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Reinforcement Application Techniques in Earthquake Damaged Buildings Caused at Central Part of Albania

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Abstract

In November 2019, the central part of Albania experienced an earthquake with a magnitude of Mw=6.4. The earthquake caused significant damage in the affected areas, including collapsed buildings, infrastructure damage, and loss of life. The cities of “Durres” and “Thumane” were particularly affected, with numerous buildings and apartment blocks collapsing or sustaining severe damage. Furthermore, numerous techniques have been employed for the rehabilitation of damaged masonry buildings in Albania. The rehabilitation process in the affected areas has yielded some successful outcomes. This article aims to describe the different techniques used for reinforcing damaged masonry structures following the Durres earthquake, including their respective advantages and disadvantages.

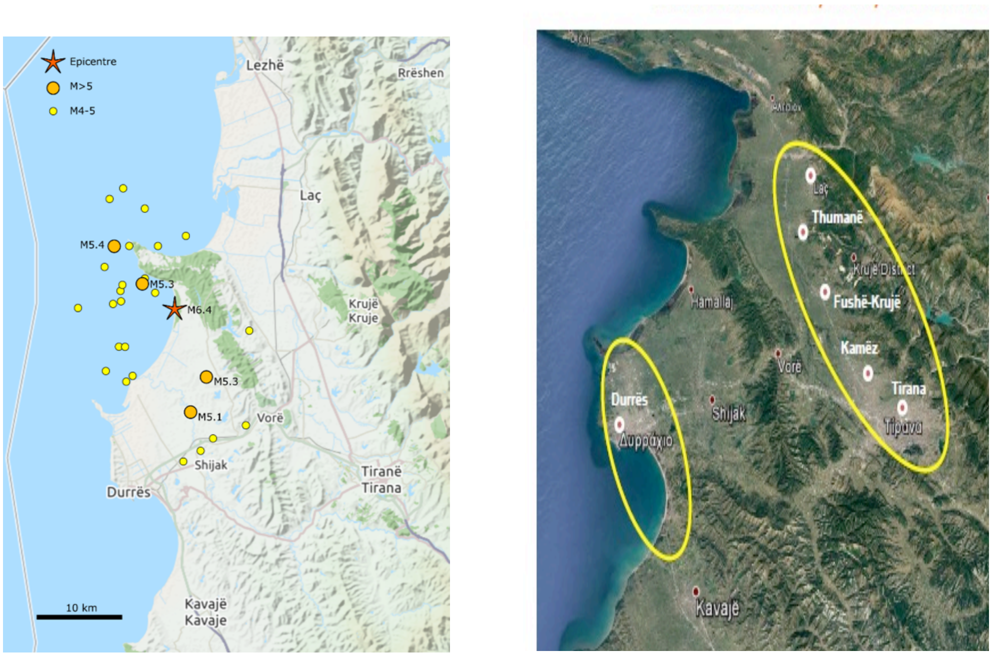
Keywords: Masonry structures; earthquake damaged buildings; reinforcement; replacement; fibre reinforcement polymers materials.

1. Introduction

In November 2019, Albania experienced a devastating earthquake that had a profound impact on the country. Striking on November 26, this powerful seismic event shook the region and left behind a trail of destruction. With a magnitude of 6.4 on the Richter scale, the earthquake's epicentre was located near the coastal city of “Durres” in western Albania, see Figure 1.

The earthquake unleashed its destructive force, causing widespread damage to buildings, infrastructure, and communities in its path. The cities of “Durres” and “Thumane” bore the brunt of the devastation, with numerous structures collapsing or sustaining severe damage as can be seen in Figure 2. The event resulted in a significant loss of life, injuries, and displacement of thousands of people.

While the earthquake's immediate impact was tragic, the focus soon shifted to the recovery and reconstruction efforts [1, 2]. The recovery process involved not only physical reconstruction but also addressing the emotional and psychological needs of those affected by the earthquake. Temporary housing solutions were established, and measures were taken to improve the seismic resilience of buildings and infrastructure in the affected areas. Based on the lessons learned from the past three years' experience in repairing and strengthening masonry buildings, it is evident that the selection of reinforcement techniques plays a crucial role in achieving favourable outcomes. In Albania, ample information has been gathered to support the informed choice of compatible materials and techniques for the repair and reinforcement of earthquake-damaged buildings.



