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RETROFIT OF RC COLUMNS CYCLICALLY LOADED IN BIAXIAL FLEXURE WITH AXIAL FORCE

J. P. Silva [1(*)], P. Rocha [2], H. Rodrigues [3, 4], N. Vila Pouca [1], A. Arêde [1]

[1] Department of Civil Engineer, Faculty of Engineering of University of Porto, Portugal
[2] Superior School of Technology and Management of Polytechnic Institute of Viana do Castelo, Portugal
[3] Faculty of Natural Sciences, Engineering and Technology - Oporto Lusophone University
[4] Department of Civil Engineer, University of Aveiro, Portugal
(*) *Email:* jpsilva@fe.up.pt

ABSTRACT

The repair and retrofit of reinforced concrete (RC) columns for seismic preparedness is an important issue to ensure a proper behaviour of structures. In addition, after a seismic event it is important, when possible, to restore the initial conditions of damaged columns or even to provide increased strength and/or ductile capacity. In this context, the present work focuses on the implementation and testing of repair procedures for RC column which have been tested before under biaxial cyclic loading and constant axial load. The strategy stems from previous works of some of the authors, but particular attention is given to the longitudinal reinforcement repair in the plastic hinge zone in particular considering a proper and controlled welding of rebar's.

The main objective was to restore the initial capacity as much as possible, without increasing the amount of longitudinal steel with a practical solution for with practice. Therefore, a few tests were made on single welded rods in order to assess and compare the behaviour of four different connection schemes, which are presented and discussed in the paper. After repairing the longitudinal reinforcement with the most appropriate solution previously defined, each column was filled with micro concrete in the intervention zones which allows achieving a stronger concrete in the potential plastic hinges.

After, the repaired columns were tested again under biaxial load. Test results are presented and compared against the previous tests on the original specimens and also compared according to the different repair solutions used.

Keywords: RC Columns, Repair, Rebar splicing, Biaxial load.

INTRODUCTION

Seismic behaviour of RC structures is a widely studied theme in the last decades however, the present study had been focused on the behaviour of RC columns under biaxial horizontal loading [1-5].

However, many difficulties are still recognized for this analysis approach and, therefore, research must be pursued addressing the biaxial behaviour of RC building columns, bearing in mind that: i) only sophisticated non-linear behaviour models can provide accurate representation of the real structural cyclic response of a given building and, ii), these non-linear hysteretic models have to be calibrated and validated with experimental results obtained from bidirectional tests on RC columns [6]

The repairing of steel rods is an important theme at repair, rehabilitation and strengthening of reinforced concrete structures, once is important to restore the elements original strength characteristics. To get that is necessary to guarantee that steel bars amendments are trustable, to get a safe strengthening design and when is necessary, for inspection for example, cut a piece of a steel bar, restore the original conditions.

Experimental research work on the inelastic response of RC members under compression axial force and biaxial lateral cyclic bending loading conditions is currently very limited. Uncertainties concerning the relationship and combination of the two orthogonal horizontal loading paths, associated to the complexity of the experimental set-up, certainly justified this lacuna [7].

From the authors who have studied the biaxial load stand out Bousias et al 1995 [8], with a vast study of biaxial load with constant and variable axial load, other authors began a few years earlier the study of biaxial models as Abrams et al (1987)[9] and Saatcioglou et al (1989)[5]. Tsuno and Park [2004] [10] tested a series of five columns with square section and designed by Japanese rules, from this job resulted two important conclusions, which are the plastic hinge length tends to stabilize by theoretical values, after some cyclic loads and this is indifferent to biaxial load [10] High displacements in the beginning of test cause high degrada-tion and low dissipation of energy, however, if the displacements amplitude begins low and increasing slowly, as standard model of Park, [10,11] the energy capacity of column until ultimate state are the same to uniaxial and biaxial loading.

Low and Moehle [1987] [12] made some tests using rectangular cross section, with different stiffness and strength in each direction. They used three specimens, one tested uniaxially (1) and two biaxially (2 and 3). The specimen 2 was tested with a load 7,5º by diagonal of section and 45º of inclination to lower inertia direction, they got similar results of series D of Saatcioglu (1984)[13, 14]. The third test followed a cloverleaf path, this test allowed conclude that in the major inertia direction, the dissipated energy in the orthogonal direction was the double than with regular square path and in the lower inertia direction happened the same.

