Investigations to the Parameters Effecting Shear Strength of RC Beams Strengthened with CFRP Laminations

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ABSTRACT - This paper focuses on the strengthening of reinforced concrete beams deficient in shear using external bonded Carbon Fiber Reinforced Polymer CFRP laminations. The CFRP laminations can be used to enhance the shear capacity of beams and to change the mode of failure from shear to flexure. The investigation is made in order to estimate the contribution of CFRP reinforcement to the shear capacity of strengthening reinforced concrete beams. The finite element method presented by ANSYS software used for modeling the reinforced concrete beam with CFRP strengthened. The model makes use of the ANSYS software abilities to evaluate the effects of number of parameters (CFRP strap height and thickness, carbon fiber direction with respect to beam longitudinal axis, concrete compressive strength, CFRP strip width and spacing) that are important in the response of the strengthened beam in shear. The numerical results are presented and discussed and conclusions drawn.

Keywords: Reinforced concrete beams; Finite element method; CFRP laminations; Shear.

1. INTRODUCTION

Throughout the world, an increasing number of reinforced concrete structures are being assessed as having inadequate shear capacity. The reasons for this include, design codes used in earlier years being less stringent than today's standards and, in some cases deterioration of the internal steel reinforcement. Even for structures designed adequately, loads greater than the design capacity is being applied and thus the structures have been rendered unsafe. Such structures must be strengthened in order to serve their intended purpose. External Carbon Fiber Reinforced Polymer CFRP strips provide means of increasing the shear capacity of a concrete beam [1]. Carbon fibers are the predominant reinforcement

used to achieve high stiffness and high strength. The term carbon fiber (graphite fibers in the USA) covers a whole family of materials which encompass a large range of strengths and stiffness. The density of carbon fiber is of the order of *1900 kg/m³*. Typical fiber module may be *230–300GPa*, whilst strengths after processing are in the range of *3000–5000MPa*. Carbon fiber is most commonly produced from a precursor of polyacrylonitrile PAN fiber which is processed by first stretching it to achieve a high degree of molecular orientation. It is then stabilized in an oxidizing atmosphere while held under tension. The fibers are then subjected to a carbonizing regime at a temperature in the range *1000–3500° C*. The degree of carbonization determines such properties as elastic modulus, density and electrical conductivity. As an alternative to the use of PAN, routes via the use of pitch and rayon have been successfully utilized and such fibers are commercially available. These fibers tend to be of lower performance than PAN-based fibers; they are also cheaper due to their use of a lower cost precursor [2]. However, it is more difficult to study the behavior of shear strengthened reinforced concrete beams, because the behavior and ultimate strength of shear upgraded reinforced concrete structures depends on many factors such as: concrete compressive strength, composite material strength, steel yield stress, longitudinal steel bar cross-section in flexural region, internal vertical steel cross-section, stirrups spacing, strengthening area, shear span to effective depth ratio, thickness of the composite material and strengthening technique[3].

The objectives of this work are to study the shear strengthening effectiveness with CFRP strips, reinforced concrete beams with shear deficiencies before strengthening. This work deals with the influence of the CFRP strap length, strap thickness, fiber direction, concrete compressive strength f_c', and CFRP strip width and spacing. The analytical investigation is made in order to estimate the contribution of CFRP reinforcement to the shear capacity of strengthening reinforced concrete beams. Successful use of a finite element method presented by ANSYS software [4] for modeling of reinforced concrete beam with CFRP strengthened has been reported in this paper. The model makes use of the ANSYS software to evaluate the effects of different parameters that are important in the response of the strengthened beam in shear.

