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EFFICIENCY OF DIFFERENT RETROFITTING TECHNICHS FOR RC COLUMNS UNDER BIAXIAL LOADING: EXPERIMENTAL STUDY

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Abstract. *The main purposes of this work it to present an experimental campaign of different strengthening strategies of RC columns, and evaluating benefits concerning their structural behaviour cyclic loading. 9 RC columns were tested, two of them original and the rest composed by strengthened columns by CFRP and steel plates jacketing. The aim is, therefore, to contribute for developing and calibration a procedure that enables the evaluation of the efficiency of the strengthening strategies, their possibilities and application. It was also an objective of this work to explore the possibility of use this techniques on the improvement of existing buildings performance*

1 INTRODUCTION

The seismic behaviour of RC structures is a widely studied theme in the last decades, however the experimental response of RC elements under biaxial cyclic bending still very limited [1, 2]. Rodrigues et al. [3-7] tested 17 RC specimens with four types of full-scale rectangular building columns tested for different loading histories. The horizontal loading patterns considered were: cruciform; diamond; expanding quadrangular; and circular. In this study the comparison of the biaxial results is performed with similar columns under uniaxial load. Based on the obtained results, it was verified that: i) The initial column stiffness in both directions it is not significantly affected by the biaxial load path; ii) when comparing the maximum strength in one specific direction of the columns, for each biaxial test against the corresponding uniaxial test, lower values were obtained for all biaxial tests than uniaxial ones (the biaxial loading induces a 20-30% reduction of the columns maximum strength in their weak direction, while reductions from 8-15% for the stronger direction); iii) the ultimate ductility is significantly reduced in columns subjected to biaxial load paths; iv) the strength degradation is practically zero, in the first loading cycles, increasing after displacement ductility demands of about 3. (from the strength degradation analysis, more pronounced strength degradation was observed for biaxial tests when compared with corresponding uniaxial tests; v) the biaxial loading can introduce higher energy dissipation (circular, rhombus and cruciform load paths) than uniaxial loading, as previously recognized by other authors; vi) the viscous damping highly depends on the biaxial load path (however the repetition of cycles, for the same maximum displacement level, has practically no influence on the equivalent damping).

The available experimental and numerical information allows us to recognize that RC elements under biaxial proved that the effect of biaxial cyclic bending moment is recognized as a very important topic for building structures in earthquake prone regions. Is also recognize the needs to strengthening of existing buildings. The experimental research work in this field is currently very limited and much behind the present knowledge about 1D bending.

It is known that many buildings, designed with older codes, can be more susceptible to serious damage when submitted to earthquake. Older buildings have been design, according to at the time the codes, for much lower seismic actions. RC column jacketing is a very effective strength technique [8] to increase the strength capacity. To increase the shear strength can be added jackets (in steel, concrete, or other types) across the column length. A variety of techniques have been subjected to experimental studies [9, 10] in order to evaluate their performances. From the analysis of the available experimental work, it was possible to verify that all the strengthening techniques improves the bending strength, the stiffness, the ductility and the shear capacity.

To analyze and assess the efficiency of different strategies for the seismic strengthening of RC columns, an experimental campaign was performed by the investigation group of Laboratory of Earthquake and Structural Engineering (LESE). The experimental campaign and the solutions were based on the previous experience of the research team in the retrofitting of columns under uniaxial bending [11]. Full-scale RC columns were tested, in the original undamaged state and original undamaged with strengthening interventions according to different techniques. This paper presents the results of nine tested specimens, two “as built” columns and seven strengthened columns with steel plates and with Carbon Fibre Reinforced Polymers (CFRP) plates jacketing.

