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# Performance Seismic Design of the Retrofit of a University Library using Non-Conventional Methods

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**Abstract.** This research proposes a structural retrofit of a reinforced concrete building older than 50 years. The structural system is dual using frames and walls, having an area of 1980 $m^2$ and 4 levels with a total height of 15.50 m. There are three unconventional methods to retrofit this infrastructure. The first is to install steel jackets with bolt anchors. The second methodology is through the use of jackets and anchors of Carbon Fiber Reinforced Polymers (CFRP). The third alternative is through reinforcement of walls with 2 diagonal struts made with CFRP sheets as struts, also installing CFRP anchors at each end of both struts to ensure that these sheets work up to their high levels of tension. These anchors together with the diagonal plates contribute to give ductility to the wall and in turn resist the effects of sliding at the base, a fault that is very common in rigid structures such as walls. Each unconventional reinforcement methodology used in this research is validated using laboratory tests results of reinforced columns and walls retrofitted with every of the three innovative methods. Nonlinear static analysis - Pushover of each alternative was performed and compared with the demand for the 1974 earthquake in Lima, scaling 3 seismic records to a PGA of 0.45g, which is the acceleration of design in Lima. It is shown that these proposals are effective in providing levels of shear base and displacement capacity in the inelastic design. For the 0.40mx0.80m columns, the results show that both reinforcements increase ductility by more than 10%; on the other hand, the proposal of reinforcement in the walls of 40cm thick, produced even better results increasing ductility by 100% and shear base by 100%.

## 1. Introduction

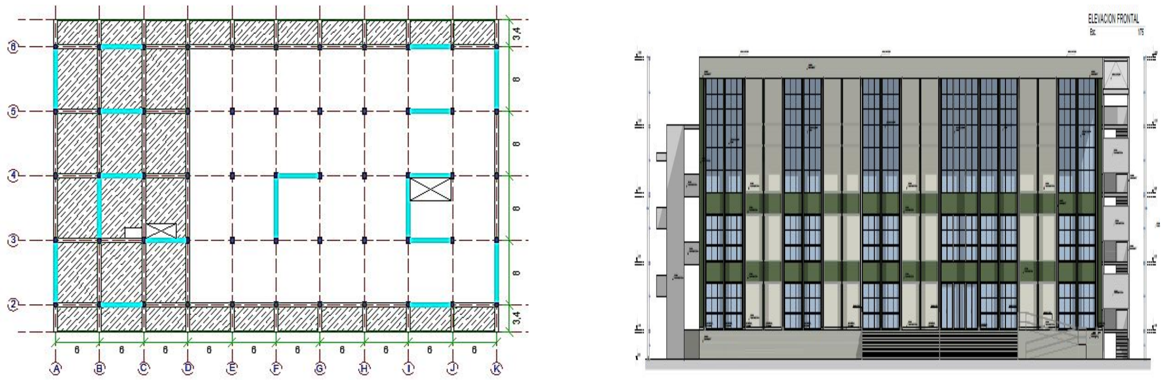
In structural engineering, the limits of inelastic deformation of individual members allow the structures to withstand a strong movement of the ground while these dissipate significant levels of seismic energy [1]. The formation of plastic hinges in columns can occur at the base of the frame where the damage incurred acts to dampen seismic loads. The ductile behavior of these is essential to avoid the complete collapse of the structure.

The collapse of structures in the face of earthquakes in recent years has highlighted the vulnerability of buildings to a seismic movement, these structures come to behave in their inelastic state. The structures of greatest vulnerability are presented in buildings built before 1970, which have design criteria below current earthquake-resistance design standards [2], that is, they do not have the ductility necessary to dissipate seismic energy during an earthquake of strong magnitude. The lack of rigidity and ductility in the structure causes the collapse of the building. Reinforcement research studies for buildings that are more than 50 years old have shown that the use of CFRP and Steel jackets improves seismic performance against an earthquake [3]. In addition, there are few studies where the main reinforcement is the use of CFRP anchors [4] used in CFRP jackets, a better response is obtained than reinforcement only using CFRP sheets.

The results of the analysis in columns and walls, and the anchoring system are also discussed to make recommendations for the use and improvements of this system in the future. it presents the case of structure analysis without beams because it is more conservative and in turn due to the limited information of the internal reinforcement of the columns and beams.