2. RESEARCH SIGNIFICANCE

While experimental methods of investigation are extremely useful in obtaining information about the composite behavior of CFRP and reinforced concrete, the use of

numerical models helps in developing a good understanding of the behavior at lower costs. Therefore, this paper provides the results of the structural evaluation of different strengthening cases for reinforced concrete beams. In the use of CFRP straps or strips to enhance the shear strength of reinforced concrete beams, it is crucial to understand the effects of the CFRP reinforcement on the beam failure mode, particularly for the development of the rational design criteria under ultimate loads. The parametric investigations presented here emphasize on the effects of CFRP different conditions on the failure mechanism of a reinforced concrete beam.

3. FINITE ELEMENT MODELING

The finite element model represents only a quarter of the full size beams used in the tests by Ayman S.Mosallam, Swagata Banerjee [5]. The symmetry and anti-symmetry boundary conditions are used at the boundaries in order to simulate the full beam adequately. As is seen in Figure 1, the beam length is *3.62m* and its clear span *2.44m*. The height of the beam is *0.25m* and its width *0.15m*. Reinforcements include two compression bars of *10 mm* diameter, two tension bars of *13mm* diameter together with *10mm* diameter stirrups at *0.61m* center to center spacing. Concrete compression strength is *27.54 MPa*, and yield stress of reinforcements is *420 MPa*, concrete modulus of elasticity is calculated from $E_c = 4700 \sqrt{f_c'}$ [6]and concrete cracking stress or rupture module is taken as $f_t = 0.62 \sqrt{f_c'}$ [6] while the Poisson's ratio for concrete is considered as *v = 0.2*. Steel modulus of elasticity is taken as *200GPa*, and it's Poisson's ratio as *v = 0.3*.
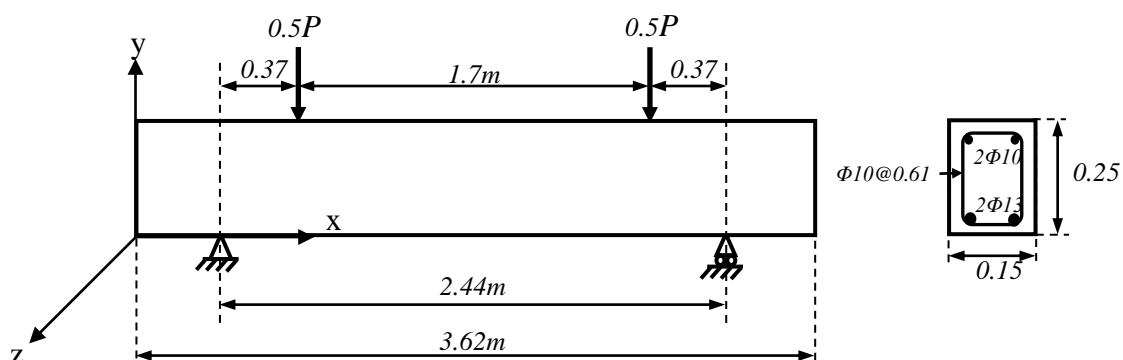

Fig.(1):- Beams geometry and reinforcements array [5].

The concrete is modeling using solid65 element [4]and it is assumed to behave as a homogeneous and initially isotropic material. The multilinear isotropic representation for

compressive uniaxial stress-strain relationship for concrete model will be used in the present study [7].

A link8 element [4] was used to model steel reinforcement. It is further assumed that steel behaves in an elastic perfectly plastic manner while strain hardening is ignored. A perfect bond between the concrete and steel reinforcement considered. However, in the present study the steel reinforcing was connected between nodes of each adjacent concrete solid element, so the two materials shared the same nodes. The same approach was adopted for CFRP composites.

A Solid 45 element [4] was used to model steel plates that added at support and loading locations in the finite element models in order to avoid stress concentration problems, an elastic modulus equal to *200GPa* and Poisson's ratio of *0.3* were used for the plates.

A Solid 46 layered element [4] was used to model CFRP composites [7]. The study assumes that high strength epoxy must be used to attach CFRP sheets to the beams which supported the perfect bond assumption. Properties used for carbon fiber materials are as shown in Table 1 below.