2 EXPERIMENTAL CAMPAIGN

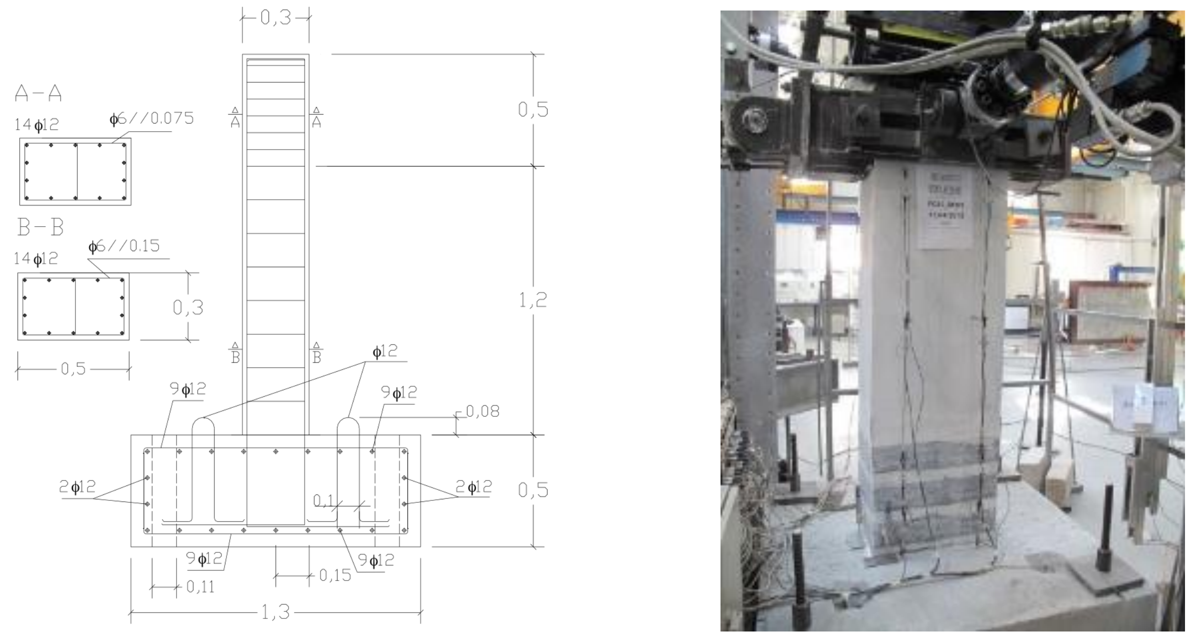
2.1 Specimens' description and experimental setup

Nine rectangular RC columns were constructed with the same geometric characteristic and reinforcement detailing, and were cyclically tested for two different loading histories. The columns and cross-section reinforcement detailing are presented in Figure 1. The specimens have 1.70m height, and are cast in strong concrete foundation blocks (1.30 x 1.30 x 0.50 m^3). The foundation block has four holes near the corners to fix the specimen to the laboratory strong floor.

With this kind of cantilever model it is assumed that the inflection point of a 3.0m height column is located at its mid-height (1.5 m). The same behaviour, special at the base, can be found in a column of a typical building when subjected to lateral demands induced by earthquakes. An extra 0.20 m height is added for attaching the actuator devices.

Details of the reinforcement and material properties are summarized and shown in Fig. 1a and Table 1.

The test setup is illustrated in Fig. 1b. The system includes two independent horizontal actuators to apply the lateral loads on the column specimens and one vertical actuator to apply the axial load. But, because the axial load actuator must remain in the same vertical during the test while the column specimen laterally deflects, a sliding device is used (placed between the top-column and the actuator), which was built to minimize spurious friction effects.



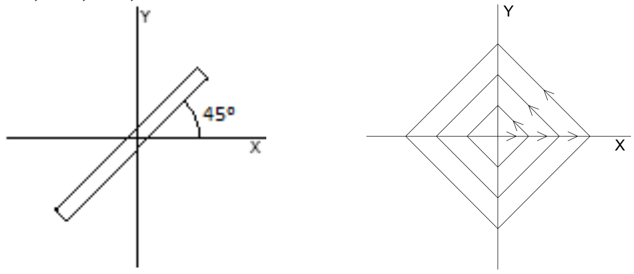
a) b)

Figure 1: a) RC column specimen dimensions and reinforcement detailing b) General view of the experimental test setup.

2.2 Loading condition

In order to characterize the response of the strengthened column specimens, several loading conditions were considered. Cyclic lateral displacements were imposed at the top of the column with steadily increasing displacement levels. The adopted load paths are summarized in Figure

2 and for each lateral deformation demand level, three cycles were repeated. The following nominal peak displacement levels (in mm) were considered: 3, 5, 10, 4, 12, 15, 7, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80.



Diagonal - 45º   Diamond

Figure 2: Horizontal displacement paths types.

For the two "As built" specimens and the rest of the specimens, strengthened with different strategies as described next, were adopted to biaxial load the paths indicated in Table 1.

Table 1: Specimens' specifications and loading characteristics.

