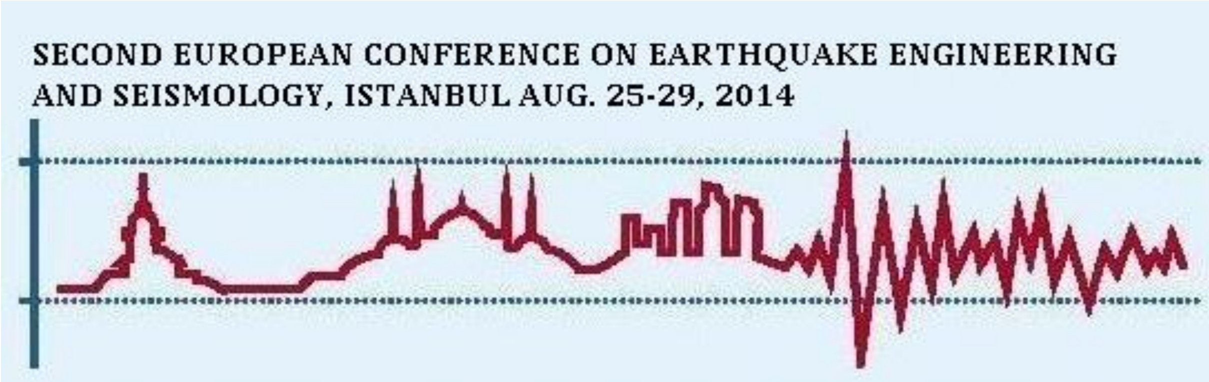

DELAYING REINFORCED CONCRETE BEAM CRACKS USING CFRP (NUMERICAL MODELING)

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ABSTRACT

The main objective of this work is to analyze the beneficial effect of strengthening RC[4] beams figure (2) under concentrated loads, using CFRP[5] laminates and sheets for delaying concrete cracks on the flexure behavior, by developing a numerical models with solid elements figure, considering all components of the beam (longitudinal and transversal steel, concrete and CFRP).

To realize a linear analysis for five (05) RC beams using different combinations of strengthening with CFRP used currently in Algeria; we used commercial software based on the finite element method RSA (AUTODESK ROBOT STRUCTURAL ANALYSIS), this strengthened RC beams are tested on the ENSP[6] laboratory in Algeria by Laichaoui.

INTRODUCTION

There are many ways to repair and strengthen existing reinforced concrete structures; we can mention: strengthening with the additional reinforcement covered with concrete, exterior prestressed cables, adding steel plates on the damaged areas and using composite materials such as CFRP laminates and sheets, this last method is the most applicated nowadays.

The effectiveness of this technique has been studied in the case of flexural strengthening of beams (Ferrier and Chafika, 1998**)**, stepped beams (Afefy and al, 2013)**,** by confining columns (Berthet and Coll,2005 **),** rehabilitation of reinforced concrete columns (seismic and corrosive areas) (Mosallam, 2000), slabs (Ayman and al, 2003)**,** in the case of masonry (Gabor and al, 2005).

CFRP can be designed and used in the form of laminates, sheets adhesively bonded to the concrete, or rods.

In this work we have used the CFRP with different combinations to delay the RC beam cracks.

Numerical models have been developed and then their results have been compared with those obtained experimentally in Algeria.

The comparison between the numerical and the experimental results shows that our models represent the real behavior of the strengthened RC beams.

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[4] Reinforced Concrete.
[5] Carbon Fiber Reinforced Polymer.
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EXPERIMENTAL TEST

The control beam was not strengthened, and the remaining four were strengthened with different arrangements of CFRP sheets and laminates (table 1).

Beams with rectangular sections are used and subjected to a concentrated load in four-point bending load up to the occurrence of cracks , all having dimensions of 160x180x1700 mm (Figure 1) ,reinforced in accordance with the French norm BAEL 99 with 3-12 # at bottom, 2–10 # at top using 6mm diameter stirrups @ 150 mm (Figure 2).

The elastic modulus of the concrete is E=33000Mpa, we used FeE24 for the stirrups FeE40 for the longitudinal bars.

