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# Optimizing Retrofit Strategies for RC Frames through Combined Techniques

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**Abstract**

Over the past twenty years, researchers have directed their efforts towards enhancing the earthquake resistance of concrete frames through repair and retrofitting. Two main approaches have emerged for bolstering the seismic resilience of previously intact structures prior to earthquake exposure. The first involves augmenting the existing structure with additional components like steel bracing, while the second entails reinforcing specific structural elements, such as employing steel cages. Seismic response analyses have been conducted on multi-story reinforced concrete (RC) frames originally designed without seismic considerations. This study aims to assess the effectiveness of retrofitting techniques by comparing the outcomes of employing steel braces, steel cages, and their combinations. The seismic performance is evaluated according to the RPA 2003 seismic code for Algeria, following the latest guidelines. Static nonlinear analysis was utilized to compare the seismic responses of existing non-ductile RC frames under various retrofitting schemes.

**Keywords:** RC frame; Retrofit; Steel bracing; Steel-cage technique; Static non lineaire.

## 1. Introduction

The majority of structures constructed before the 1970s were primarily engineered to withstand gravitational forces. While these buildings demonstrated sufficient resilience against vertical loads, their ability to withstand seismic forces remained uncertain. Recent seismic events, notably the earthquakes in Taiwan (1999) and Algeria (2003), resulted in considerable damage to buildings. Many reinforced concrete structures collapsed during these earthquakes due to their failure to adhere to contemporary seismic regulations. Common deficiencies included inadequate detailing, fragmented load paths, and insufficient capacity design provisions.

To enhance the seismic resilience of existing undamaged structures prior to seismic exposure, two primary retrofitting approaches have been identified. One involves incorporating new structural elements like structural walls or steel bracing, while the other entails strengthening deficient structural elements selectively, utilizing methods such as concrete or steel caging and fiber-reinforced polymers. Steel bracing is commonly employed in retrofitting RC frames, proving efficient and cost-effective in resisting lateral loads. Several studies have investigated the effectiveness of steel bracing in increasing shear resistance capacity, although challenges persist in architectural detailing and connecting steel bracing to RC frames. . Among the first studies on retrofitting using this technique were [1, 2]. Model tests have also been reported in [3]. Their study indicated the effectiveness of this method in increasing the shear resistance capacity of the structure. Two of the flaws of this method are architectural details and difficulties making connections between the steel bracing and the RC frames. Authors in [4] performed experimental studies on the pushover response of scaled RC frames braced with both diagonal and knee bracing systems. Authors in [5] investigated the seismic behavior of RC frames reinforced with various steel bracing systems, including X, inverted V, ZX, and Zipper systems. By adding bracing, they were able to improve deformation, strength, and ductility. It was found that X and Zipper bracing systems perform better than others. Authors in [6] examined the use of hysteretic dampers and column strengthening to develop the desired behavior of buildings with an open first floor. Authors in [7] studied the impact of retrofitting RC frames with steel X-bracing on the global behavior of the frame, including its global displacement, performance level, and inter-story drifts. Similarly, the authors in [8] analyzed the seismic response of steel X-bracing numerically and concluded that it greatly reduces the shear loads on the beam-column joint. The maximum lateral displacement in RC frames is also reduced by retrofitting them with X-braces. In the tests conducted in [9], the joint displayed excellent self-centering properties without deteriorating in strength. The application of friction dampers to a self-centering PC frame was also studied for seismic retrofitting of reinforced concrete structures. A recent study [10] found that disk springs could provide self-centering capabilities without the drawbacks associated with post-tensioned tendons.

The steel caging method is generally favored because of its high retrofitting effectiveness and economic efficiency [11-12]. Authors in [13-16] first applied the steel-cage retrofitting method for bridge columns in California. Authors in [17] studied the efficiency of rectangular solid steel caging and partial steel caging. Authors in [18-19] described the effect of a partially stiffened steel caging and composite prefabricated jacket on improving the strength and ductility of RC columns. Recently, authors in [20] suggested an extension of the previous works, introducing a new genetic algorithm that minimizes the cost of seismic upgrading. In the current study, a structure that was designed without seismic design criteria was retrofitted with three techniques: steel caging technique, steel bracing system, and their combination were studied and examined. The seismic performance of these frames was determined by nonlinear static pushover analysis.