Specimen	Geometry [cm x cm]	f_{cm} [MPa]	f_{yk} [MPa]	Axial Load [kN]	Horizontal Displace-ment path type	Strengthening Technique
PC12-N13	30 x 50	14.8	575.6	300	Diagonal – 45º	As Built
PC12-N14					Diamond	
PC12-N10S		8.4	573.7		Diamond	CFRP plates jacketing
PC12-N11S						Steel plates jacketing bonded with epoxy resin
PC12-N12S						CFRP plates jacketing
PC12-N15S		14.8	575.6		Diagonal – 45º	Steel plates jacketing bonded with epoxy resin
PC12-N16S					Diamond	Steel plates jacketing bonded with epoxy resin
PC12-N17S					Diagonal – 45º	CFRP plates jacketing
PC12-N18S					Diamond	CFRP plates jacketing

2.3 Retrofit Techniques

Seven specimens were strengthened with two different techniques: CFRP plate's jacket; and steel plates (see Table 1) The design and retrofit procedure is based on previous research work [12-14].After the construction of all specimens, seven of them were submitted to two different strengthening techniques: CFRP plates jacketing and steel plates jacketing.

2.3.1. CFRP plates jacketing

The total thickness of CFRP jacketing t_j = 0.342 mm was obtained for the total repaired zone height (500 mm). The total area value along this height (0.342 x 500 = 171 mm^2) was divided by 3 CFRP plates with 80 mm wide, spaced at 70mm (40mm between the footing and the first plate), each one with 6 layers of CFRP sheet thickness of 0.117mm. Figure shows a general schematic view of the CFRP plates jacketing for specimens strengthened with this technique (Table 1).

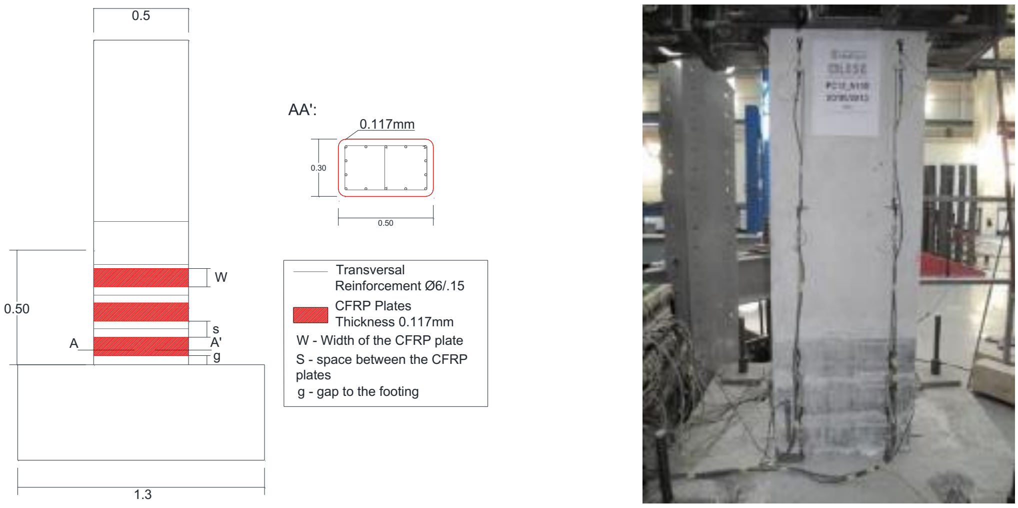


Figure 3 - Strengthened column specimen with CFRP plates jacketing.

2.3.2. Steel plates jacketing

The plates were placed in four previously defined levels at different distances from the footing (125 mm, 225 mm, 325mm and 425 mm). After welding the steel bars in place, the voids between the plates and the concrete were filled with injection of two component epoxy resin in order to ensure full contact and early efficiency of the external strengthening. Figure 4 shows the general schematic view of the specimen strengthened with steel plates jacketing.