## 2. Background: infrastructure to reinforce

The building is a University Library in the city of Lima Peru built in 1969 and supported by soft ground. This is the National Agricultural Library (BAN). This facility is considered essential since it is required to remain operational after an important seismic event. Its structural system for lateral forces is made of porches and reinforced concrete walls in both orthogonal directions. The plan views are shown in figure 1a and elevation in figure 2.



(a) (b)

**Figure 1.** (a) Detail in Plan of the National Agricultural Library (BAN).
(b) Elevation detail of the National Agricultural Library (BAN).

Data collection was obtained, obtaining essential information such as: material, structural system, height and year of construction. Likewise, the studies of representative trials such as diamantine extraction and sclerometer were performed at key points of the structure of the National Agricultural Library (BAN). These data show us the effort to compress the concrete "f'c" of the following structural elements; columns, beams and walls, finding fc values of less than 180kg/cm2 for columns, and less than 170kg/cm2 for beams. The walls have an average of 175kg/cm2 of concrete capacity. Limited information on the existing reinforcement was obtained, so for this investigation the capacity of each structural element was calculated considering a minimum number of rods that are similar to several of the construction practices of the 60s, that is, a smaller amount than that provided in Current design codes in Peru. This study began with the need to reinforce existing structures, with age over 50 years, which were built under design criteria that do not meet the technical design specifications of current regulations.

## 3. Structure Capacity vs. Seismic Demand

### *3.1. Estimation of Plastic Hinges for the retrofit methods*

The capacity of the structure in its longitudinal direction was calculated for 4 cases: AS-BUILT, reinforcing only columns with steel jackets and metal bolts, reinforced only columns with jacket and CFRP anchors and finally reinforcing walls with diagonal struts in two directions using CFRP sheets and anchors. Pushover modal was performed specifying the modes attributed to the longitudinal direction. The software used was SAP2000 v.20.

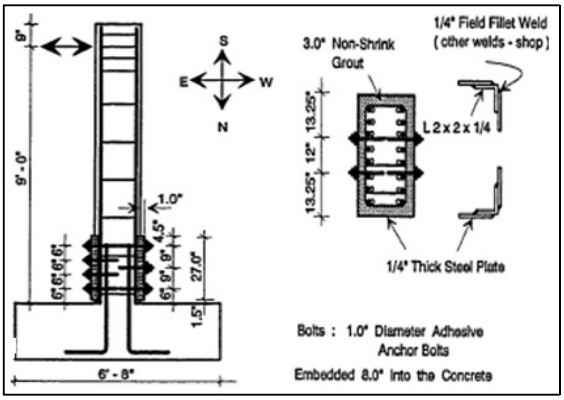
*3.1.1. As-Built.* In order to determine the Ball joints for As-Built structures, the ASCE - 41[5] Standard was followed, in which the labels will be determined according to the parameters and conditions of the

National Agricultural Library (BAN). Table 1 presents a fragment of table 10-13 of ASCE Standard 41 [5], which according to the case of the evaluation of the structure, in our case will be condition ii; which refers to structures with short overlaps and a minimum amount.

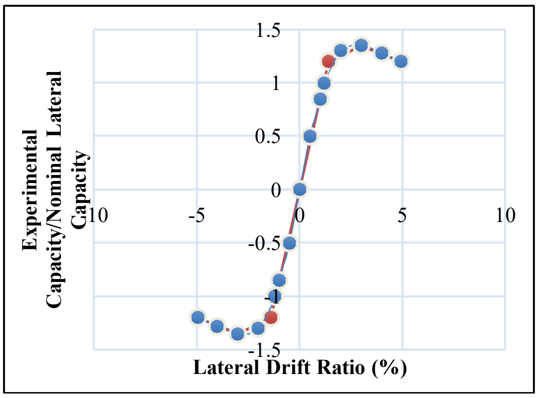
**Table 1.** Modeling parameters a numerical acceptance criterion for nonlinear procedures – reinforced concrete columns [5].

