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General behavior of t– section RC beams strengthened with epoxy–bonded carbon strands

Abstract

There are no widely accepted guidelines for the design of concrete girders strengthened in shear using externally bonded FRP systems. The current research introduces the use of externally bonded CFRP strands to strengthen the beams in shear and increase its shear capacity, not in a U–shape form, but in a discrete form– on the sides only. Experimental behavior and test results of five T–section RC beams strengthened in shear are present. The main objectives of this research are to evaluate, based on the experimental work, the impact of CFRP strands amount per strip and spacing between strips on the shear behavior of RC beams and to evaluate the applicability of existing analytical models of RC beams strengthened in shear with CFRP Strands. The discrete strips of CFRP Strands are applied with different widths and spacing, bonded externally to the test specimens in order to observe the overall behavior of the RC T–beams and the mode of failure of the applied Carbon Strands strips. Results from the experimental program shows that the application of Carbon Strands strips to RC T–beams did in fact enhance the overall behavior of the specimens. The strengthened specimens respond with an increase in shear capacity. The spacing between the CFRP strands should be less than half the effective depth of the strengthened beam (d/2), and larger than the sum of width of the strengthening strip and the quarter of the effective depth of the specimen (W+d/4). The geometry of the CFRP strands allows full penetration of the epoxy through the strengthening strips, which eliminates the deboning of the strips. The dominant mode of failure is cracking of the concrete cover under the CFRP strands strips, separating the strengthening strips from the specimens, followed by shear failure.

Keywords: shear, externally bonded, FRP, strengthening, RC beam, carbon strands, epoxy

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Abbreviations: CS; Carbon Strands Sheet, FRP; Fiber Reinforced Polymers, f_y: yield strength of steel bars, d: beam effective depth, t_s: slab thickness, t_b: beam total thickness, B: flange width, b: web width, W: width of the strengthening CFRP strands strip

Introduction

In recent years, repair and retrofit of existing structures with externally bonded FRPs have been among the most important challenges in civil engineering. The need to strengthen and rehabilitate existing concrete and steel structures has increased the use of fiber reinforced polymers (FRP) in structural strengthening applications since the mid 1980's.[1] Although it is demonstrated by many researchers and practitioners that FRP systems have significant potential for various civil engineering applications, they mostly rally to become the prime material among the other alternatives for retrofit and rehabilitation of the reinforced concrete structures. Such FRP systems are lightweight, exhibit high tensile strength, are not prone to electrochemical corrosion, they can be formed, fabricated, are easy to install, and bonded easily to concrete substrate; these features facilitate handling and help expedite repair or construction. The high strength– to–weight ratio of FRP composites makes them more structurally efficient than traditional strengthening materials.[2] Extensive research has shown that FRP systems improve both short and long term flexural behavior of concrete girders. Externally bonded FRP systems composites are generally used for flexural strengthening, confinement and improvement of ductility in columns, or shear strengthening. Although the flexural strengthening is the main dominant on the use of FRP, in such cases, the shear capacity should be enhanced to avoid catastrophic failures. A significant amount of research has been conducted on flexural and axial strengthening but limited investigations have been conducted on the use of externally bonded FRP for shear strengthening. Several analytical studies have dealt with the shear behavior of concrete girders strengthened with FRP systems and a number of models were developed to predict such behavior and found that the size–effect of test specimens has little influence on the effectiveness of externally bonded FRP and thus empirical design expressions calibrated from small– scale test results should provide reasonable accuracy.[3] However, the analytical and experimental studies on shear strengthening with FRP systems are limited. Nevertheless, some of these studies have shown that FRP systems can provide an effective means for increasing the shear capacity of concrete girders; still, there are no widely accepted guidelines for the design of concrete girders strengthened in shear using externally bonded FRP systems.