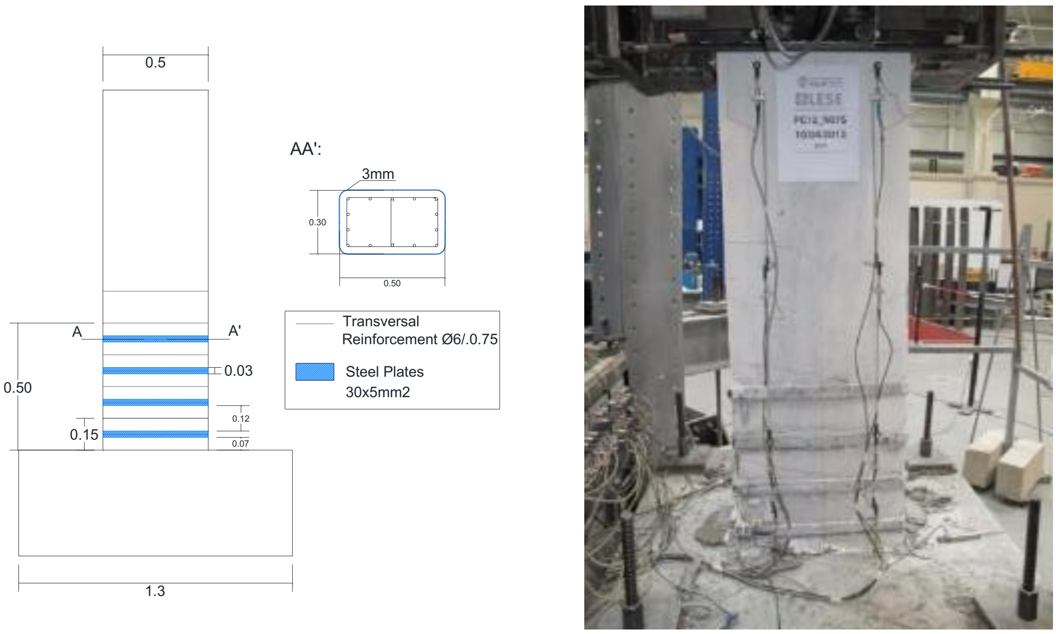


Figure 4 - Strengthened column specimen with steel plates jacketing.

The different strengthening techniques and details are described in Table 2.

Table 2 - Specimen's strengthening techniques and details.

Specimen	Strengthening technique	Solution details
PC12-N10S	CFRP plates jacketing	3 CRFP plates, 8cm wide spaced at 7cm, with 4cm of gap to the footing and 3 CFRP layers per plate
P12-CN11S	Steel plates jacketing bonded with epoxy resin	Steel plates (3x0.5 cm^2), simply bonded with epoxy resin, spaced at 12cm with 7 cm of gap to the footing
PC12-N12S	CFRP plates jacketing	3 CRFP plates, 8cm wide spaced at 7cm, with 4cm of gap to the footing and 3 CFRP layers per plate
PC12-N15S	Steel plates jacketing bonded with epoxy resin	Steel plates (3x0.5 cm^2), simply bonded with epoxy resin, spaced at 12cm with 7 cm of gap to the footing
PC12-N16S	Steel plates jacketing bonded with epoxy resin	Steel plates (3x0.5 cm^2), simply bonded with epoxy resin, spaced at 12cm with 7 cm of gap to the footing
PC12-N17S	CFRP plates jacketing	3 CRFP plates, 8cm wide spaced at 7cm, with 4cm of gap to the footing and 3 CFRP layers per plate
PC12-N18S	CFRP plates jacketing	3 CRFP plates, 8cm wide spaced at 7cm, with 4cm of gap to the footing and 3 CFRP layers per plate

3 EXPERIMENTAL RESULTS

For the study of the efficiency of the strengthening technics applied in the behaviour of RC columns, the measured displacement and shear force paths (along the X and Y directions) are analyzed: Figure 5 shows the shear-drift results for the "As built" specimens; and in Figure 6 and 7 the shear-drift diagrams for the columns strengthened with CFRP plates jacketing; and steel plates jacketing strengthened columns respectively. In order to help the understanding of each strengthening technic increments, the enveloping obtained in the tested 'as built' column with the same biaxial load path was also included, and a picture

The analysis of the obtained results can be summarized as follows:

- In their enveloping curves the post-yield hardening zone is larger and the softening phase tends to start for higher drift demands in strength columns with both technics. This tendency is more evident in the tests with the diamond biaxial load path.
- The initial column stiffness, in both directions, it is not significantly affected by the strengthening technic.
- When comparing the maximum strength in one specific direction of the columns, for each strengthening technic against the corresponding 'as built' column test, higher values were obtained for all tests with the diamond load path (increase around 12%). In the tests with the diagonal load path the maximum strength is similar in "as built" and strength columns.