Finally Rodrigues et al . [15, 16] tested 17 RC rectangular columns with four types of full-scale quadrangular 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 maximum strength of the columns in their weak direction, Y, while reductions from 8-15% for the stronger direction, X, 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 recognised by other authors. It was confirmed that the energy dissipation also depends on the column's geometry; vi) The viscous damping highly depends on the biaxial load path. The repetition of cycles, for the same maximum displacement level, has practically no influence on the equivalent damping.

In fact in the literature, the lack of knowledge concerning column retrofitting for biaxial load conditions is the strongest motivation for the work presented.

TESTING SOLUTIONS OF STEEL BARS REPAIRING

To strengthening/amend of steel bars were tested three different arrangement of the bars, the solutions were:

a. An amendment steel bar with a splicing steel bar with 10mm of diameter and 20cm length. This solution is called Amendementϕ10;
b. The same solution as a. replacing de splicing steel rod for one of 12mm of diameter. This solution is called Amendementϕ12;
c. An amendment steel bar with a strengthening splicing of two welded of steel bars of 8mm of diameter at each side This solution is called Amendement2ϕ8;
d. The last solution is the amendment top to top with two different welding cords, one with continuous cord (TTP), perfect weld, impossible to replicate at work, and other solution with discontinuous welding cord (TTO).

At figure 1 is shown some tested specimens and Figure 2 shows the testing solutions schemes.

Figure 1 Testing Specimens

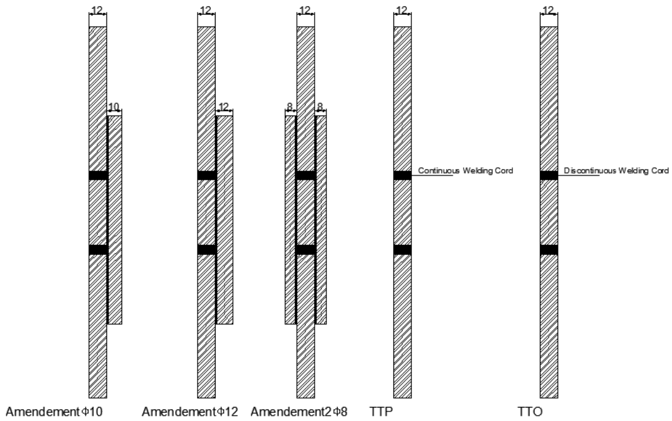

Figure 2 Testing Specimens Scheme

RESULTS ANALISYS

STEEL BARS TESTING RESULTS

The results of the different tested solutions are presented in Figure 2 to 6 and some conclusions about these tests are derived:

- Figure 2 shows with this solution the yielding baseline is not present and is visible some deviation of 12mm amendment steel bar, that happened due to the load was driven to 10mm steel bar and the cross of welding cords wasn't allow the distribution of load by the two bars.
- At Figure 3 the improvement behaviour with the increasing of two 8mm bars, however, that solution presents a increases of the initial stiffness when compared with the initial solution. This solution could drive to an unwanted behaviour, once that could make the plastic hinge, go up or down, but probably would down and drive to a test type rocking which drive to a base of column damage concentration.
- Figure 4 shows the solution with a splicing 12mm bar, this solution get similar results to the first proposal. At this solution the deviation observed wasn't so pronounced and this solution can easily be applied in a real situation.

- The Figure 5 presents the solution welded top to top with continuous cord isn't feasible at work, this solution doesn't present a proper behaviour, and at least, one specimen broke in the welding.
- Figure 6 represents the solution welded top to top with discontinuous cord, however this solution has a poor behaviour than the solution with continuous welding cord, this solution doesn't present any yielding baseline and have some cases that broke by the weld, appearing a fragile rupture which conditioning the global behaviour of repaired structure.

From the results analysis of different solutions tested, solution that presents best results and which introduces the minor perturbation of initial conditions and guarantees a good conditions and behaviour is the solution with a 12mm splicing steel bar. This solution can be done placing the bar at the core section of the column to guarantee that wouldn't cause problems placing and lashing the transverse reinforcement.

