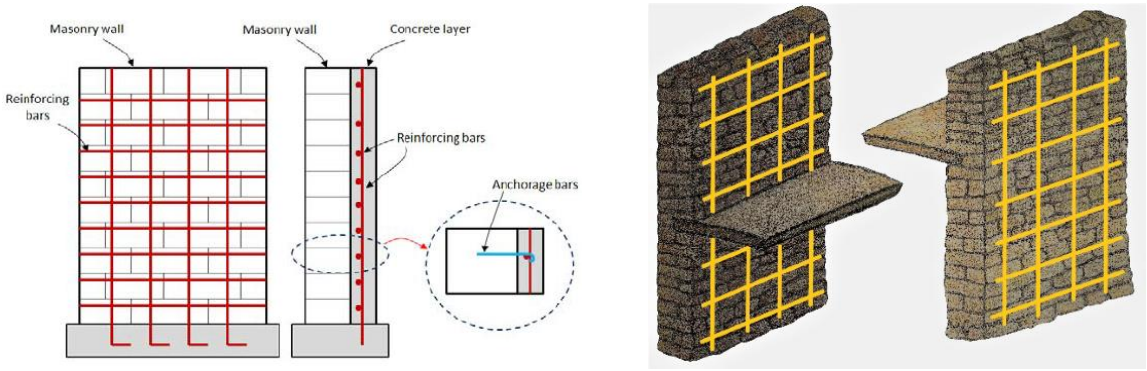

Figure 8. Placement of reinforced concrete layer (left), and FRP rebars (right) strengthening method for masonry walls

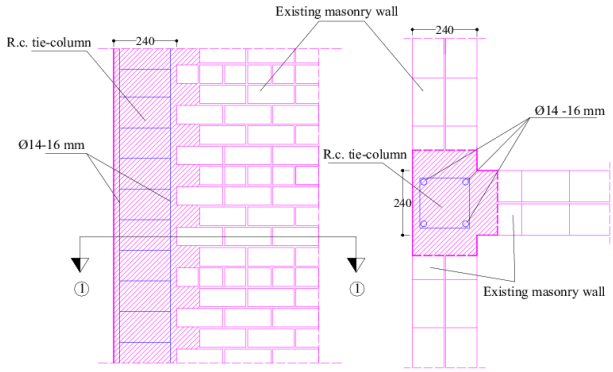

Figure 9. Application of tie-column in masonry walls

Conclusion

From the research mentioned above we can draw some conclusions about the possible causes that have led to major damage to the inspected structures can be: constructions made with non-respected standards, seismic design code was not considered or little considered at the build time, construction of additional floors on existing structures, used materials of poor quality (concrete in reinforced concrete structures), use of materials with poor ductility (case of masonry structures), as well as defects during implementation of structures.

Most of the inspected structures can be retrofitted and continue to be used. Some of the methods that enhance strength and ductility and which can be used are: reinforced concrete jacketing, steel jacketing, FRP wraps, FRP rebars, etc. Using of these retrofitted methods depend from structure type and and the material from which it is constructed.

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