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C-FRP ROPES AS EXTERNAL STRENGTHENING REINFORCEMENT OF RC COLUMNS

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Abstract

Deficient columns and joints of common reinforced concrete structures constructed according to old seismic regulations and practices or without seismic design often lead to local or even global failure. Easy-to-apply techniques based on Near Surface Methods (NSM) for the strengthening of columns have been recently proposed. The innovative material of Carbon-Fiber Reinforced Polymer (C-FRP) ropes is applied as external reinforcement for the strengthening of reinforced concrete columns and the body of the adjacent joint. A real-scale specimen externally strengthened with C-FRP ropes and a pilot specimen with the same geometrical and mechanical characteristics have been constructed and tested under the same cyclic loading sequence. All C-FRP ropes have been placed into notches curved on the concrete surface (NSM). The strengthened column compared to the unstrengthened pilot specimen exhibited improved hysteretic capacity in terms of maximum loads, stiffness and energy dissipation per

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loading step. Therefore, it can be concluded that the application of the C-FRP ropes as external strengthening reinforcement has been an efficient strengthening technique.

Keywords: Reinforced Concrete, Beam-column connections, C-FRP ropes, Cyclic tests, Hysteretic response.

1 INTRODUCTION

The seismic process that causes damage to the reinforced concrete elements of the constructions and therefore repair and strengthening are research fields of utmost importance for both safety and economic reasons. Conventional techniques use reinforced concrete and steel bars as repairing and strengthening materials. However, materials such as C FRP in composite sheets can repair the damage and strengthen a reinforced concrete structural element, as well (Karayannis and Sirkelis 2008) [1]-[8].

Recently, carbon fiber materials in the form of flexible ropes have been proposed as alternative solutions to strengthen buildings [9]-[18]. The advantages of these materials are the high tensile strength, the small specific weight and the high resistance to fire protection. They are used as external surface reinforcements in reinforced concrete elements. It is emphasized that C-FRP ropes are characterized by high tensile strength and linear elastic stress-strain response and cannot receive compressive forces. They present a brittle behavior. It is emphasized that their shear strength is negligible.

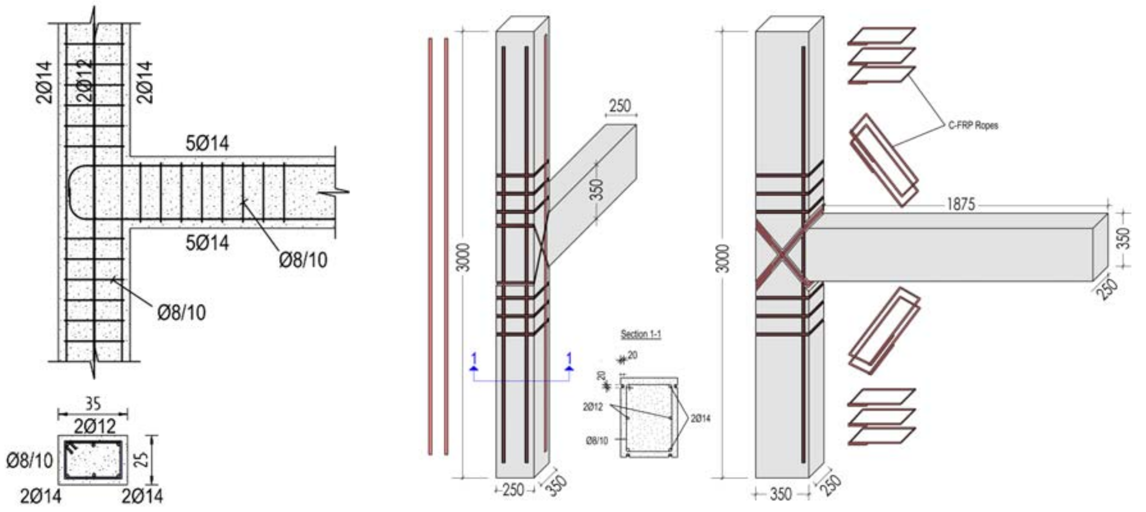
Also, another disadvantage is their high cost. On the other hand, although their use as surface reinforcement of elements is very attractive due to their easy application. The experimental results of their application so far have shown a very innovative and easy-to-use technique.