As pointed by Rodrigues *et al* [15], the columns under biaxial load the post yielding plateau tends to be shorter and the softening is more pronounced. With the tested strengthening technics was enhanced the behavior of the columns mostly given by the; delaying of the strength degradation beginning of, keeping the initial stiffness and, small increasing of the maximum strength of the elements.

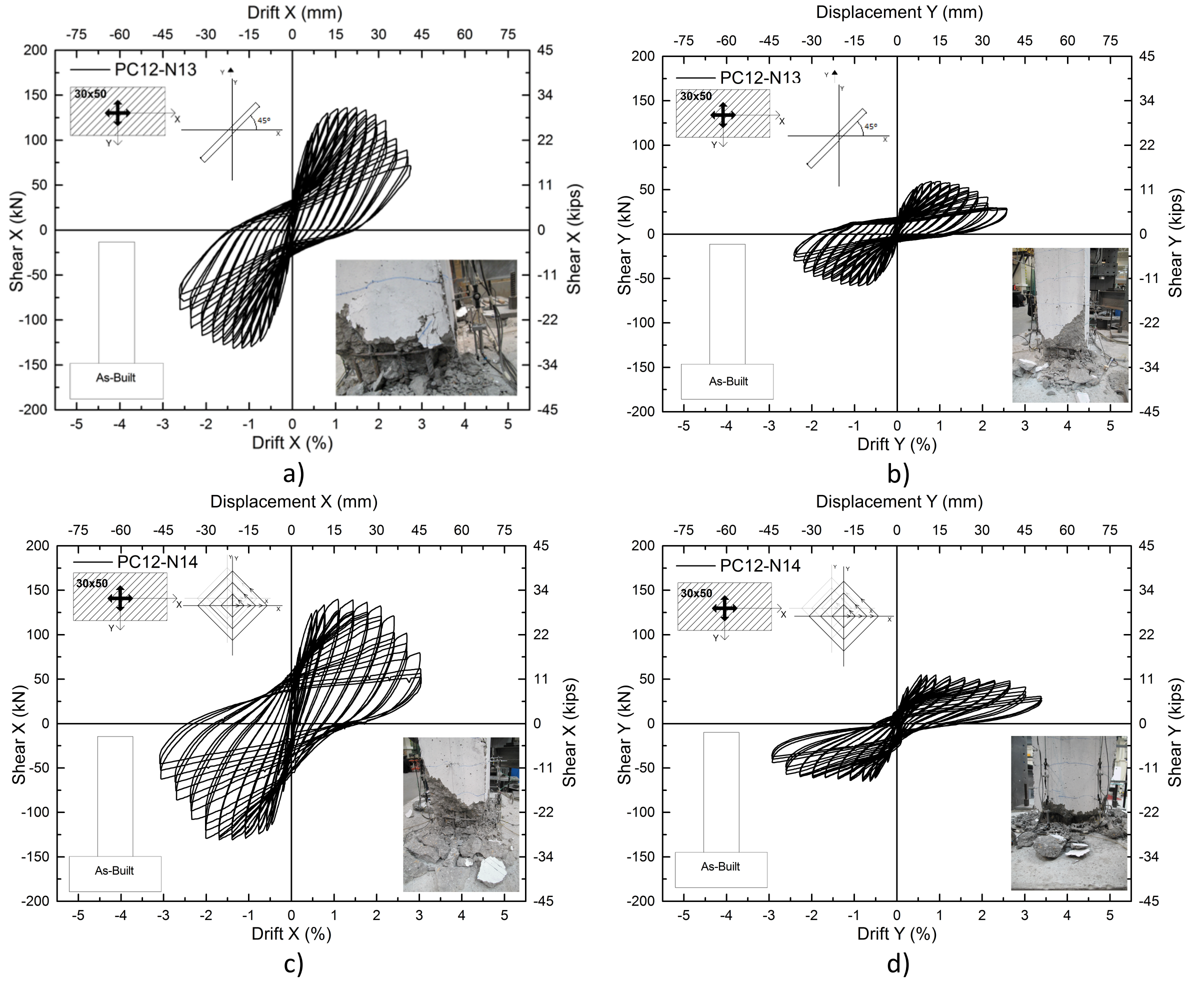
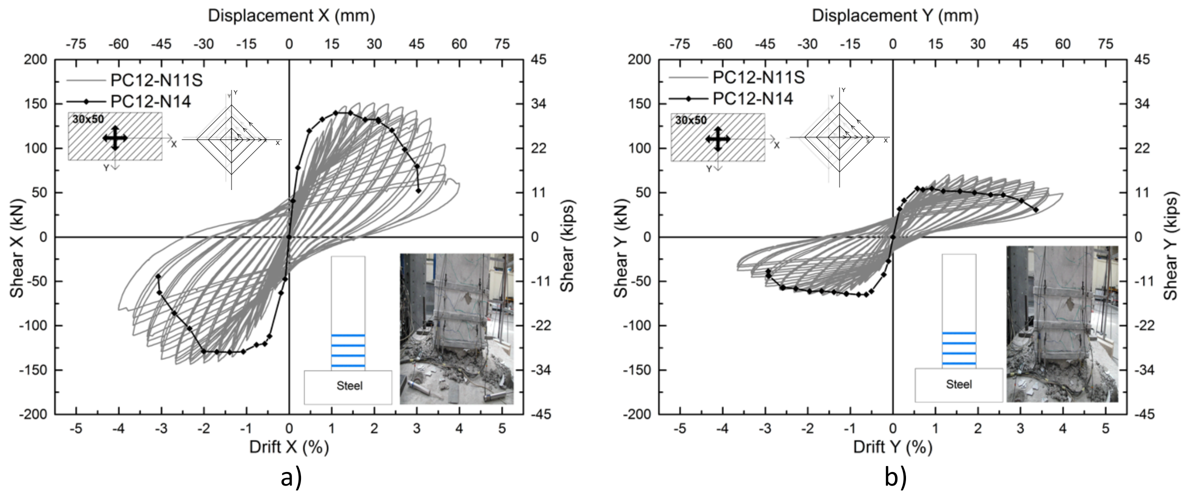