Table (1):- Summary of material properties for CFRP composite [8].

Elastic modulus (MPa)	Major Poisson's ratio	Shear modulus (MPa)
$E_x = 62000$	$v_{xy} = 0.22$	$G_{xy} = 3270$
$E_y = 48000$	$v_{xz} = 0.22$	$G_{xz} = 3270$
$E_z = 48000$	$v_{yz} = 0.30$	$G_{yz} = 1860$

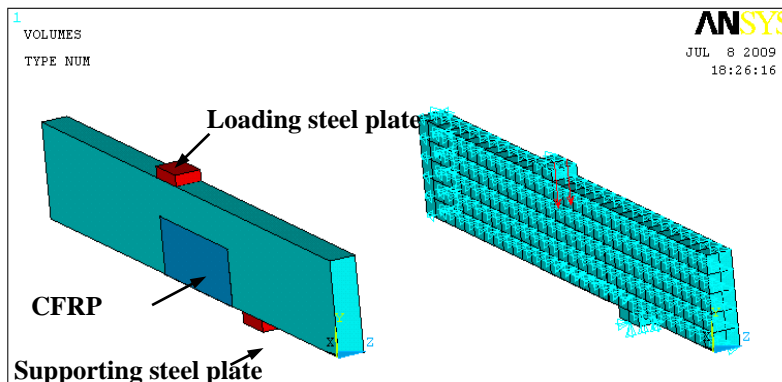The finite element mesh, boundary condition and loading regions of the beam are shown in Figure (2).

**Fig.(2):-** Geometry of model in ANSYS program, considering symmetry.

## 4. EVALUATING THE EFFECT OF DIFFERENT PARAMETERS

In this section, the beam with geometry and material properties mentioned previously used to examine the effect of different parameters such as CFRP strap height and thickness, fiber direction with respect to beam longitudinal axis, concrete compressive strength, CFRP strip width and spacing are examined in order to find the best way that can be used to strength the reinforced concrete beam.

4.1 Effect of Strap Height

Five different values of CFRP strap height used to evaluate the height effect on the reinforced concrete beam strength, the height values taken as a portion of the beam height *h*. Figures (3a) and (3b) show the load-deflection curves and load-maximum compressive strain curves for concrete respectively obtained for beams with different values of CRFP strap height. As is seen, the ductile behavior increases with increasing the CFRP strap height, but the maximum increase in the ductility obtained by using strap height equal to *0.6 h*. Further investigation related to the behavior of beams shall be carried out considering a strap height of *0.6h (150 mm)*.
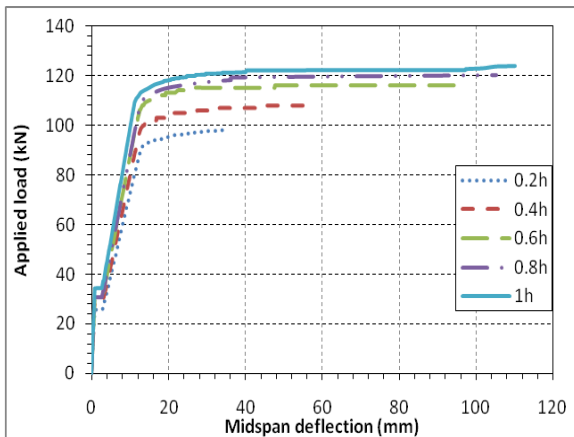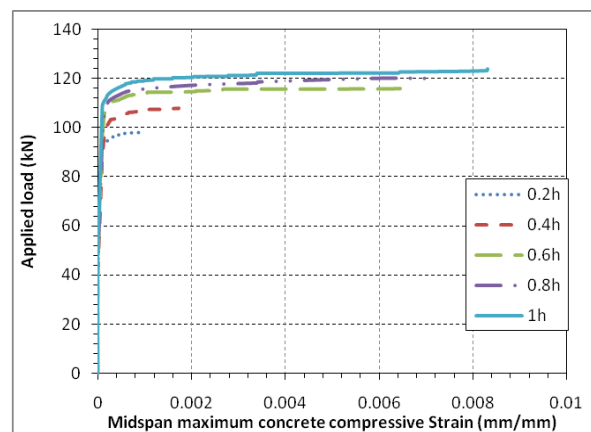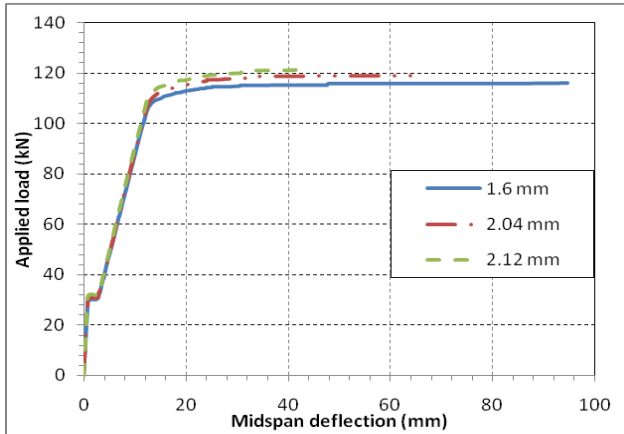