The present work investigated the effectiveness of technical reinforcement C-FRP ropes placed in U-shaped grooves carved into the surface of the reinforced concrete column. Special attention is paid to the reinforcement of the beam-column joint area. Apart from the quick and easy application of the ropes, their application does not change the geometrical elements of the construction.

2 CHARACTERISTICS OF THE SPECIMENS

Cross-sections, dimensions, materials and reinforcement arrangements of the specimens were chosen in the way that both specimen (Sp0V), (Sp0VF2X2c) represents common RC buildings designed according to earlier codes without the proper shear reinforcement in the joint body. Specimen Sp0V, are pilot specimens (Figure 1a) whereas the other specimen Sp0VF2X2c (Figure 1b) has been strengthened using carbon fibre ropes.

The total length and cross-section of the column are 3.0 m and 250/350 cm, respectively, whereas the free length and the cross-section of the beam are 1.875m and 250/350 cm, respectively. The tested specimens, their names, the geometrical characteristics and the reinforcement arrangements are presented in Figure 1 and Table 1.



(a) **(b)**

Figure 1: steel reinforcements(a), applications of C-FRP ropes as external reinforcement (b)

		Geometry and Reinforcement (in mm)			
Name	<u>Joint area</u>	<u>Beam</u>		<u>Column</u>	
	Steel	Cross-section	Beam	Cross-section	Steel
Sp0V	-	{250×350}	5∅14 up 5∅14 bot. ∅8/100	{250×350}	4∅14 2Ø12 ∅8/100
Sp0VF2X2c	2x C FRP				

Table 1: Geometrical and reinforcement characteristics of the tested exterior beam-column joint specimens.

2.1 Application of the C-FRP ropes

The applied strengthening procedure includes the following operations:

a) determining and marking the location of the C-FRP ropes placement
b) U-grooves 25 mm deep and 30 mm wide in the aforementioned positions
c) holes Ø16 mm and 80 mm deep at the free anchoring ends of the C-FRP ropes
d) coating of epoxy resin in the notches using a small paintbrush
e) placing the epoxy-impregnated C-FRP ropes in the U-grooves
f) placing the free ends of C-FRP ropes in the anchor holes
g) filling the U- grooves with a special epoxy resin

Thus, in specimens Sp0VF2X2c, two (2x) carbon fibre ropes have been used for the strengthening of the column and the joint body. The placement of the cords on the surfaces of the column is done on the right and left towards the side of the beam and on its back side. (Figure 2a)

(a) **(b)** **(c)**

Figure 2: Real scale specimens. Notches (a) and placement of the ropes - strengthening of the joint area and column (b, c)

2.2 Materials

The compressive strength of the concrete used for the specimens was measured by supplementary compression tests of six standard D×h=150×300 mm cylinders. The mean value at the age of 28 days was f_c=34 MPa. The steel of the longitudinal bars and the stirrups was B500C with yield tensile strength fy=550 MPa. The Carbon Fibre Ropes (also called Carbon Fibre Strings) used for the strengthening of the tested connections are SikaWrap® FX-50 C and their tensile tics and the reinforcement arrangements are presented in Figure 1b and Table 1. strength is given equal to 4000 MPa (ASTM4018); further their modulus of elasticity in tension is 240 GPa and the cross section based on the carbon fibre content is $A_s \geqslant 28$ mm^2.

2.3 Loading setup

The loading procedure of the specimens includes full reverse cyclic deformations that are applied near the free end of the beam. The examined beam-column subassemblages are subjected to seven loading steps and each step comprised three full cycles as shown in Figure 3. The used loading program permits the evaluation of the structural performance parameters of the specimens. Tested specimens suffered seven loading steps with maximum displacements equal to ±8.5 mm, ±12.75 mm, ±17.0 mm, ±25.5 mm, ±34.0 mm, ±51.0 mm and ±68.0 mm at each step, respectively; thus the loading sequence was performed as shown in Figure 3.