## 2. Description of different retrofitting procedure

### 2.1. Steel caging technique

The application of steel caging in RC columns aims to the increase the shear strength, the strengthening of the lap-splicing region and ductility capacity. The steel caging option involves the total encasement of the column with thin steel plates placed at a small distance from the column surface, with the ensuing gap filled with non-shrink grout

**Figure 1.** Retrofitting of RC frames with steel caging [21]

### 2.2. Steel bracing

Steel bracing can be a very effective method for global strengthening of buildings. Some of the advantages are the ability to accommodate openings, the minimal added weight to the structure and in the case of external steel systems minimum disruption to the function of the building and its occupants.


**Figure 2.** Retrofitting of RC frames with steel bracing [31]

## 3. Description of frame models

A five-story RC building has been used in this study (Fig. 3). The slabs were represented in the structural model of the building using their weight in the gravity load case and as concentered masses at all joints, with bay lengths of 4 m and height of 3 m. The building was designed without seismic design criteria, and is located in a high seismicity region with a peak ground acceleration of 0.32 g. Table 1 shows the details of the design sections, where the characteristics of the original frame and the reinforcement of the beams and columns were determined according to the Algerian seismic code, (RPA 2003).

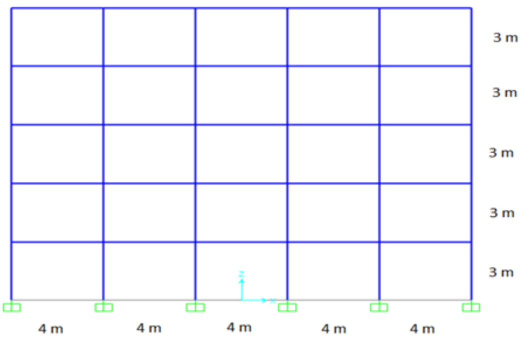



**Figure 3.** Structural model

| AA | Details of columns | Details of beams |
|---|---|---|
| Original Frame | 30×30, 3T12, 3T12 | 30×30, 3T12, 3T12 |
| RPA Frame | 40×40, 8T14 | 30×50, 3T16, 3T16 |

**Table 1:** Reinforcement's details.

To retrofit the structures with the bracing system, it is necessary to have studied the influence of variation in the section of the bracing element and different bracing systems (X, V, Zipper and ZX). Fig. 4 shows the RC frames retrofitted with different steel bracing systems

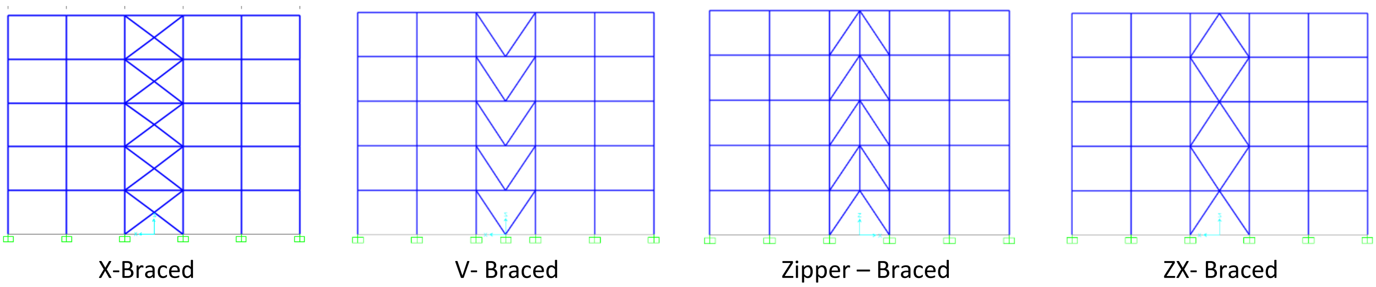



**Figure 4.** Bracing models

To retrofit the structures with steel caging technique, it is important to have investigated the impact of retrofitting vertical and horizontal bays with steel caging. The figures 5 and 6 shows the retrofitting details and the models of retrofitting vertical and horizontal bays with steel caging respectively.