a. Load-deflection curves   **b.** Load-compressive strain curves for concrete

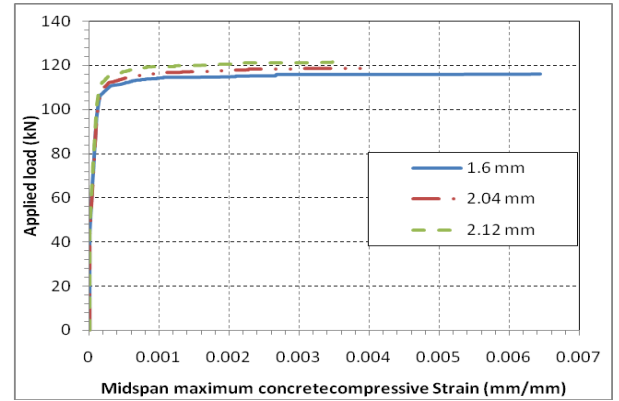**Fig.(3):-** Evaluation of the effect of CFRP strap height.

4.2 Effect of Strap Thickness

Figures (4a) and (4b) show the load-deflection curves and load-maximum compressive strain curves for concrete respectively obtained for beams with different values of CRFP thickness. The ultimate load capacity of the beams increases with the increasing of the thickness of CFRP strap, but the same time there is a decrease in the beam ductility. The decrease in beams ductility occurs due to the bond failure between concrete and CFRP laminates, therefore, the best thickness of CFRP laminates is *1.6 mm*, and further investigation shall carry out considering a thickness of *1.6 mm* for CFRP laminates.

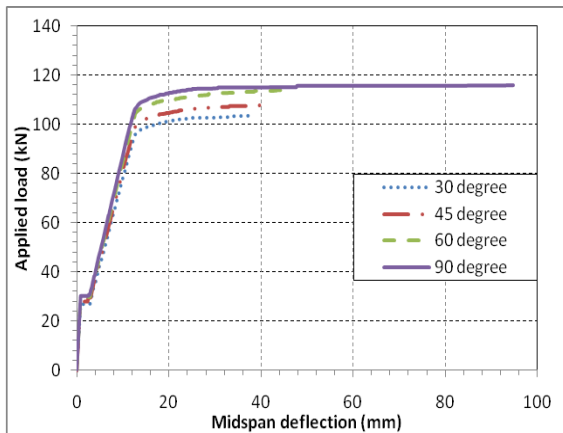**a.** Load-deflection curves.