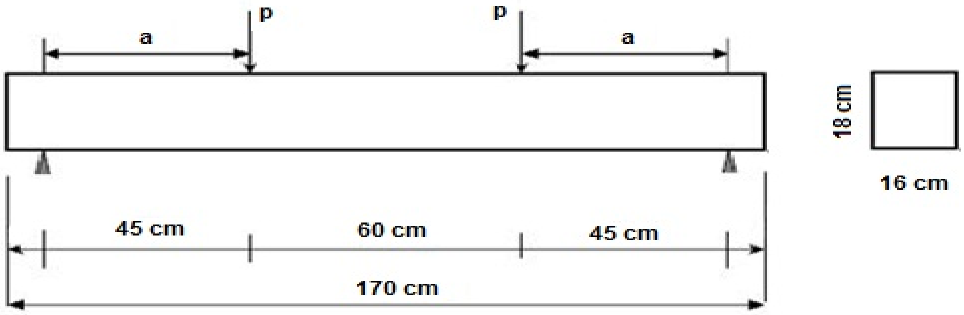


Figure 1. Longitudinal and Cross Section of the control beam

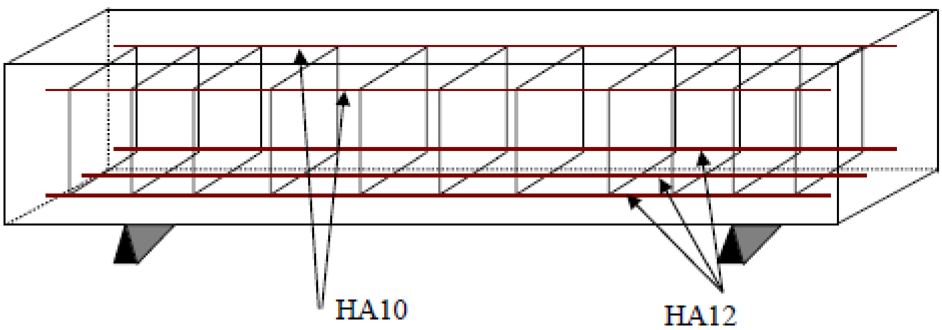


Figure 2. Concrete beams' reinforcement.

Table 1. Beam Designation

Beam type	CFRP type	CFRP properties Laminates (1,2 mm Thickness , 307 g/m^2,weight of Fiber) Sheets (0.13 mm Thickness , 225 g/m^2,weight of Fiber)							
		Length (mm)		Tensile strength (GPA)		Tensile Modulus (GPA)		Ultimate Elongation (%)	
		Laminate	sheet	Laminate	sheet	Laminate	sheet	Laminate	sheet
Control beam (CB)	/	/	/	/	/	/	/	/	/
CFRP strengthened beam (SB1)	Laminate (single layer)	1200	/		/	165	/	1.7	/
CFRP strengthened beam (SB2)	Laminate (single layer) and sheets(two sides)	1200	1200	2.8	3.5	165	230	1.7	1.5
CFRP strengthened beam (SB3)	Laminate (single layer) and sheet (covered)	1200	1200	2.8	3.5	165	230	1.7	1.5
CFRP strengthened beam (SB4)	Laminate (single layer) and sheets (six "U")	1200	520x6	2.8	3.5	165	230	1.7	1.5

NUMERICAL INVESTIGATION

The numerical program consisted of modeling all the beams, so the problem can be solved using the finite element method.

In this study the behavior of the beam is linear elastic until concrete cracks.

Up to now, Hook's law is used for the evaluation of homogeneous and isotropic beams in tension, compression or bending which is given by:

$$\sigma = E\,\varepsilon \qquad (1)$$

Where σ is the normal stress, E is the elastic modulus and ε is the tensile strain.

This law can be generalized to study the elastic structures

$$\varepsilon_{ij} = ((1+\upsilon)/E).\ \sigma_{ij} - (\upsilon/E).\ \sigma_{kk}.\delta_{ij} \qquad (2)$$

And in matrix form by:

$$\begin{bmatrix} \sigma_{LL} \\ \sigma_{TT} \\ \sigma_{NN} \\ \sigma_{LT} \\ \sigma_{LN} \\ \sigma_{TN} \end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ & 1-\nu & \nu & 0 & 0 & 0 \\ & & 1-\nu & 0 & 0 & 0 \\ & SYM & & \frac{1-2\nu}{2} & 0 & 0 \\ & & & & \frac{1-2\nu}{2} & 0 \\ & & & & & \frac{1-2\nu}{2} \end{bmatrix} \begin{bmatrix} \varepsilon_{LL} \\ \varepsilon_{TT} \\ \varepsilon_{NN} \\ 2\varepsilon_{LT} \\ 2\varepsilon_{LN} \\ 2\varepsilon_{TN} \end{bmatrix}$$

Where υ is passion's ration and δ_{ij} is the Kronicker's symbol.