(a) (b)

Figure 1. (a) Location of epicentre and the aftershocks in the first days of the 26 November Earthquake (b) the most affected areas from the Earthquake

(a) (b)

Figure 2. The damaged columns of concrete structures (a) internal view (b) external view, located in Durres city

The knowledge gained from the recent earthquake has enabled professionals in Albania to make well-informed decisions regarding the appropriate materials and techniques for repairing and reinforcing structures affected by last seismic events [1-4].

A comprehensive understanding of the building history, geometry, structural details, crack patterns, wall construction techniques, materials, and material properties is crucial at this stage. This knowledge can be acquired through on-site visits, laboratory experimental investigations, structural analysis using appropriate models, and final diagnosis, see Figure 3.

(a) (b)

Figure 3. (a) Testing process and (b) laboratory investigation in situ, located in Durres city

Various techniques can be considered, and the optimal one can be selected based on factors such as the best intervention compatible with the available budget while ensuring the building's safety [1]. This entails using new materials for repair and strengthening that are chemically, physically, and mechanically compatible. Presently, the need for rehabilitating and repairing damaged masonry and concrete buildings provides an opportunity for the application and experimentation of both traditional and advanced techniques. This research work aims to describe the different techniques used for reinforcing damaged masonry structures following the Durres earthquake, including their respective advantages and disadvantages.

2. Methodology and Interventions Techniques

During the selection of materials or technologies for reinforcing and strengthening damaged structures, it is essential to consider the compatibility between the new and original components of the buildings. In the case of Durres, an intriguing option was the utilization of both traditional/innovative materials and techniques. Traditional materials often exhibit compatibility with the original damaged parts of structures, as they possess similar properties that allow for effective integration. In this research work, interventions techniques have been focused on external reinforcement technique and the usage of fibre reinforcement polymers (FRB) materials.

2.1 External Reinforcement or Jacketing

One important approach for enhancing the strength, capacity, and stiffness of existing damaged structures is to apply high-performance materials on their exteriors. This method involves the use of reinforced concrete jacketing, which entails applying a layer of high-performance material around the existing structural element [5-9]. It was primarily implemented to stabilize compression-loaded elements like pillars and columns as can be depicted in Figure 4. The objective was to provide continuous confinement, thereby enhancing the strength and stiffness of the structural elements.

(a) (b)

Figure 4. The process of jacketing in two damaged columns in one hotel in Durres city

The jacketing of masonry walls can be implemented using fully non-invasive and removable techniques. However, it should be noted that this approach is obtrusive as it conceals the original masonry behind the new material, see Figure 5. The connection established between the covering and the original material produces a reinforcing or enlarging effect. In some cases, the jacketing may not be easily removable, and compatibility issues can arise when the confinement material is significantly stiffer than the original material. Additionally, the creation of an external waterproof barrier may hinder the natural perspiration of the original masonry or stone, presenting further challenges [6, 7].

(a) (b)

Figure 5. Jacketing process of masonry walls in the underground floor (a) step 1 and (b) step 2

2.2 Structures Reinforcement using FRP Materials

The strengthening technique involves the incorporation of high-performance materials with substantial tensile strength, such as Fiber Reinforced Polymer (FRP) materials. FRP encompasses various types of fibers, including Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), and Aramid Fiber Reinforced Polymer (AFRP), embedded within a continuous polymer matrix as can be seen in Figure 6. FRP materials possess advantageous characteristics, such as lightweight, excellent durability, high strength, and ease of installation. These properties have rendered FRP materials highly attractive for the rehabilitation and strengthening of both reinforced concrete structures and unreinforced masonry structures in the Durres area.

(a) (b)

Figure 6. The process of reinforcement of a concrete slab using FRP Materials (a) step 1 and (b) step 2

3. Reinforced building application

The presented case is a 2-story masonry structure with reinforcing beam-column system of 216 m^2, located in Durrës area as can be seen in Figure 7 and 8. The building was damaged during the earthquake and evaluated by the authors for seismic capacity. Due to the moderate to mid-damage to structural system, the building was classified for retrofitting techniques. The following ones has been applied to the building:

- Jacketing of the reinforced concrete columns
- Reinforcing of the beams with FRP technique
- Reinforcing of the shear walls with jacketing technique
- Partial reinforcing of foundations