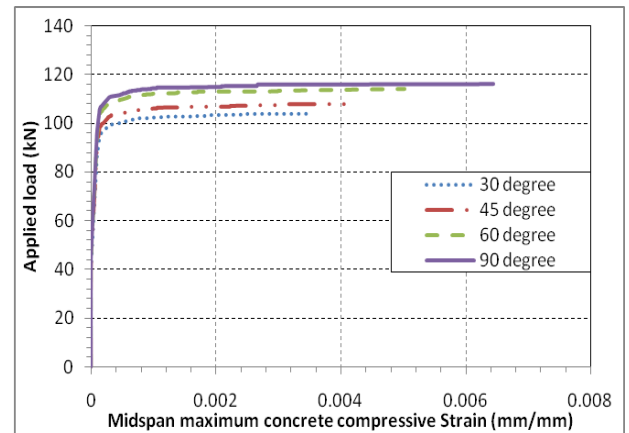**b.** Load-compressive strain curves for concrete

Fig.(4):- Evaluation of the effect of CFRP strap thickness.

4.3 Fiber Orientation

In this section the carbon fiber used in CFRP laminates assumed to be in different angles with respect to the beam longitudinal axis. Figures (5a) and (5b) show that the 90 degrees orientation provides the highest strength gain and a more favorable (ductile) behavior. Further investigation related to the behavior of beams area therefore carried out considering a 90 degrees orientation.

a. Load-deflection curves.

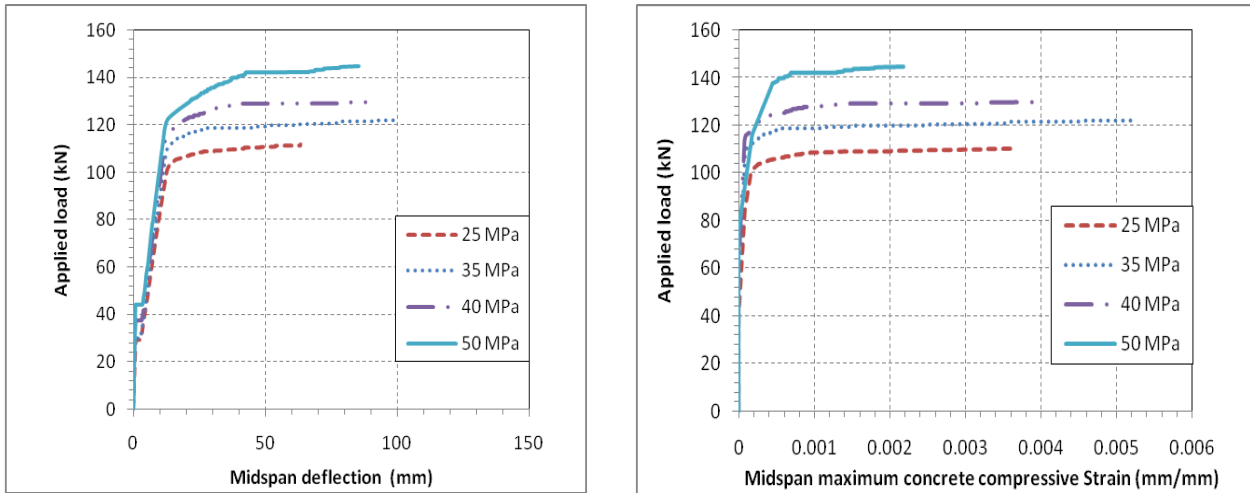**b.** Load-compressive strain curves for concrete

Fig.(5):- Evaluation of the effect of fiber orientation.