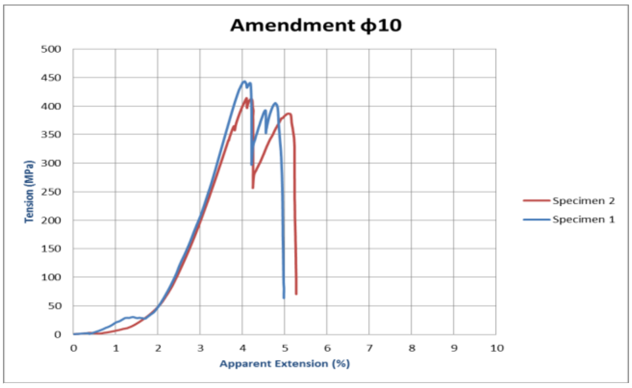

Figure 3 Maximum tension to apparent extension to solution a

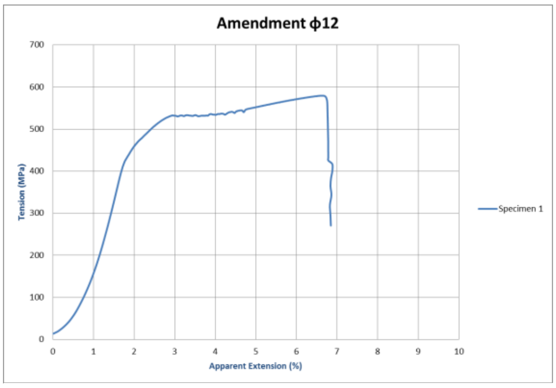

Figure 4 Maximum tension to apparent extension to solution b

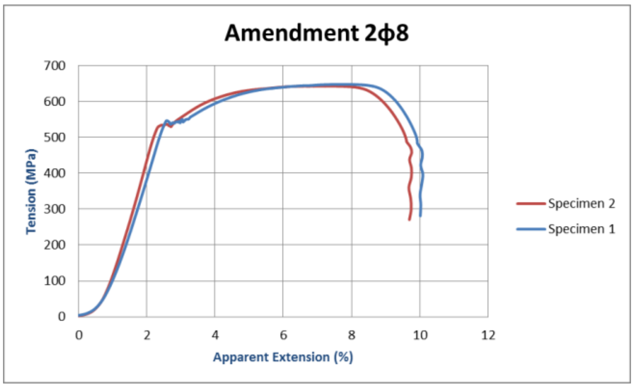

Figure 6 Maximum tension to apparent extension to solution c

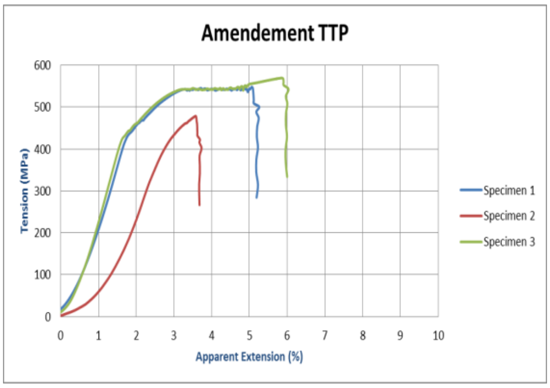

Figure 5 Maximum tension to apparent extension to solution d (TTP)

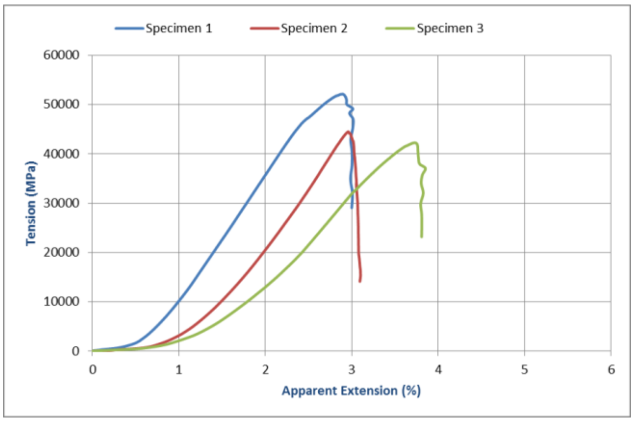

Figure 7 Maximum tension to apparent extension to solution d (TTO)