FEM modeling

FEA software RSA is adopted for predicting the load displacement response of the control and strengthened beams numerically. The program offers solid B8 for beam, steel and CFRP elements (Figure 3).

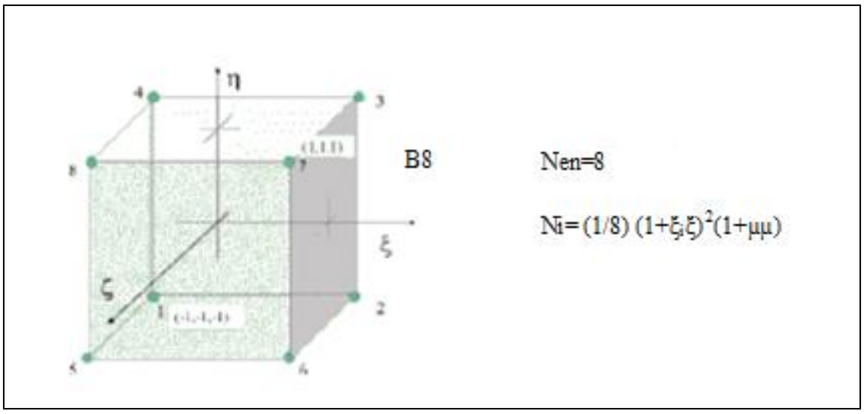


Figure 3. B8 element used on RSA

The mesh of the control beam model defined 6272 elements and 7425 nodes in order to represent the longitudinal and the transversal reinforcement, a very fine mesh is needed to obtain results of sufficient accuracy.

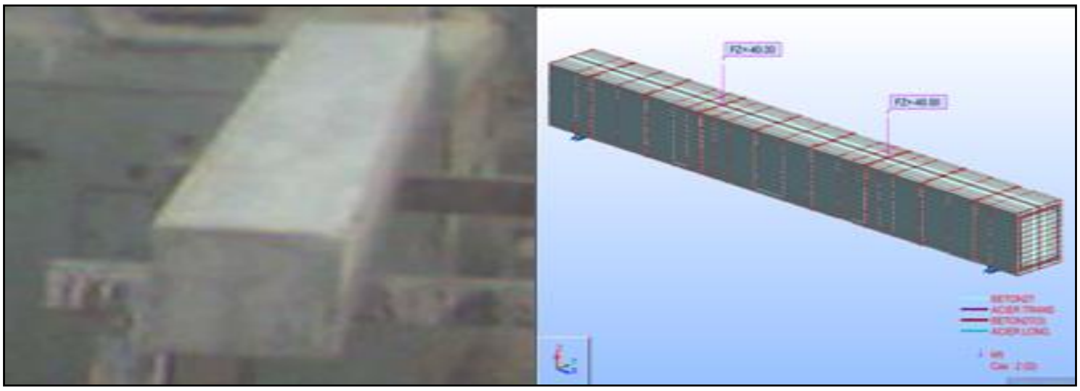


Figure 4. Control beam (CB experimental and FE model)

As it will be mentioned below, we shall use four combinations of strengthening the beams:

The first combination where the application of the CFRP laminate is limited only at the bottom of the beam (figure 5)

The mesh of this strengthned beam model defined 6416 elements and 7600 nodes in order to take in consideration the CFRP laminate.