| Condition ii [2] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{P}{A_g f'_c}$ [a] | $\rho = \frac{A_v}{b_w s}$ | $\frac{V}{b_w d \sqrt{f'_c}}$ [4] | | | | | | | | |
| ≤ 0.1 | ≥ 0.006 | ≤ 3 (0.25) | 0.032 | 0.060 | 0.2 | 0.005 | | | 0.045 | 0.060 |
| ≤ 0.1 | ≥ 0.006 | ≥ 6 (0.5) | 0.025 | 0.060 | 0.2 | 0.005 | | | 0.045 | 0.060 |
| ≥ 0.6 | ≥ 0.006 | ≤ 3 (0.25) | 0.010 | 0.010 | 0.0 | 0.003 | | | 0.009 | 0.010 |
| ≥ 0.6 | ≥ 0.006 | ≥ 6 (0.5) | 0.008 | 0.008 | 0.0 | 0.003 | | | 0.007 | 0.008 |
| ≤ 0.1 | ≤ 0.0005 | ≤ 3 (0.25) | 0.012 | 0.012 | 0.2 | 0.005 | | | 0.010 | 0.012 |
| ≤ 0.1 | ≤ 0.0005 | ≥ 6 (0.5) | 0.006 | 0.006 | 0.2 | 0.004 | | | 0.005 | 0.006 |
| ≥ 0.6 | ≤ 0.0005 | ≤ 3 (0.25) | 0.004 | 0.004 | 0.0 | 0.002 | | | 0.003 | 0.004 |
| ≥ 0.6 | ≤ 0.0005 | ≥ 6 (0.5) | 0.0 | 0.0 | 0.0 | 0.0 | | | 0.0 | 0.0 |

*3.1.2. Steel Jacket with Anchors – Columns.* According to Aboutaha [6] he proposes a reinforcement with steel jackets and anchors (bolts) in columns with inadequate splicing overlap as shown in figure 2a, including lateral load versus drift ratio response, this is defined as tip displacement divided by column height. Figure 2b shows the profile of the column to be reinforced and the section of the column and the reinforcement with the Steel Jacket and Anchors.



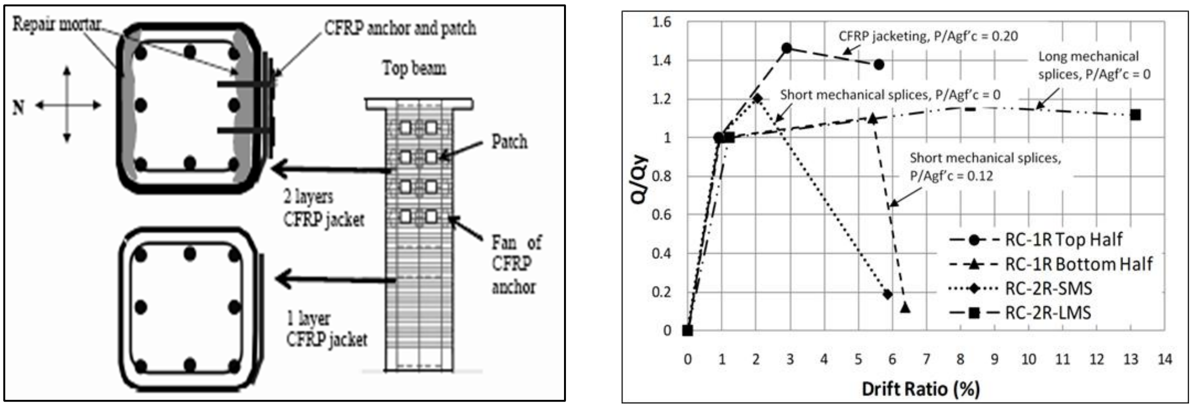

(a)




(b)

**Figure 2.** (a) Details of the Column and section with Steel Jackets and Anchors (Bolts [6] (b) Standardized force-strain curves for columns reinforced with Steel Jacket with Anchors [6].