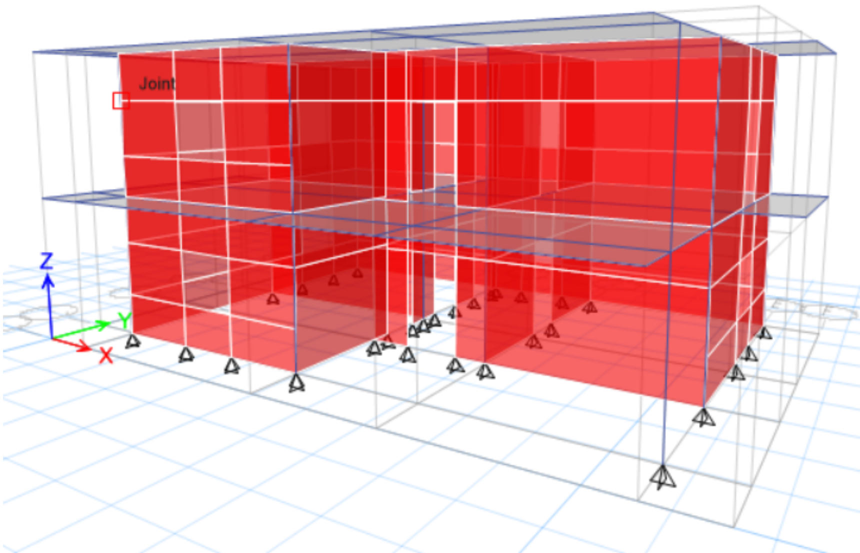


Figure 7. Building model before reinforcement, located in Durres city

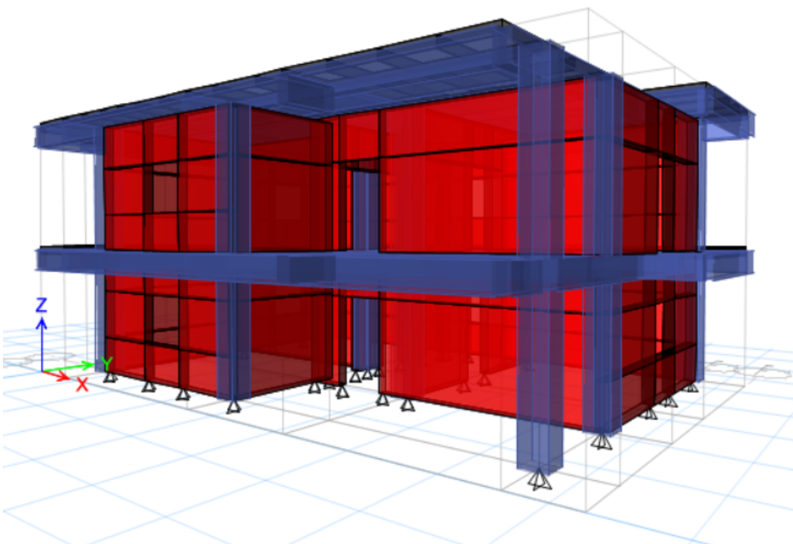


Figure 8. Building model after reinforcement, located in Durres city

The building models were subjected to pushover analysis and the capacity curves are generated for both. The seismic capacity of each model is then evaluated as the EN-2 method and the capacity are compared for both in the figures and tables below:

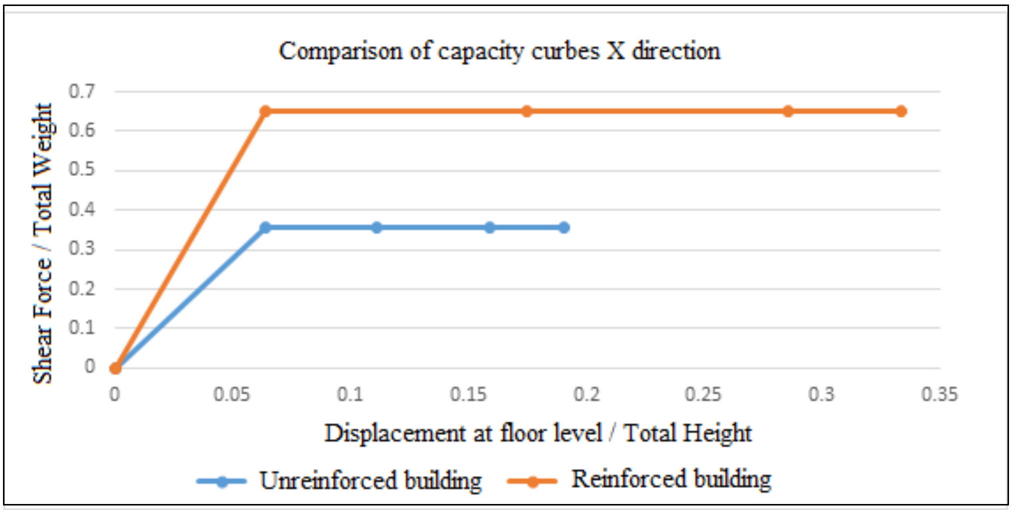


Figure 9. Comparison of capacity curves, X direction

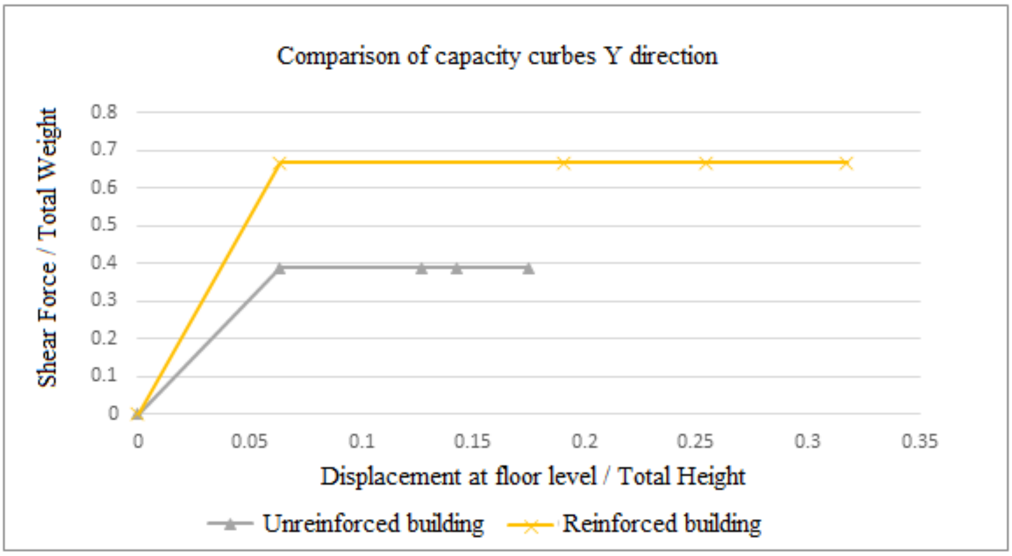


Figure 10. Comparison of capacity curves, Y direction

Furthermore, the building after the intervention has increased capacity against horizontal and vertical loads. The main reason is to build a proper beam-column frame system, which better absorbs and redistributes horizontal loads during a seismic event. In terms of maximum horizontal bearing strength, the capacity of the structure has increased by over 80% (from 0.35 to 0.65). The stiffness has increased significantly, where its values have increased by about twofold (from 1057 to 2502) according to both directions. Table 1 depict the comparison of global mechanical characteristics of the building before and after reinforcement.

Table 1. Comparison of global mechanical characteristics of the building before and after reinforcement

Building	Maximal shear force/ Weight of building (%)		Stiffness (kN/m)		Ductility (%)	
	X	**Y**	**X**	**Y**	**X**	**Y**
Before	35.61	38.97	1057	1157	3	2.75
After	64.87	66.88	2502	2580	5.25	5

4. Results and Discussion

Several types of structural reinforcement techniques were implemented in the areas affected by the November 26, 2019 Durres earthquake. A summary of reinforcement techniques for masonry and concrete structures, along with their respective advantages and disadvantages, is provided below:

- Increase in the strength of masonry components. Effective in preventing water penetration through joints and reversibility depends on the mortar used.
- Restoration of continuity in multi-leaf wall sections. Enhances the strength of the elements.
- Increased stability and integrity of the structure. Improves the overall structural behaviour.
- Prevention of water penetration through cracks and voids.
- Risk of corrosion if proper reinforcing bars and adequate cover are not provided.
- Irreversibility and high invasiveness. May result in eccentricity under dynamic loading due to increased stiffness at the element where applied.
- FRP materials is sensitivity to heat and radiation. Bond loosening due to moisture in FRP strengthening.

5. Conclusions

A general overview of the main reinforcement techniques used in the areas affected by the Durres Earthquake reveals various types of interventions. Most of the research conducted focuses on the mechanical aspects of these techniques. It should be noted that certain intervention techniques can lead to significant modifications in the original structural behavior. Although these techniques are considered "in principle correct" since they contribute to improved resistance, seismic load redistribution, and ductility, there are limitations associated with the theoretical models used. Consequently, accurately predicting the real behavior of strengthened structures becomes challenging. Certain intervention techniques of this nature, such as substituting floors and roofs with reinforced concrete slabs can result in substantial structural changes.

Conflict of Interest

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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