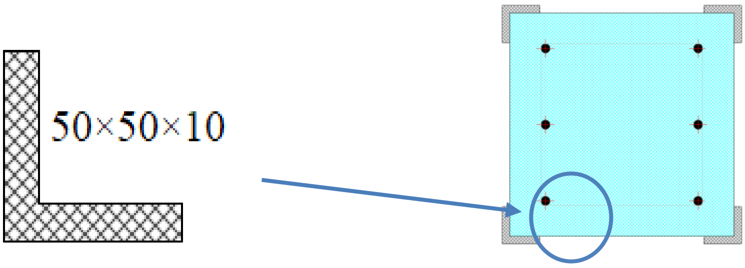



**Figure 5:** Retrofitting details with steel caging

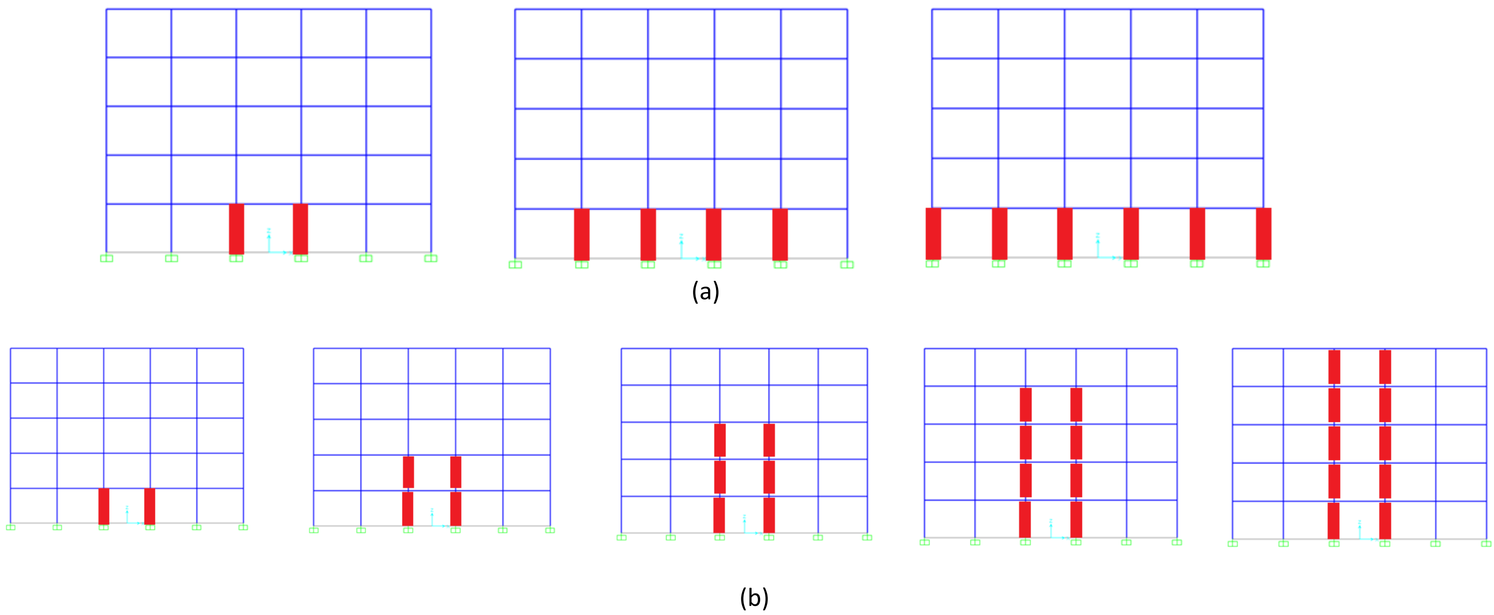



**Figure 6 :** Reftrofitting with steel cage (a) horziontal bays (b) vertical bays

**4. Results and Discussions**

**4.1. Pushover Results of the Original and RPA Frame**

Butts of reinforcement of the structure is to increase the capacity of resistance has shearing and the ductility of the original frame until to the capacity of new the structure calculating by Code RPA, to wait this butts in has to start with an analysis nonlinear static to know esteem between the two capacity of the structure (Original and RPA), and follows from there choose the type of reinforcement. The figure 7 represent comparison between two curve of capacity of the original frame and the RPA in remark that the base shear of structure new is larger with (5%, and the ductility is larger 58%.

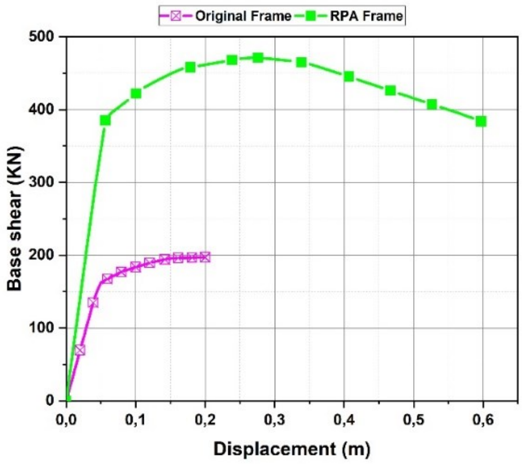



**Figure 7.** Curve of capacity for Old end RPA structural.

### 4.2. Pushover results for different system of retrofitting

The results show that when the bracing section is increased, ductility is decreased and strength is increased. The behavior of the different systems is much stiffer. The results show that the section of D76.1×3.2 for all the bracing systems except the X system gives a behavior close to the RPA frame with reference to the lateral load