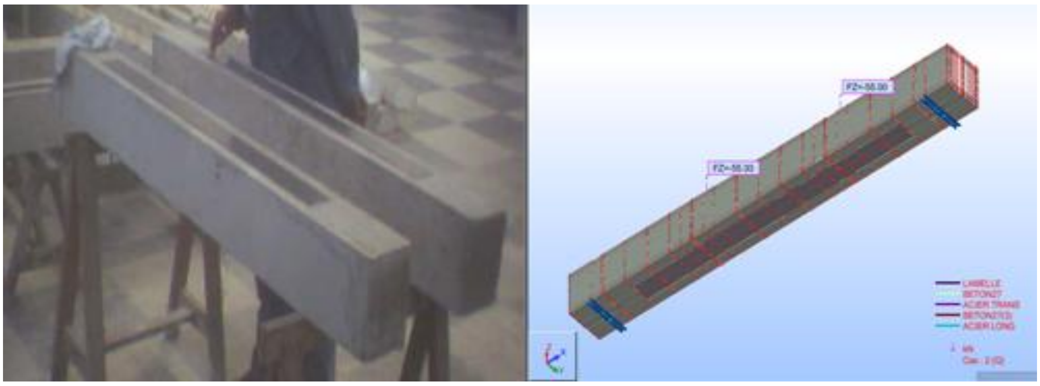


Figure 5**.** The first combination of strengthening (SB1 experimental and FE model)

For the second combination a bonded sheets are added into the first strengthened beam on its two lateral sides (figure 6).

The mesh of this strengthned beam model defined 6704elements and 7950 nodes in order to take in consideration the CFRP laminate and sheets.

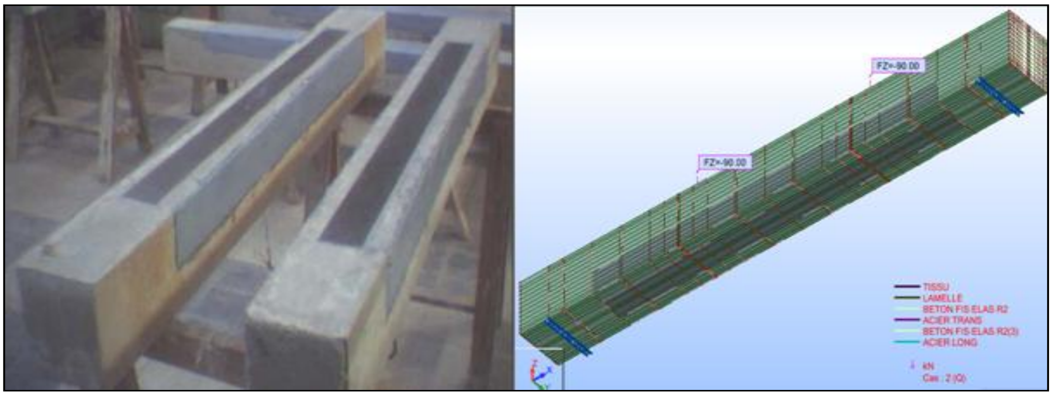


Figure 6**.** The second combination of strengthening (SB2 experimental and FE model)

One bonded sheet is used to confine the first strengthened beam; in this case the beam's bottom is completely covered by the CFRP sheet (figure 7).

The mesh of this strengthned beam model defined 7424elements and 8725 nodes in order to take in consideration the CFRP laminate and sheet.

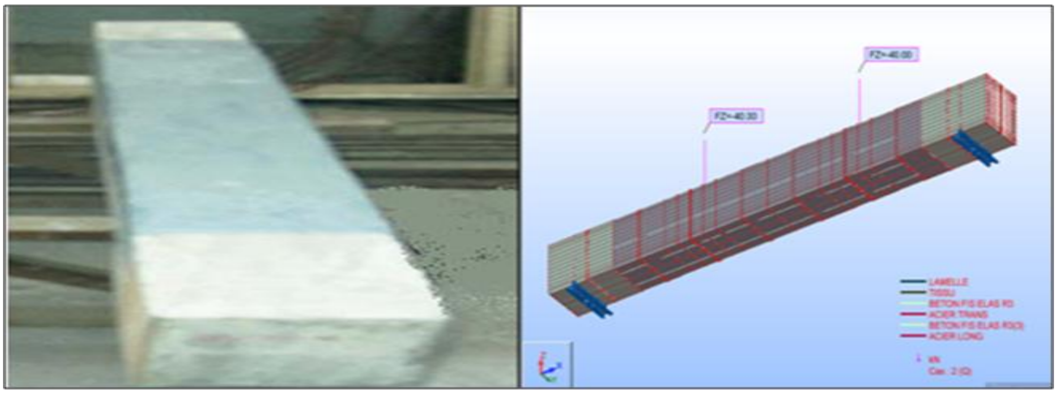


Figure 7. The third combination of strengthening (SB3 experimental and FE model)

Six “U” sheets of CFRP were added to SB1 to develop the fourth combination SB4 (figure 8).
The mesh of this strengthned beam model defined 7280elements and 8790 nodes in order to take in consideration the CFRP laminate and sheets.