Figure 5: Shear-drift diagrams for "As built" columns under biaxial load path a) and b) PC12-N13 and c) and d) PC12-N14.



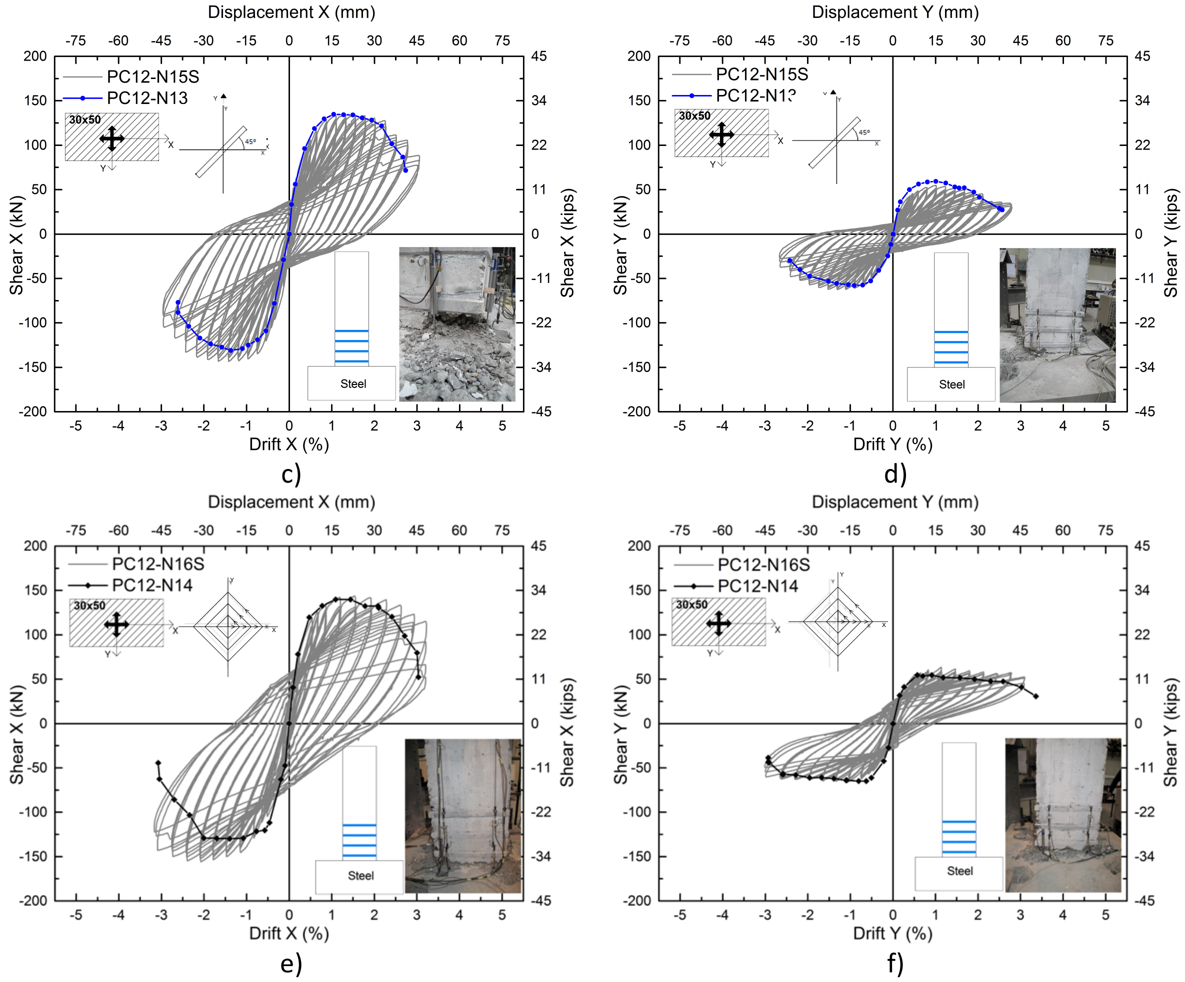
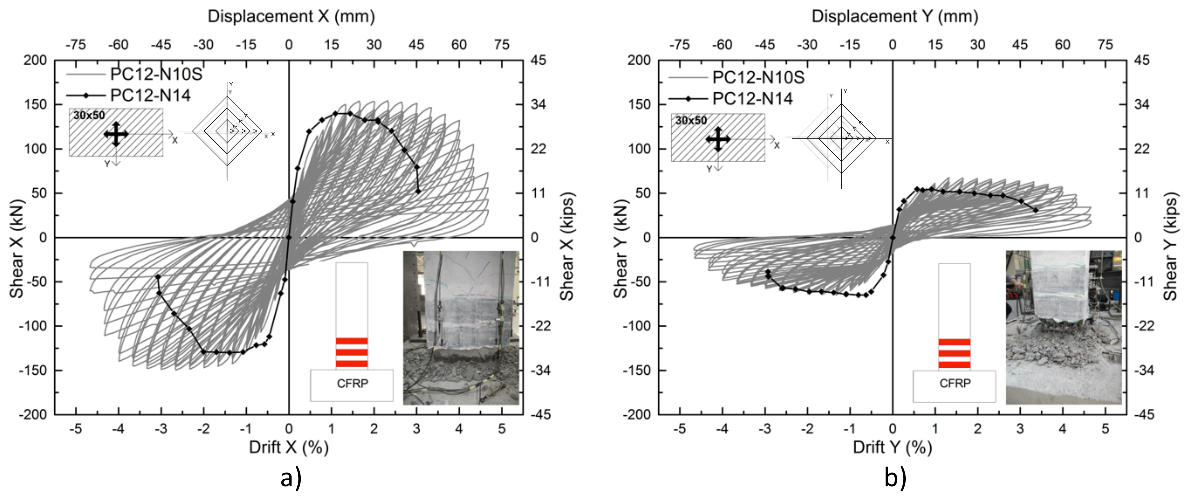


Figure 6: Shear-drift diagrams for strengthened columns with steel plates jacketing a) and b) PC12-N11S and c) and d) PC12-N15S and e) and f) PC12-N16.