4.5 Concrete Compressive Strength

The effect of concrete compressive strength on the strengthened beams strength evaluated using four different values of concrete compressive strength (25, 35, 40, 50) MPa. As is seen in Figure 6 a and b, the ductility is highest at the 35 MPa, this means that there is a regular stress distribution between different components at this strength level. The results

showed that strengthening the high strength concrete beam increase the serviceability limit, the yield load and the maximum load capacity.
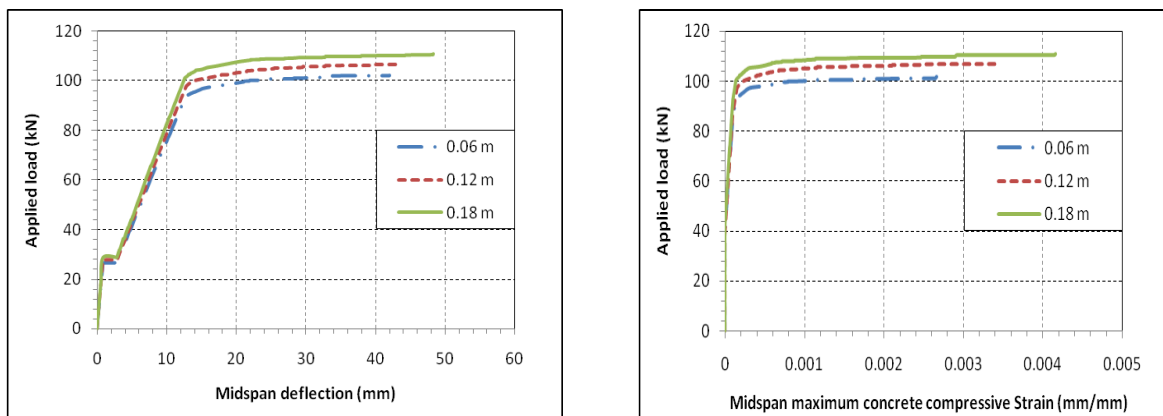

a. Load-deflection curves.   **b.** Load-compressive strain curves for concrete

Fig.(6):- Evaluation of the effect of concrete compressive strength.

4.6 Strip Width

In this section and the next section, the CFRP laminates used as a number of strips of U shape, the thickness of CFRP laminates is *1.6 mm* and its height is *150 mm* on each web side, the strip used in *0.18m* center to center spacing. As seen in Figures (6a) and (6b) increasing the strip width will be directly proportioned with the beam load capacity and ductility.
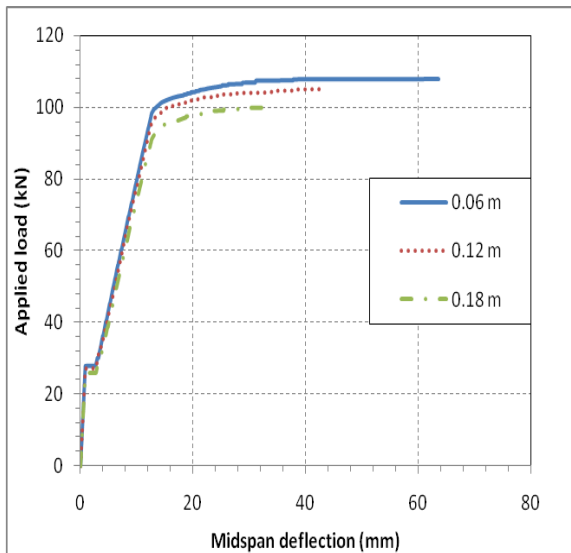

a. Load-deflection curves   **b.** Load-compressive strain curves for concrete

**Fig.(7):-** Evaluation of the effect of CFRP strip width

4.7 Strip Spacing

The effect of center to center spacing of CFRP strip on the structural behavior were investigated by tacking three different values for CFRP strip spacing. A comparison of the deflection responses and strain quantities shown in Figure 8 a and b of beams with different values of CFRP strip spacing showed improvement in stiffness beyond yield and increase in the ductile behavior of strengthened beams.