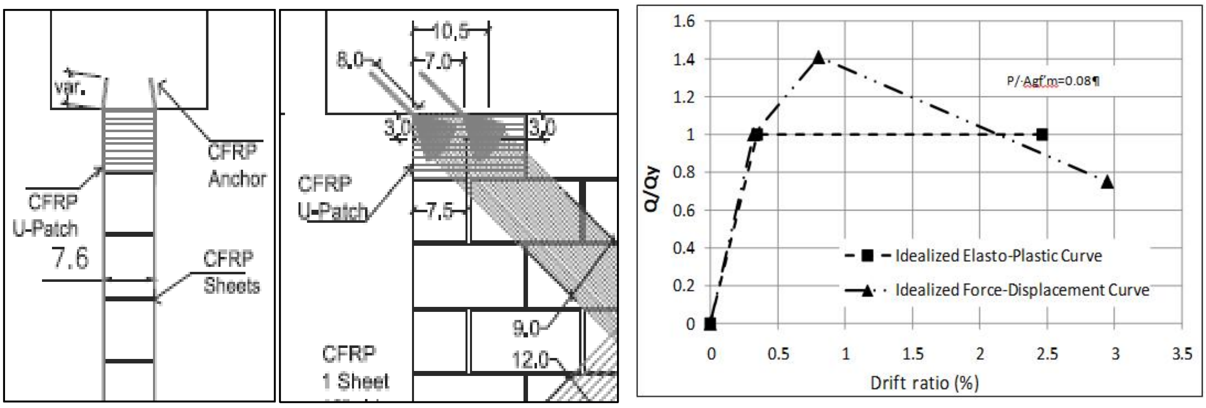
*3.1.3. CFRP with Anchors – Columns.* Huaco [7, 8] mentions in his research that he follows the guidelines available ASCE 41-13. It is presented in figure 3a the pattern of installation of the CFRP Jackets and CFRP Anchors for severe damaged columns, and figure 3b shows the bi-linear and tri-linear curve for the design of the capacity curve of the structure with reinforcement with carbon fiber jackets and anchors in columns.




(a) (b)

**Figure 3.** (a) Section of the Column Reinforced with CFRP Jackets with Anchors, units in inches [7] (b) Standardized force-strain curves for columns with CFRP reinforcement with Anchors [8].

*3.1.4. CFRP with Anchors – Walls.* According to Huaco [8, 9] in his research, two types of behavior models were proposed for the reconstructed masonry walls: The Elastic - Plastic and Strength - Displacement models. The first idealized curves were developed from the main curves, and then normalized as ASCE 41 [5] provisions indicate. Figure 4a shows the details of the reinforcement in walls with 2 diagonal struts made of CFRP sheets, also installing CFRP anchors at each end of both struts to ensure that these sheets work to their high levels of tension. Figure 4b shows the bi-linear and tri-linear curve for the design of the capacity curve of the structure with reinforcement with struts of sheets and carbon fiber anchors in walls.




(a) (b)

**Figure 4.** (a) Detail of the sheet and anchors of CFRP in walls, units in inches [9] (b) Standardized force-strain curves for walls with CFRP reinforcement with Anchors [8].

*3.2. Seismic Demand Curve Estimation*

*3.2.1. Seismic Catalog of Peru.* It was used ground motions records from station near the location of the library, as well from earthquakes with PGA above 0.10g. No scaling was made to the records. According to the CISMID PERU database, the following seismic records were considered is shown in table 2. Spectral Acceleration vs. Period curves were calculated using a damping of 5% which correspond for concrete material. Figure 5 shows the variation of Sa vs. T. These curves represent the Seismic Demand Curves for the performance base design of the retrofit of the library.

**Table 2.** Ground Motions Records for Seismic Demand.

| Event | Station | PGA (g) | Distance from Library |
|---|---|---|---|
| Lima 1966 | Cercado L. | 0.27 | 20km |
| Lima 1974 | HUACO | 0.21 | 6km |
| Lima 1974 | UNALM | 0.12 | <1km |