In this research, an experimental program is devised to investigate the shear resistance of Carbon Strands externally bonded to RC T–section beams. No experimental tests have been conducted on beams shear– strengthened with Carbon Strands externally bonded on the sides only in II– shape not U– shaped shear– strengthening. All experimental beams are specially designed to fail in shear in order to better study the interaction between the concrete and the externally applied Carbon Strands. The general goal of this research is to study the shear behavior of RC T–beams strengthened with Carbon strands on the beams sides only. Aiming at this goal, five RC T–beams are designed such that a shear failure is induced to the beams. The test specimens in this experimental study are strengthened with external strips of II– shape Carbon Strands at different spacing, it should be noted that the CFRP strips are not effective at all at spacing greater

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than half the effective depth of the specimen.[4] Previous researches investigated the two–sided wrapping in shear strengthening and advised that either wrap all schemes continuously or discretely,[5] concluded that center to center spacing between strips must be equal or smaller than (d/4+strip width). It is hypothesized that strengthening the RC T–beams with Carbon Strands increases the overall shear capacity of the beams.

Materials

Concrete mix: All beams are cast from the same concrete mix which has a 28 day mean compressive cylinder strength of 40 N/mm^2. The mix consists of type I cement with maximum limestone coarse aggregate sizes of 19 mm and 13 mm.

Longitudinal Steel Reinforcement of High Tensile steel (f_y: 360 N/mm^2): each beam is reinforced in flexure with 6 bars of 25 mm diameter on 3 rows, spaced with a 25 mm transverse separator. The top flange is reinforced using 4 longitudinal steel bars with 12mm. diameter, and 6mm diameter bars in the transverse direction, as shown in Figure 2A.

Transverse reinforcement of Mild steel (f_y: 240 N/mm^2): closed stirrups of 8 mm. diameter are distributed along the beams with spacing of 170 mm, as d/2=168 mm.

Strengthening sheets: Carbon Strands Sheets (Figure 1), Japanese sheets: Tensile strength: 2060 N/mm^2, Modulus of Elasticity: 118 GPa, and Ultimate strain of 0.0175. It is a unidirectional carbon strand, each strand of 0.572 mm. diameters, they come attached together in sheets of dimensions 500 × 3000 mm.

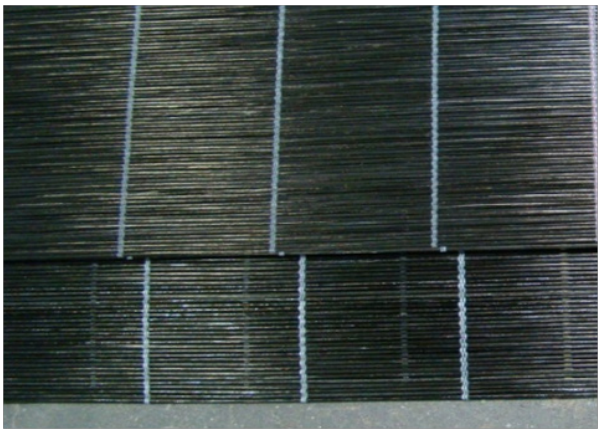

Figure 1 Unidirectional Carbon Strands Sheet.

Epoxy: adhesive material: Chimapoxy 2000, Egyptian Product, manufactured by CMB Group. The Chimapoxy had a pot life of 3 hours, a working time of 30 to 60 minutes and a cure time of 24 hours. All test specimens had cured at least 7 days before being placed on the reaction frame for shear testing. (Figure 2).

Beams specimens and strengthening schema

Beams specimens

a. All specimens are manufactured and tested at the Concrete Laboratory of the Faculty of Engineering, Ain Shams University, in Cairo, Egypt.

b. Concrete dimensions of T section beam specimens: beam length; 2300 mm., beam span; 2000 mm., t_s;120 mm., t_b; 400mm., B; 500 mm., b; 150 mm. as seen in Figure 2A.