a. Load-deflection curves
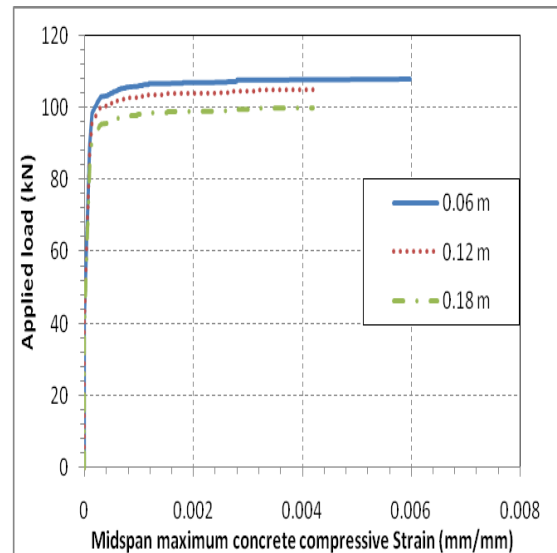
b. Load-compressive strain curves for concrete

5. CONCLUSIONS

The paper investigated the behavior of reinforced concrete beams strengthened by CFRP laminates. Different strengthening cases were discussed, the following conclusions are drawn:

- The ductile behavior increases with increasing the CFRP strap height, but the maximum increase in the ductility obtained by using strap height equal to *0.6 h*.
- The ultimate load capacity of the beams increases with the increasing of the thickness of CFRP strap, but in the same time there is a decrease in the beam ductility.
- The 90 degrees orientation for carbon fiber with beam longitudinal axis provides the highest strength gain and a more favorable (ductile) behavior.
- Strengthening the high strength concrete beam increase the serviceability limit, the yield load and the maximum load capacity. The ductility is highest at the *35 MPa*; this is due to preferable distribution of stresses between different components at this stress level.

- Increasing the CFRP strip width will be directly proportioned with the beam load capacity and ductility.

- Decreasing the CFRP strip spacing showed improvement in stiffness beyond yield and increase in the ductile behavior of strengthened beams.

More parametric studies are needed to investigate the effects of the previous parameters on response of reinforced concrete beams with different geometries and reinforcement.

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Investigations to the Parameters Effecting Shear Strength of RC Beams Strengthened with CFRP Laminations

تقصي العوامل المؤثرة على مقاومة القصّ للأعتاب الخرسانية المسلحة المقواة بصفائح بوليمرات ألياف الكاربون

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الخلاصة

يركز هذا البحث على تقوية العتبات الخرسانية المسلحة الضعيفة التحمل في القص باستخدام صفائح بوليمرات ألياف الكاربون الملصقة من الخارج. حيث يمكن استخدام صفائح بوليمرات ألياف الكاربون لتحسين تحمل الأعتاب في القص وتغيير نمط الفشل من القص الى الانحناء. استخدم التقصي لغرض تخمين مقدار مساهمة صفائح بوليمرات الياف الكاربون في زيادة مقاومة القص للعتبات الخرسانية المسلحة المقواة. استخدمت طريقة العناصر المحددة المعتمدة في برنامج (ANSYS) لتمثيل العتب الخرساني المسلح والمقوى ببوليمرات الياف الكاربون. التمثيل يستخدم إمكانيات برنامج (ANSYS)لتقييم تأثير عدد من العوامل (ارتفاع وسمك حزام صفائح بوليمرات ألياف الكاربون، اتجاه ألياف الكاربون بالنسبة إلى محور العتب الطولي، مقاومة انضغاط الخرسانة، عرض وتباعد شرائح بوليمرات ألياف الكاربون) المهمة في تحسين مقاومة العتب للقص. النتائج العددية أظهرت ونوقشت وتم استخلاص الاستنتاجات.

الكلمات الدالة: أعتاب كونكريتية مسلحة؛ طريقة العناصرِ المحددةِ؛ تصفيح بوليمرات ألياف الكاربون؛ القصّ.