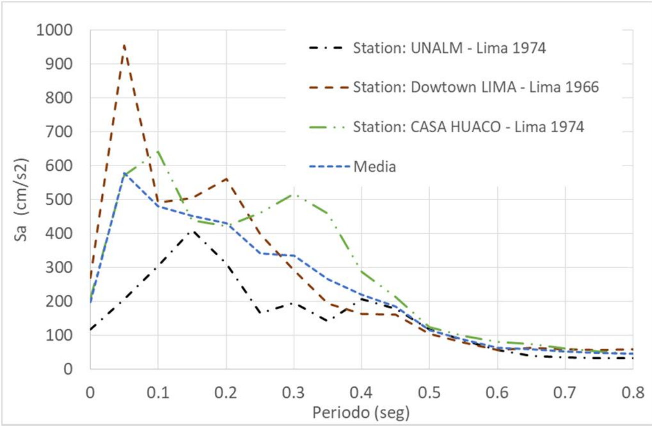


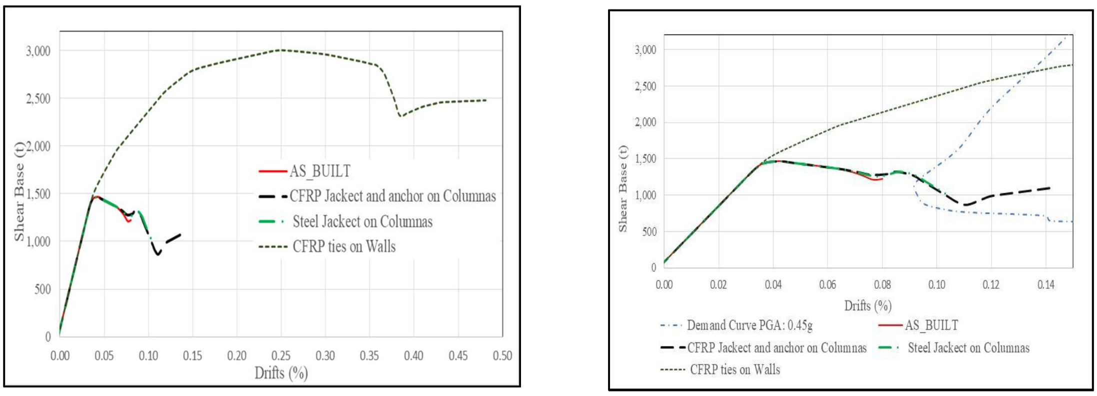

**Figure 5.** Pseudo Accelerations of the Seismic Catalog of Peru.

## 4. Results and discussions

In the collection and processing of data from the National Agricultural Library. The building capacity curves were obtained using the Non-linear Static Analysis - Pushover, in its longitudinal direction where the columns have lower inertia capacity and lower wall density. We proceeded with the As-built structure, and with each of the methodologies used. Likewise, several iterations were performed and finally obtaining the capacity curves for as-built and each retrofit procedure which are show in figure 6a. It can be seen the improvement in strength and ductility using CFRP at masonry walls compared to the installation of CFRP or steel jackets.

With the application of the ATC-40 [10] methodology by ADRS, the guidelines for the normalization of the demand of the Seismic Catalog of Peru are followed with the Shear Base (t) vs. Drift (%) axes. The Demand media curve was scaled to have a PGA 0.45g that correspond of design earthquake of Peruvian seismic code E030 [11] for Lima City located at Zone 4, severe earthquakes.

Having the structure capacity and seismic demand curves, the performance points are obtained as shown in figure 6b, which are the intersection points between the capacity curves and the demand curve according also to ATC-40 provisions.




(a) (b)

**Figure 6.** (a) Structure Capacity Curves of the National Agricultural Library]
(b) Performance Points for each of the retrofit procedures applied to the building.

## 5. Conclusions

The use of CFRP materials in the reinforcement of structures over 50 years shows that it has a significant increase in capacity and a better response to an severe earthquake.

Retrofit of concrete walls with diagonal CFRP sheets and installations of CFRP anchors, is obtained better performance than reinforcement in columns with CFRP jackets. This shows that, in buildings over 50 years old with walls present, it is recommendable to retrofit the walls because it releases the greatest amount of seismic energy at the base of the building.

The seismic demands obtained from the Seismic Catalog of Peru were scaled up in the PGA of Zone 4 having a PGA 0.45g. This procedure is useful for evaluation criteria at the point of seismic performance.

The performance point of a structure in this case the National Agricultural Library BAN, defined as the intersection of capacity and demand curves, were determined from simple models of a degree of freedom. These models can reasonably represent the capacity and demand of the structure, either AS-BUILT and reinforced.

The reinforcement proposed in the National Agricultural Library in both columns and walls. It was found that the reinforcement of walls using CFRP sheets diagonally installed and CFRP anchors at each extreme of infill, it will increase the shear base capacity as well the ductility considerably in order to fulfill the objective of the continuity of the useful life of the structure due a severe earthquakes.

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