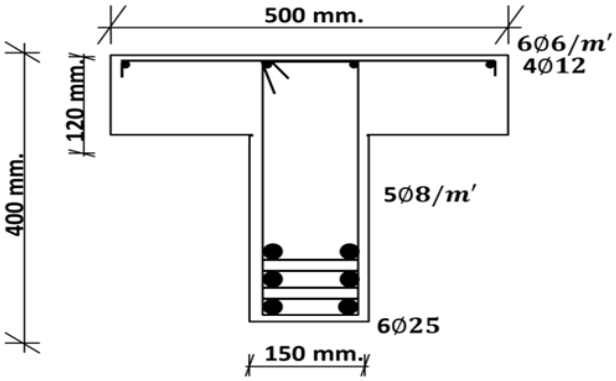

Figure 2A Typical cross section reinforcement of tested beam.

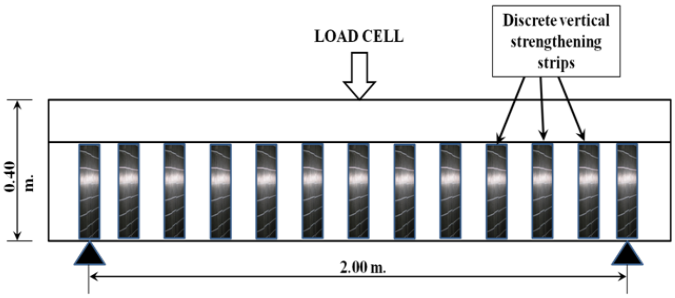

Figure 2B Typical elevation of tested beam.

Strengthening schema

a. In order to make the CS placement easy, the test beams are flipped on the side and pre– fit markings are drawn on the beam to make sure that the carbon strands are being placed at the specified locations. The sheet of CS is used to strengthen the specimens; it is cut into strips 280 mm. long and 30 or 50 mm. width that would be placed on the test specimens. The wet method is used to apply the carbon fabric to the test beams. In this method, the surface of the beams is checked for any irregularities that might alter the adhesion of the epoxy mix and then a first heavy coat of epoxy is rolled on the surface of the beams. The CS strips are then positioned in the pre– fit markings on the beam and placed on the surface of the beams. A second coat of epoxy mix is then applied on top of the strips.

b. One beam, labeled as the control beam Bo, is tested in shear in the loading frame to locate the shear cracks at failure; no CS strips are applied to the control beam. Four strengthened beams are labeled as follows B–X–II–Y; where X is the width of the CS strip in cm. II means the CS strips are placed on the beam sides only under the flange, and Y is the center to center spacing in cm. along the beam span. Detailed description of strengthening matrix is given in Table 1.

Table 1 Test matrix

Beam ID	CS strip width "W" mm.	CS strips spacing mm.
Bo	N/A	N/A
B3II10	30	100
B3II17	30	170
B5II15	50	150
B5II17	50	170

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Test setup and instrumentations

i. All beams are tested using a three point bending configuration. The span of the beams is constant 2000 mm. The test setup allows two shear spans (distance between the support and the applied load) of 1000 mm each. The beams are supported on a roller support at one end to allow beam expansion under loading and a hinged support at the other. One hydraulic jack of 1500 kN capacity is used to apply the load on top of a rigid steel beam that equally distributes the load through the flange width.

ii. A total of four electrical resistance strain gages and three LVDTs are used to measure the tensile strains and the deflections on each beam, respectively.

iii. The four electrical resistance strain gages are attached to the transverse reinforcing bars (stirrups) two on each end of the beam near the support, one is located on the stirrup mid height at a distance d/4 from the support (45^{o} angle), and the second at same height at 500 mm. (a/d) from the support, to measure the strains in the stirrups at the critical shear crack patterns.

iv. The deflections are measured using the LVDTs. One is placed at mid span and the other two are located at quarter span on both span ends.