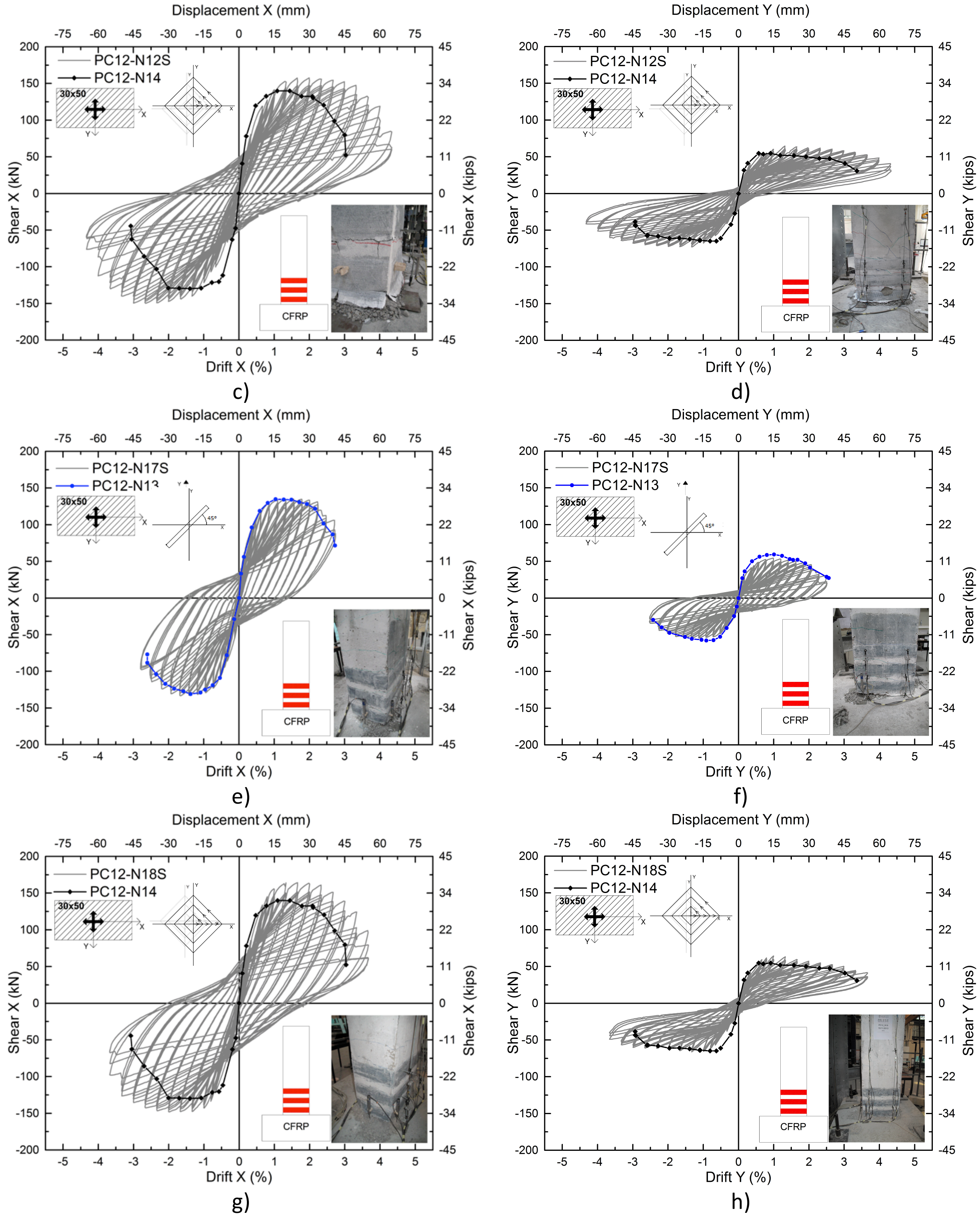


Figure 7: Shear-drift diagrams for strengthened columns with CFRP plates jacketing a) and b) PC12-N10S and c) and d) PC12-N12S and e) and f) PC12-N17S and g) and h) PC12-N18S.

CONCLUSIONS

An experimental campaign was carried out on 9 RC columns with: same geometries and reinforcement; subjected to similar biaxial horizontal displacement paths; and with equal constant axial load. The study was focus on the influence of different strengthening strategies on the behavior of columns under certain load conditions.

In different strengthening strategies studied and in both directions the initial stiffness it is not significantly affected. However, the strengthened columns present higher maximum strength capacity of about 12% (in particular in columns under diamond biaxial horizontal load path). The strength degradation in the strengthened columns starts for higher levels of drift demand. This improvement that different strategies caused on strength degradation is clear and more significant for the diamond path.

The stiffness degradation is significantly reduced in the strengthened columns when compared with the original columns tested. Any of the proposed strengthening strategies leads to strong concentration of deformation and the concrete degradation at the critical section (base) of the specimens reducing significantly the plastic hinge length.

A large number of questions are still open concerning the influence strengthening technics and the influence of the biaxial behavior of RC columns. In the present work, an exploratory work is presented giving a preliminary step towards this goal. Even so, the research work reported is expected to contribute towards a better understanding of the biaxial response of RC columns and for the calibration of suitable numerical models for the response representation of reinforced concrete strengthened columns under biaxial lateral cyclic loading reversals.

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