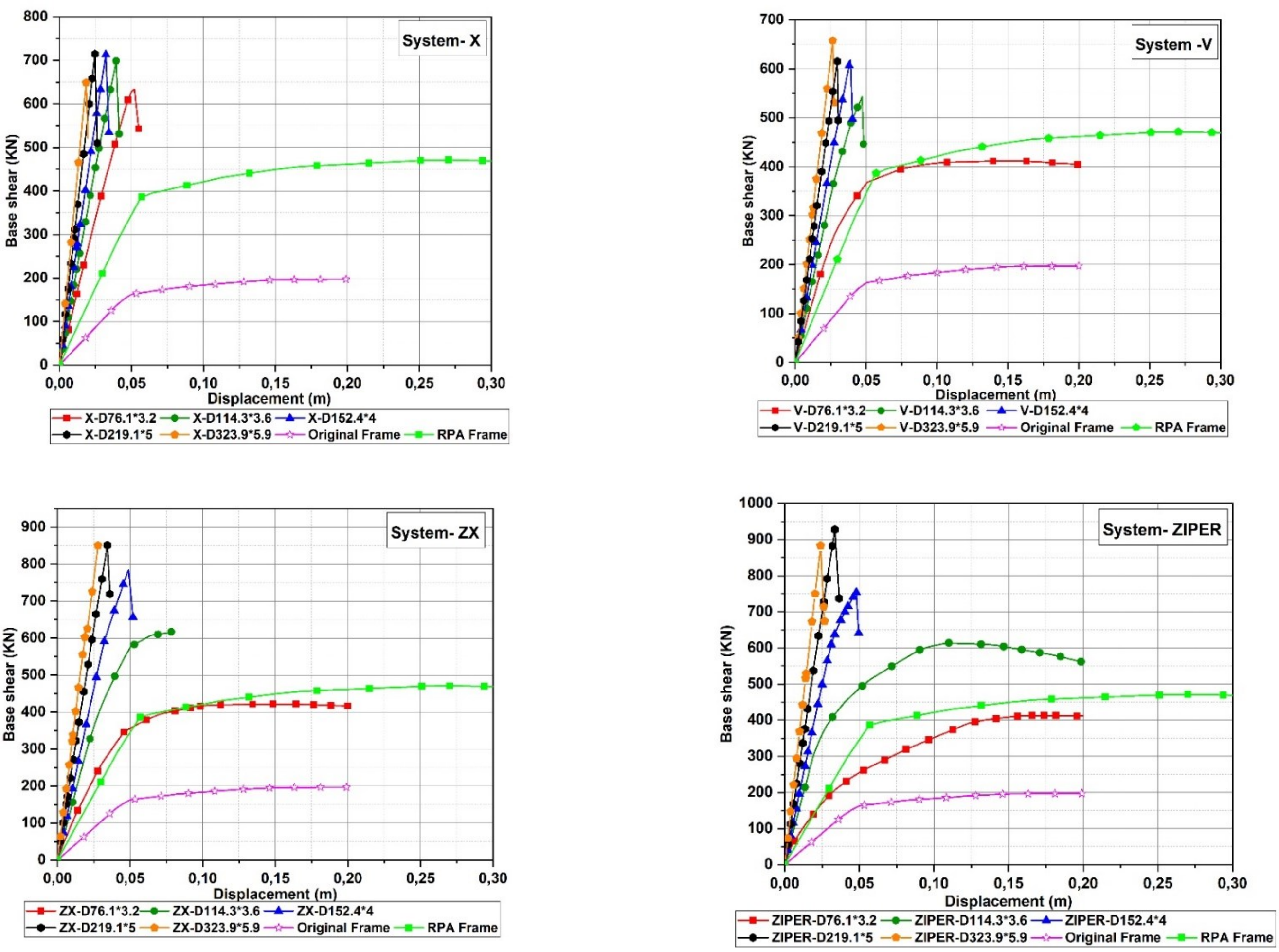



**Figure 8.** Lateral load–displacement response retrofitting with different steel bracing system (System X-V- ZX- ZIPER).