Results and discussion

All five test specimens are subjected to a three point loading system and failed as expected in a shear failure. Shear cracks are marked as they appear on the specimen along with the corresponding load during the test. Figure 3 shows the load versus mid–span deflection relations of the tested beams. Typical load deflection behavior comparing the control beam Bo to the strengthened beams reflecting the effect of the strengthening strips width between B3II17 AND B5II17, and the effect of center line to center line spacing between strips by comparing B3II10 with B3II17, and B5II15 with B5II17. Test results indicate that the pre and post cracking stiffness are identical for B5II15 and B5II17 which experienced a brittle shear failure, without neither warning nor moderate shear cracks propagation, and subjected to a 3% decrease in the load carrying capacity in B5II15, as for B5II17. Using thin CS strips in B3II10 and B3II17 allows shear cracks propagation through the beam prior to failure; hence lead the strengthened beams to exert a ductile failure. The beams experienced an increase in the load carrying capacity of 10 %, and 22% for B3II10, and B3II17, respectively.

Figure 4 shows the vertical displacement profile of the control beam, where the data from two LVDTs on both sides of the beam are shown to be similar, and hence more reliable. The largest shear cracks are noticed at the south end of all tested specimens where the loss of aggregate interlock occurred at failure. The control beam failed in shear with shear cracks propagating from the support to the top flange at an approximately 45° angle. Figure 5 shows the failure pattern and the location of the shear cracks at failure of B_o, under ultimate load of 470.83 kN. The largest vertical deflection was measured by LVDT located at the midsection of the beam, and was 10.38 mm. As expected, the control beam failed in a brittle manner. The presence of the CS strips of width 50 mm. strengthening beams B5II15, and B5II17, also led to a brittle failure, where the shear cracks propagate with 45° angle, from the third strip approximately at distance d from support, to the top flange. Figure 6 & Figure 7 show the failure pattern and the location of the shear cracks at failure, under ultimate loads of 455.72, and 481.48 kN, respectively. The largest vertical deflection are measured by LVDT located at the midsection of the beams, and are 9.62, and 9.39 mm. respectively. Specimens B3II10 and B3II17 failed as expected in shear, showing diagonal shear cracks that initiate from the supports up to the loading point and through the CS strips ((Figure 8) (Figure 9) respectively). The largest shear crack is located at the south end of the beam in the shear span area. The ultimate loads carried by the strengthened beams are 519.8, and 577.35 kN, respectively. Upon failure, the concrete cover cracked under the CS strips, fully separating the strips or partially separated from the specimens, bridging the shear cracks leading to failure. The maximum vertical deflection is also measured by LVDT, where the larger deflection is noted on the failed zone for tested beams as illustrated in Table 2. The tensile strains in the transverse reinforcements (stirrups) were measured with steel strain gauges and shown in Figure 10 & Figure 11. The control beam exerted brittle failure due to crack propagation from support to top flange with angle 45^{o}, no sudden jumps in the strain gauges reading are illustrated as B_o failed due to crushing of concrete at support location. For beams B5II15 and B5II17, they failed suddenly at loads close to the failure load of the control beam. The sudden jump in the strain gauges is caused by the shear cracks at angle 45^{o}. Beam B3II17 was able to carry more load than the control beam B_o. The strain gauges reading varied appropriately with the increase in the load, hence the shear carrying capacity of the beam increased. The sudden jump in strain reading at angle 45^{o} was detected after failure, the reading of tensile strain at crack propagation was not recorded due to error in the strain gauge reading, as shown in Figure 11, and constant strain reading was recorded for a wide range of loading. As for B3II10, the shear cracks propagated in the two directions, 45^{o} from support to top flange, and the support to loading point, the critical shear crack is from the support to loading point, which is illustrated by the uniform increase in the tensile strain readings of B3II10 on the 45^{o} crack angle from the support in Figure 10 and the sudden jump in the strain readings of B3II10 on the crack from support to loading point in Figure 11.