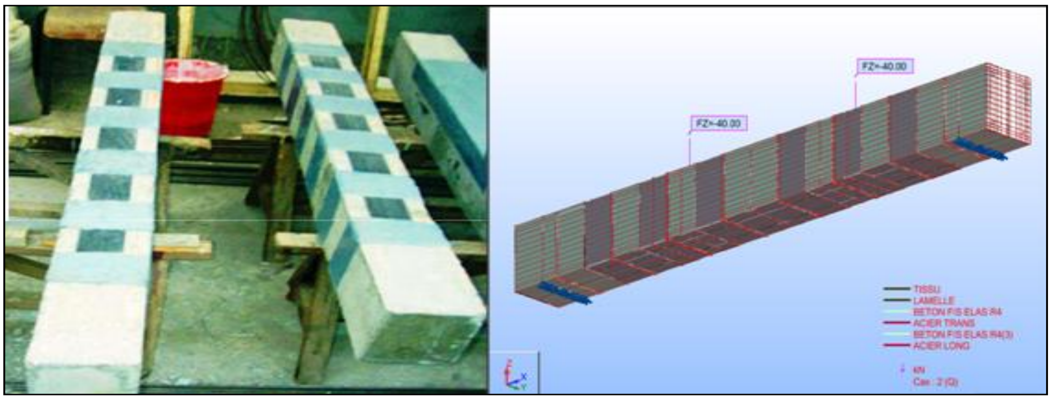


Figure 8. The fourth combination of strengthening (SB 4 experimental and FE model)

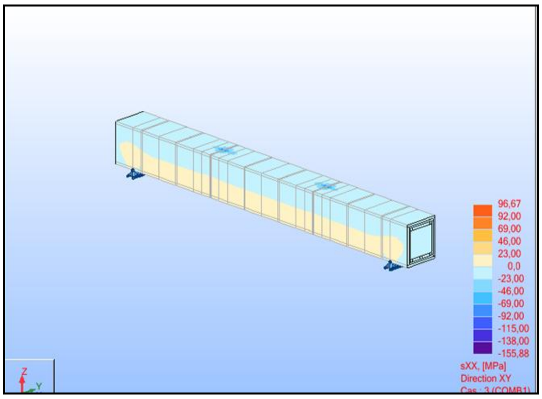
RESULTS

Based on the experimental and numerical results, we can observe that significant increase in strength can be realized at all the load values by adding CFRP sheets and laminates.

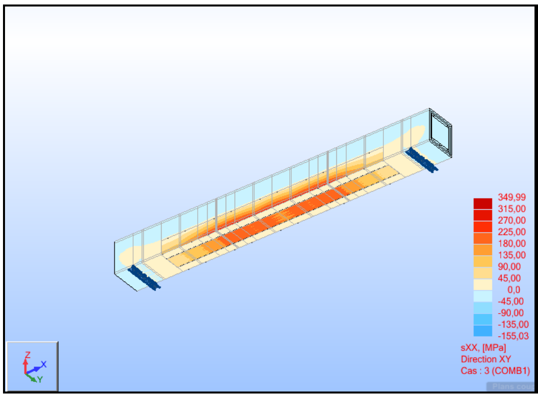
The confinement and the external bonding of beams decrease flexural stress on the concrete for all the strengthened beams (figure 9) and increase in tensile cracking strength.

The control beam has been cracked at the load of 40 KN with a 2.30 mm’s deflection and the strengthened beam SB 4 at the load of 90 KN with a 3.4 mm’s deflection.