### 4.3. Pushover Results for Steel Caging Technique

The results show that whatever the reinforcement of the structures, whether horizontal or vertical, the ductility is almost identical to the RPA frame, but the lateral capacity is increased by 27.3% in comparison with the original frame

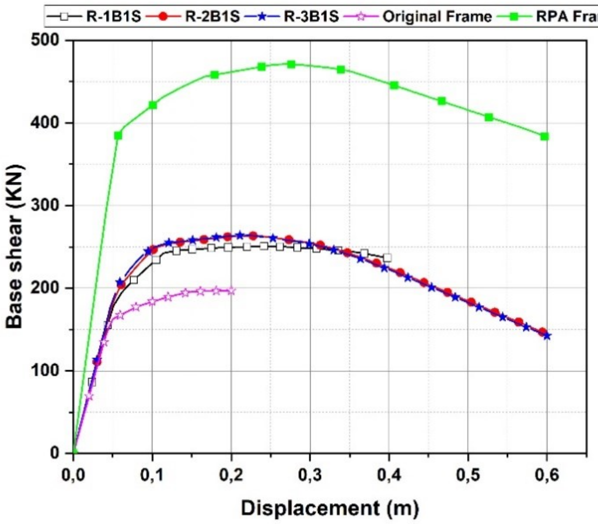



**Figure 9**. Lateral load–displacement response retrofitting horizontal bays with steel jacketing

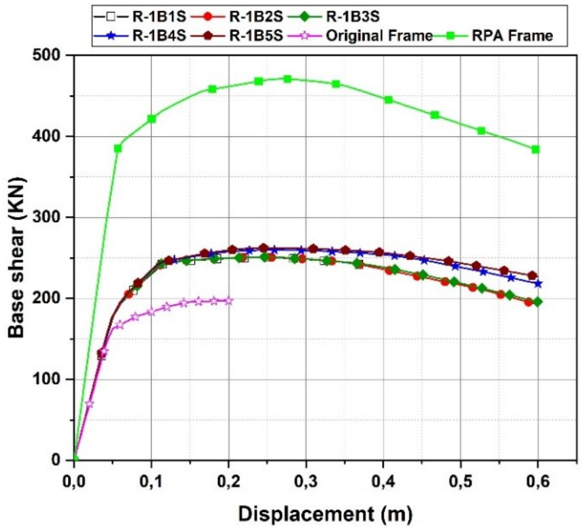
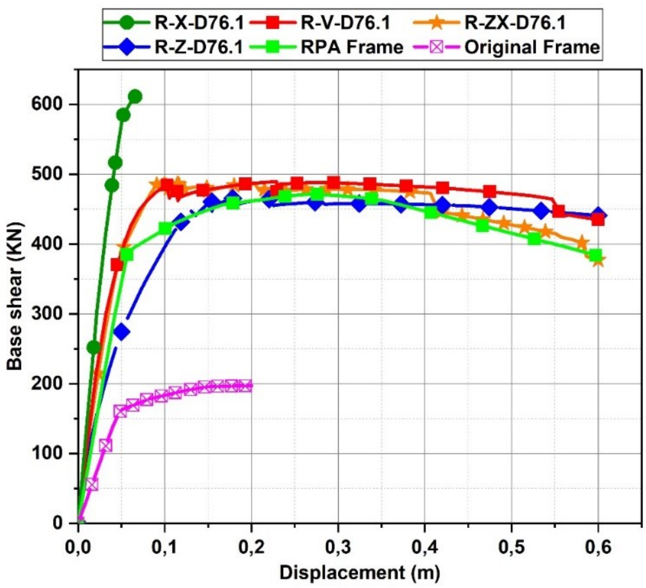



**Figure 10.** Lateral load–displacement response retrofitting vertical bays with steel jacketing

### 4.4. Pushover Results for Retrofitting with Steel Bracing and Steel caging

It is clear from the Figure that the base shear was increased by 100% compared to the reinforcement with the steel bracing system only. The V and Zipper system with the steel caging technique give almost the same curves as the RPA frame. The results show that the section of D76.1×3.2 for all the bracing systems gives a behavior close to the RPA frame with reference to the lateral load.




### 5. Conclusions

The main purpose of this research is the retrofitting of an RC frame that has been designed without seismic design criteria, and is located in a region of high seismicity. In the present work, the retrofitting of this structure was done by three techniques, namely the steel bracing system, the steel caging technique, and the combination of these two methods. The main results of the present work can be summarized as follows:

1. The results show that all systems have a given ductility for a small section and when there is an increase in the section of the bracing the ductility is decreased and the strength is increased.
2. Whatever the reinforcement of the structures, whether horizontal or vertical, the ductility is almost identical to the RPA frame.
3. Retrofitting with Zipper and V systems in combination with steel caging gives similar results to the RPA model.

4. The models with steel bracing and steel caging are good for predicting damage in the nonlinear analysis of RC structures.

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**Conflict of Interests**

The Author(s) declare(s) that there is no conflict of interest.

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