Table 2 Summary of experimental results

Beam ID	Failure load (kN)	Maximum deflection at mid span (mm.)	Maximum deflection at failure zone (mm.)	Maximum tensile strain at angle 45^{o} from support (microstrain)	Maximum tensile strain at support to loading point (micro strain)
Bo	470.83	10.38	8.18	2035	9772
B3II10	519.8	9.73	9.32	9162	2598
B3II17	577.35	10.33	10.03	6268	11677
B5II15	455.72	9.62	9.66	11424	1490
B5II17	481.48	9.39	9.79	10866	9943

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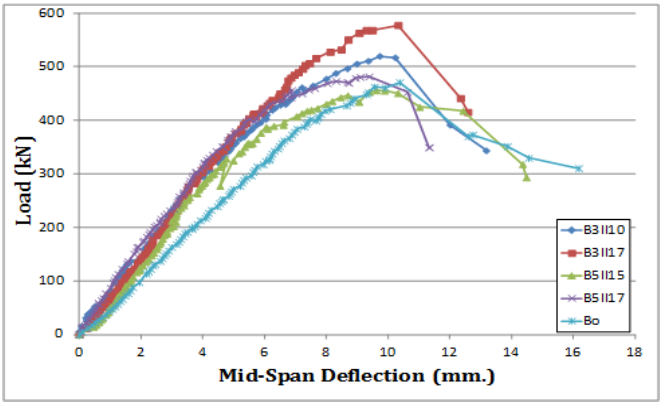

Figure 3 Typical Load-Deflection curve for tested beams.

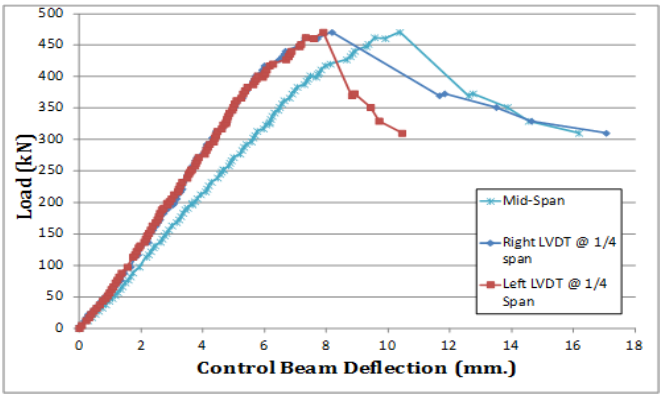

Figure 4 Typical Load-Deflection curve for control beam of middle and two sides LVDTs.

Figure 5 Failure of B_o control beam.

Figure 6 Failure of B5II15.

Figure 7 Failure of B5II17.

Figure 8 Failure of B3II10.

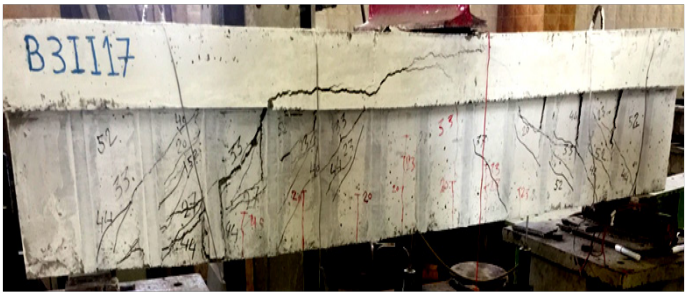

Figure 9 Failure of B3II17

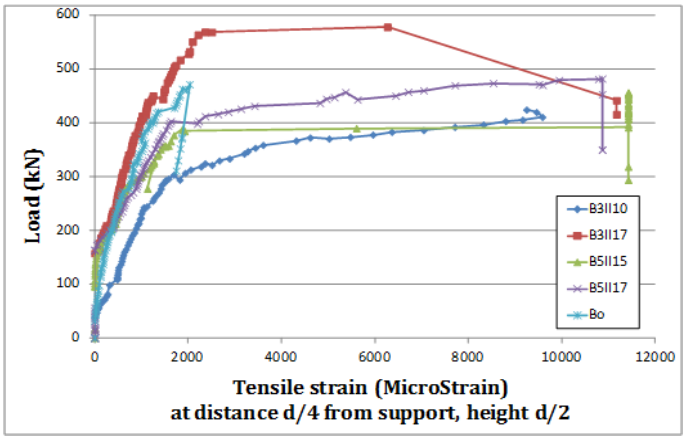

Figure 10 Micro strain readings at mid-height of beam from support to top flange with angle 45°.