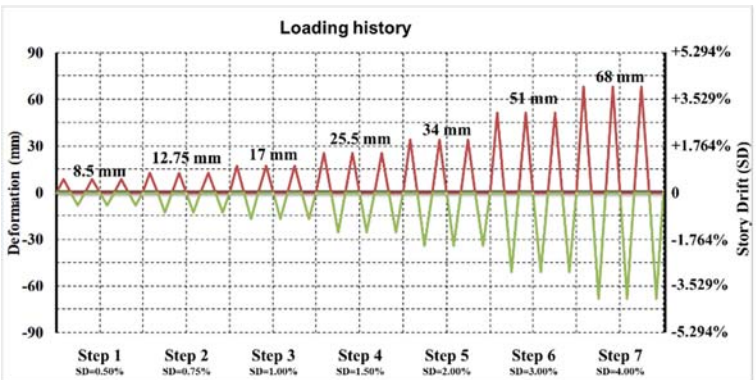
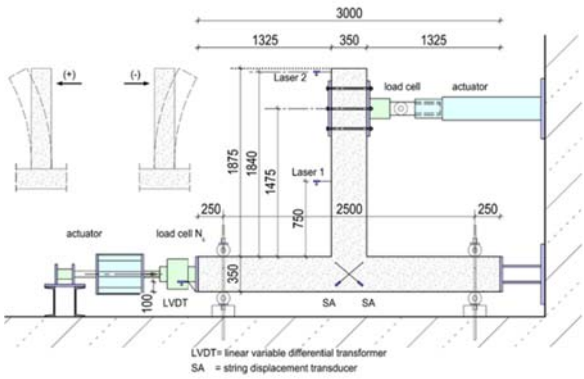


Figure 3: Loading procedure

The experimental setup and the instrumentation are shown in Figure 4. Each beam-column joint specimen is placed after 90° counter clockwise rotation in the way that the column is in the horizontal direction whereas the beam is in the vertical direction. The specimen is supported by rotational devices that allow rotation in order to simulate the inflection points of real columns in the middle of their deformable heights.

Compressive axial load equal to N_c=150 kN is applied to the horizontally placed column element throughout the testing procedure. This loading is almost equal to 5% of the nominal strength of the concrete section of the column (N_c=0.05$A_c f_c$).



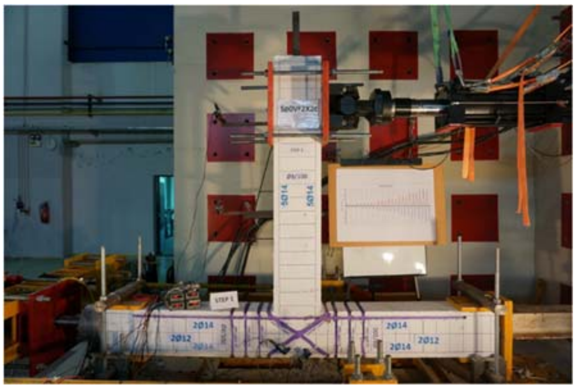


Figure 4: Test setup

3 TEST RESULTS AND DISCUSSION

For the evaluation of the efficiency of the studied retrofitting procedure the overall performance of each original beam column joint is examined and compared to the performance of the corresponding retrofitted one in terms of hysteretic responses and energy dissipation curves.

3.1 Hysteretic responses - Load carrying capacity

The effectiveness of the strengthening method is studied based on the overall behavior of the tests. The hysteretic responses of the tested specimens are presented in figure 5. In this figure the hysteretic curves of the unstrengthened specimen Sp0V and the strengthened specimen Sp0VF2X2c are presented in figures 5a and 5b, respectively.