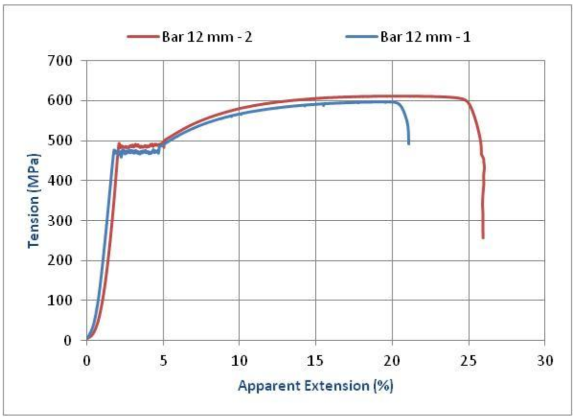

Figure 8 Maximum tension to apparent extension to original bars

RESULTS ANALISYS OF TESTED COLUMNS

This section presents the application of the chosen technique of repairing steel bars in a tested column. The original column tested is the PC12_ N05, that column was tested with a biaxial load path with 45^{o} inclination at cross section, which implies the same displacement for weak and strong direction.

The repaired specimen were tested with the same load path, this specimen was repaired at all length of plastic hinge, about 50cm, at this area was improve the transversal reinforcement space from 15cm to 7.5cm, that duplicate the transversal reinforcement area. The repaired area was filled with grout and all longitudinal bars were repaired with the same solution.

The Figures 7 and 8 shows the two specimens tested.

Figure 9 PC12_N05

Figure 10 PC12_N03R

In Figures 9 and 10 is present a comparison of horizontal load vs. horizontal displacement in both directions for the initial and repaired solution. It possible to observe that at this test:

- it was possible to improve that load capacity, namely, to negative side at weak direction about 20%;
- The ductility improved, and has a resultant displacement of 75mm to repaired column. This significant ductility improvement can be explained by the increasing of transversal reinforcement area improvement;
- This repairing solution delayed the stiffness decay, which happened only after passing the maximum displacement of original column.

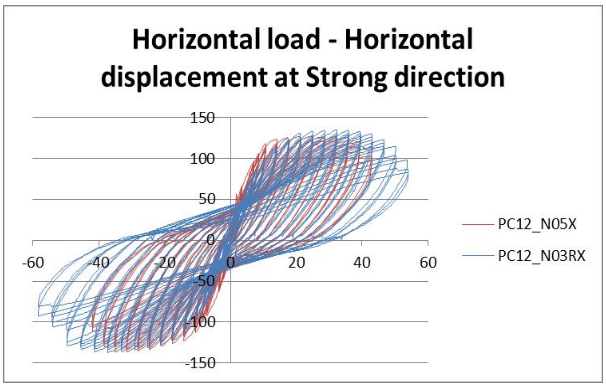

Figure 11 Horizontal load - horizontal displacement at strong direction

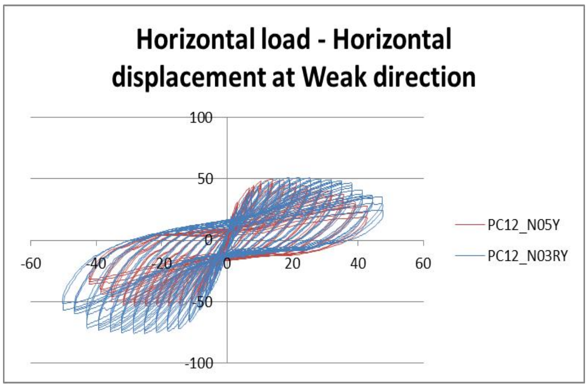

Figure 12 Horizontal load - horizontal displacement at weak direction

CONCLUSIONS

From the experimental assessment of the structural response of RC columns the main finding were: The repaired columns showed an excellent behavior, with a simple solution was possible to restore the original capacity of the column, that solution can easily be done in a real situation to do that is only need to take out the old concrete, increase the shear reinforcement area and fill again with concrete.

The repaired solution allowed restoring and improving the original ductility. The original load capacity was restored with this solution. Although was observed a small decrease of initial stiffness, this was the only negative point observed, but the maximum load was restored.

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