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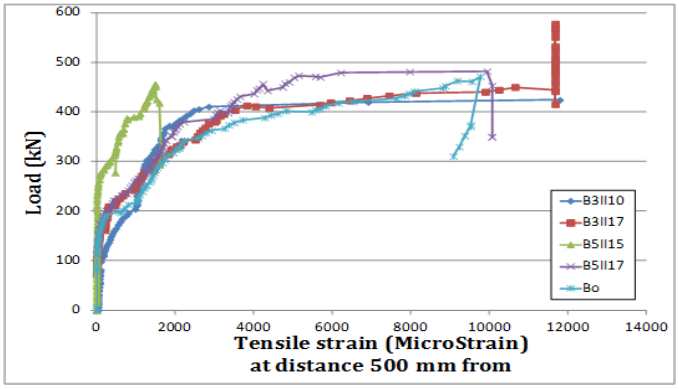

Figure 11 Micro strain readings at mid-height of beam from support to loading point (a/d).

Conclusion

1. Externally bonded FRP can be used to enhance the shear resistance of concrete beams.
2. Externally bonded FRP systems can be applied in a discrete strips form; on the sides only.
3. Strengthening of concrete beams with externally bonded composite sheets appears to be a feasible way of increasing the load– carrying capacity and stiffness characteristics of existing critical and special structures.
4. The results have shown that the externally bonded CS strips in RC concrete T– beams for shear strengthening, applied on the sides only, when using the CS strips of width 30 mm. spaced at 170 mm. from center to center of the strips (d/2), improved the overall shear capacity of the specimens by 22% compared to the shear capacity of the control beam, shear cracks propagation were clearly observed on the beam prior to shear failure, and led the beam to become more ductile.
5. When using large strips of CS 50 mm. with different spacing, no significant increase in the shear load carrying capacity of the beam was observed, on the contrary, the shear cracks propagation were arrested, and the beams became more brittle.
6. The spacing and the amount of Carbon Strands per strip used to reinforce the test specimen should be carefully planned, because spacing equal d/4+ width of strip, and a large amount of CS/strip hardly improved the shear behavior of the strengthened beam.
7. A serious concern in real practice of FRP is the lack of comprehensive design codes, guidelines and specifications. It is a fact that without design codes and standards, the real life applications of these FRP systems will remain limited. Further research efforts and investigations are essential to quantify and understand better the mechanisms associated with the use of externally bonded FRP systems for shear. Accordingly new design models and comprehensive guidelines can be developed.
8. These new design guidelines unquestionably should lead to more economic, simpler and safer applications of FRP for shear strengthening.

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Conflict of interest

The author declares there is no conflict of interest.

References

1. Soliman J. *Behavior of Reinforced Concrete Beams Strengthened with Externally Bonded Fiber/Steel Reinforced Polymers and Grancrete*. Ph.D Thesis, Ain Shams University, Cairo, Egypt. 2012:244s.
2. ACI Committee 440. *Guide for The Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures. ACI 440.2R-08*. Farmington Hills, MI: American Concrete Institute, USA; 2008.
3. Kuchma D, Ayoub A, Mirmiran A, et al. Design of FRP Systems for Strengthening Concrete Girders in Shear. Transportation Research Board, *NCHRP Report. 678*. 2011:120.
4. Kang THK, Ary MI. Shear-Strengthening of Reinforced & Prestressed Concrete Beams Using FRP: Part II – Experimental Investigation. *International Journal of Concrete Structures and Materials*. 2012;6(1):49–57.
5. https://theconstructor.org/structural-engg/rcc-beams-strengthening-shear-frp-plate/15148/.