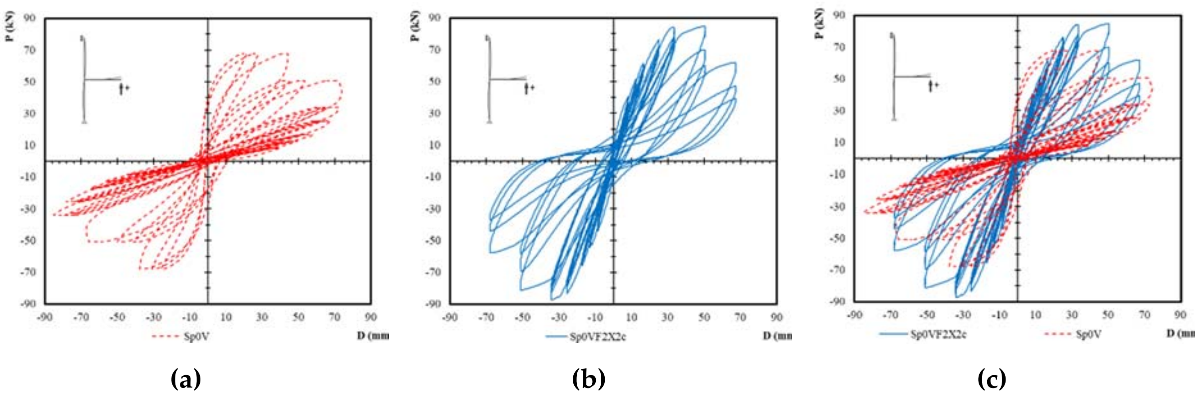


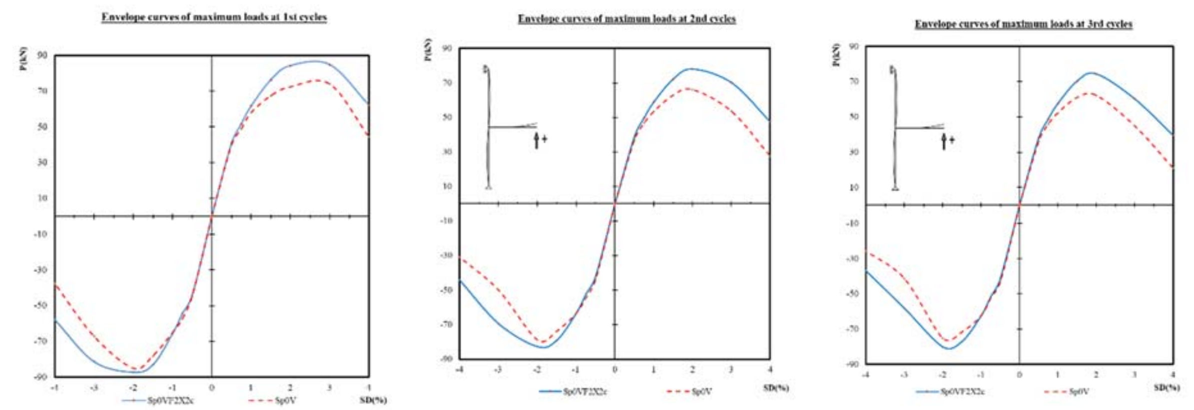
Figure 5: (a) Hysteretic response of the specimen Sp0V and (b) hysteretic response of the corresponding strengthened specimen Sp0VF2X2c. (c) Comparative presentation of the hysteretic responses of specimens Sp0V-Sp0VF2X2c

Further, the responses of both specimens are presented in the same diagram (figure 5c) for comparison reasons. From these comparisons, it can be concluded that the specimen with the C-FRP ropes as external reinforcement exhibits substantially improved behavior compared to the corresponding unstrengthened specimen in terms of load carrying capacity per loading cycle.