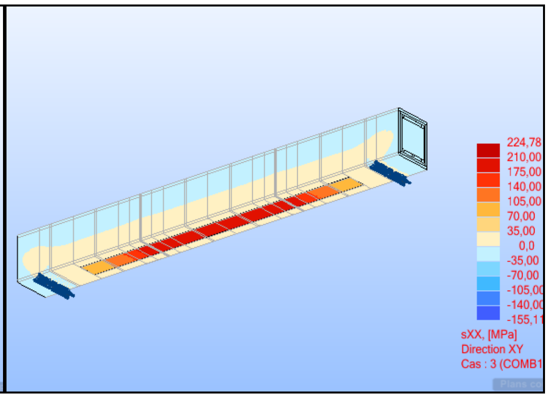
This indicates the beneficial effect of strengthening RC beams by CFRP sheets and laminates for the delaying beam cracks and the increasing of the cracking load.



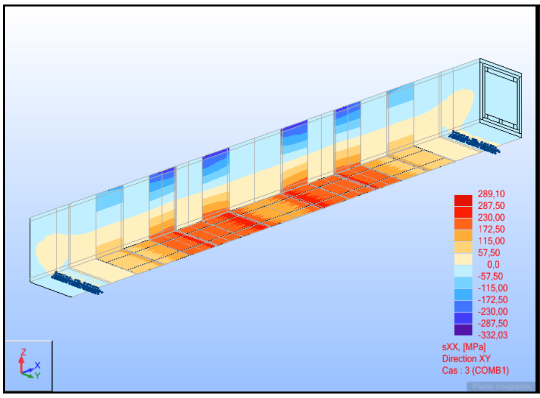
(a).



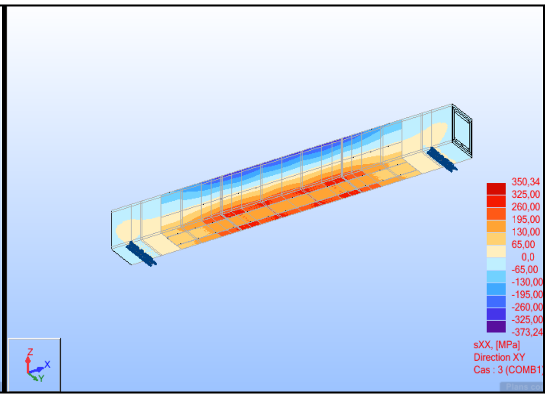
(c)



(b)



(e)



(d)

Figure 9. Flexural stress distribution for: (a) Control beam (CB), (b) Strengthened beam (SB1), (c)Strengthened beam (SB2), (d) Strengthened beam (SB3) and (e) Strengthened beam (SB4).

The load–deflection curves obtained for control beam and strengthened beams (experimental and numerical respectively) are shown in figures 10, 11.

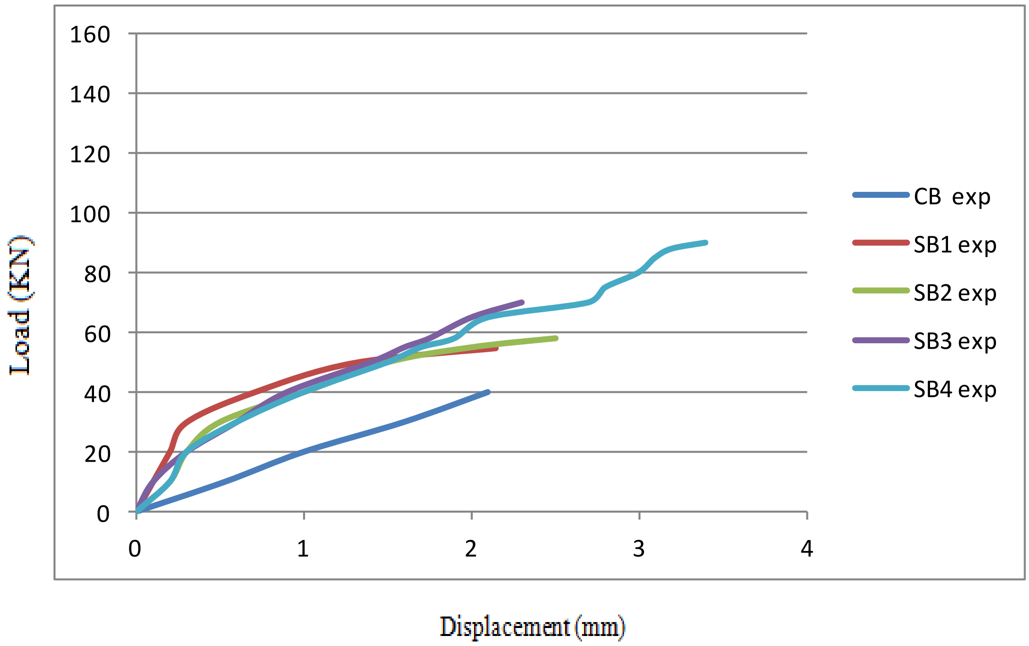


Figure 10. First cracks of the RC beams with deferent combinations (experimental).

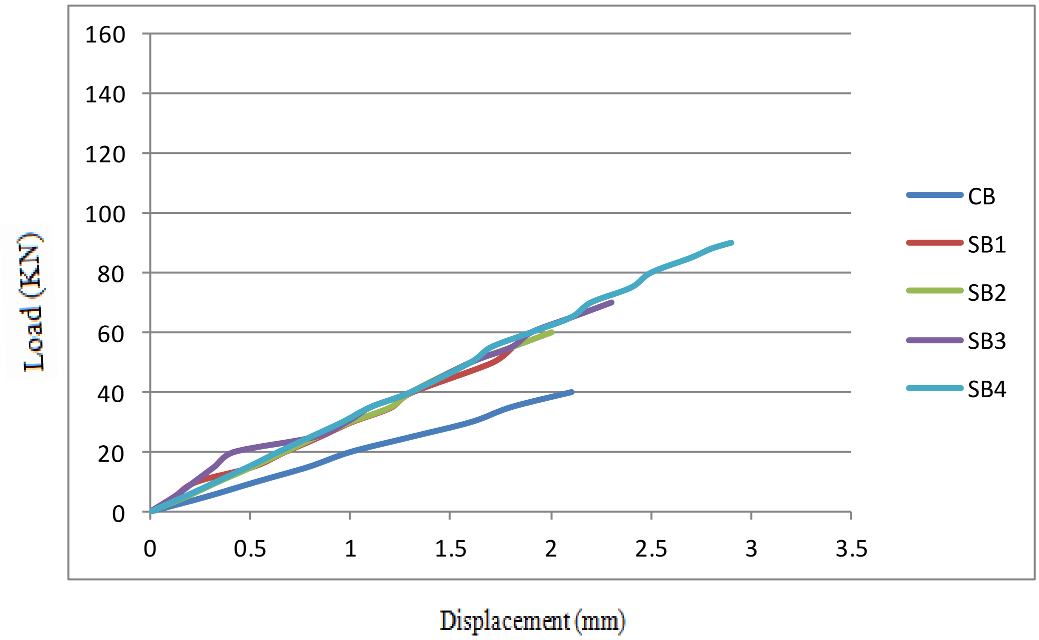


Figure 11. First cracks of the RC beams with deferent combinations (numerical).

The results of the control and strengthened beams are reported in Table 1

Table 1. Increasing the cracking load (numerical and experimental comparison).

Location	Control beam	SB1	SB2	SB3	SB4
Cracking load(KN)	40	55	58	70	90
Displacement exp (mm)	2.23	2.15	2.50	2.35	3.4
Displacement num (mm)	2.10	2.7	2.85	3.40	4.3

CONCLUSIONS

Based on the experimental and numerical results we can draw the following conclusions:

1. The adopted CFRP strengthening combinations can restore the capacity of delaying concrete
2. cracks, increase the cracking load (37 % for SB1, 45% for SB2, 75% for SB3 and 125% for SB4) and decrease relatively deflection for all combinations.
3. The strengthened beam SB4 present the best performance of delaying concrete cracks (125 %), this is due to the double strengthening by the laminate and sheets (laminates delay flexural cracks and "U" sheets delay shear cracks) and the "U" sheets position.
4. Both results experimental and numerical show almost the same deflection value at mid-span for fist cracks between SB1 and SB2.This is due to the same strengthening at the bottom.
5. In this work, strengthened beam gives appreciable delaying concrete cracks when compared to control beam.
6. Reducing the beams deflections significantly is observed during the loading stages, thereby increasing strengthened beams' stiffness
7. The numerical results show good agreement with the experimental results; elastic isotropic behavior was used to represent the strengthening behavior.

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