(a) (b)

Figure 6: Damage state at the of the loading (a) Cracking of specimen Sp0V and (b) Cracking of strengthened specimen Sp0VF2X2c

Figure 6 presents the damage state of the examined specimens at the end of the testing procedure. In the first specimen (Sp0V) cracks have been formed from the beginning of the loading sequence in the joint body. Subsequent loading cycles resulted in a gradual increase of the width of the cracks across the joint region and finally the concrete of this region was partially fragmented severely damaged as shown in figure 6a. On the contrary, in the other specimen (Sp0VF2X2c) hairline cracks were observed during the first loading cycles at both the joint region and the end of the beam; in subsequent loading cycles, however, cracks did not cause fragmentation of joint body and at the end of the loading procedure the specimen's damage can be characterized as moderate as shown in figure 6b.

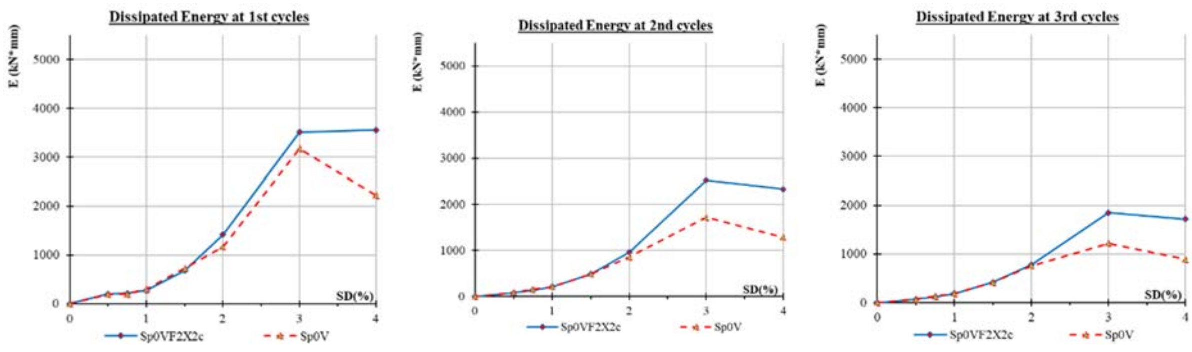


(a) **(b)** **(c)**

Figure 7: Comparison of the envelopes of the hysteretic responses of the strengthened column (Sp0VF2X2c) to the pilot (unstrengthened) specimen (Sp0V). Envelope curves of the maximum loads at the 1st cycle (a), 2nd cycle (b) and 3rd cycle of each loading step.

Comparisons of the envelope curves of the maximum loads at the 1st cycle (a), 2nd cycle (b) and 3rd cycle of each loading step are presented in figures 7a, 7b and 7c, respectively. The improved capacity of the strengthened specimen is apparent in the comparisons between the envelopes of the hysteretic responses of the two specimens (figure 7).

3.2 Dissipated energy capacity



(a) **(b)** **(c)**

Figure 8: Comparison of the dissipated energy of the two specimens. Comparisons of the dissipated energy of the 1st cycles (a), of the 2nd cycles and of the 3rd cycles of each loading step. The improved energy dissipating capacity of the strengthened specimen (blue lines) is clearly observed especially in the 6th and 7th loading steps or 2% and 3% story drift (SD), respectively.

Comparisons of the dissipated energy at the 1st cycles (a), 2nd cycles (b) and 3rd cycles of each loading step are presented in figures 8a, 8b and 8c, respectively. The improved capacity of the strengthened specimen becomes apparent in the comparisons between the two specimens (figure 7) in the 6th and 7th loading cycles (or story drift equal to 2% and 3%, respectively).

4 CONCLUSION

The use of C-FRP ropes as external reinforcement both at the joint area and the column was experimentally investigated.

It is concluded that the hysteretic response in terms of maximum loads per load step of the strengthened specimen is improved with respect to the unstrengthened one.

Also, the dissipated energy capacity of the strengthening specimen is higher than the one of the unstrengthened specimen.

Finally, but not least, the observed damage of the joint body of the unstrengthened specimen is apparently more severe than the one of the strengthened specimen.

Therefore it can be concluded that the presented strengthening technique proved to be efficient and easy to apply.

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