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"SHEAR STRENGTHENING OF REINFORCED CONCRETE T-BEAMS USING ANCHORED FRP WRAPS"

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ملخص البحث :
يشتمل هذا البحث دراسة مدى تأثير تدعيم البلاطات الخرسانية المستمرة بأستخدام شرائح البوليمرات المسلحة بالياف الكربون المثبتة فى تحسين مقاومة القص وتاثيرها على حدود التشغيل. تم أختبار عدد احدي عشر عينه لكمرات خرسانية المسلحة والمدعمة المدعمة بألواح البوليمرات المسلحة بألياف الكربون المربوطة من الخارج. تتكون الكمره الخرسانية من بحر حيث ان طول البحر الفعال 2.5 م و تم تحميلها تحت تأثير قوي القص حتى الانهيار. أظهرت النتائج كفاءة شرائح البوليمرات المسلحة بالياف الكربون المثبته على زيادة قدرة تحمل الكمرات المدعمة بنسبة تصل الي 45% بالاضافة الى زيادة جساءتها.

1. Abstract

This research study the effect of using different types of CFRP anchors combination with U-shaped CFRP jackets for shear strengthening of reinforced concrete T-beams.eleven RC beams were tested; one beam was kept as control beam; whereas other beams were strengthened externally with CFRP U-strips. Test variables were, effect space of CFRP-U strips, method of insulation anchor, and presence of anchors. Test results showed that, the ultimate shear capacity of RC beams can be increased significantly using this techniques, a maximum increases of 45% was obtained. For beams strengthen with small space between CFRP-U strips has a large effect on both carrying capacity and ductility. For more improvement shear strength, beams has been proposed to predict the contribution of CFRP–U strips to the shear capacity of the strengthened beams, which fail by CFRP debonding using anchors at the end of strips.

Keywords: CFRP; anchors; T-section; Strengthening; Beams; shear; Wrapping; sheets.

2. Introduction

Carbon Fiber Reinforced Polymers (CFRP) is a convenient material for strengthening and rehabilitating RC structures because it has a light-weight, flexibility and have easy installation techniques. Epoxy is used to make full ponding between concrete and FRP.
The promotion of fiber-reinforced polymer (FRP) composites as a repair and strengthening material for reinforced concrete (RC) beams, slabs and columns in structural engineering implementations has increased through the previous twenty years [1.2] The high strength to weight ratio and non-corrosive characteristics of FRP's make them an extremely desired repair material and can consequence in augmentation in serving life of structures [3]. Lately, the influence of CFRP anchors in flexural application was verified by [4,5]., who stated that the failure of members strengthened using FRP materials was due to fracture of the FRP fiber. The members with anchors attain much higher capacities than those without anchors. However, the strain in shear reinforcement is not potentially to achieve 1% because of the compression capacity of

the concrete in shear is dominated by a principal tensile strain. The Orientation for FRP sheets to debone at loads below their tensile strength has drove researchers to investigate diverse approaches and designs to augmentation the efficiency of the installed FRP sheets for shear strengthening of RC members [6,7,9,10]. Various anchors, wrapping techniques and clamps have been explored to postpone and/or delay the debonding procedure in externally bonded FRP members [11,12]. FRP anchors are of private interest because they have the selfsame material characteristics as the FRP sheets and can be installed simultaneously with the sheets. Research is required to study the adequacy of FRP anchors used to secure externally applied FRP sheets to strengthen beams in shear. This research study has been designed to examine the effectiveness of using commercially fabricated FRP anchors to control and/or ignore the debonding of externally bonded FRP sheets used to strengthen RC beams in shear.

3. EXPERIMENTAL PROGRAM

Test was carried out on eleven T-shape beams, the specimens tested under one point load. .The test variables were: the type of FRP strengthening material (CFRP), FRP configuration and presence of FRP anchors.

4.1 Test Specimens

Specimens were cast with a beam span of 2500 mm, beam width of 150 mm and depth 300mm.the concrete dimensions and reinforcement are shown in Figure 1. All beams were tested under one point load over span 2500 mm, the test set up shown in Figure 2.

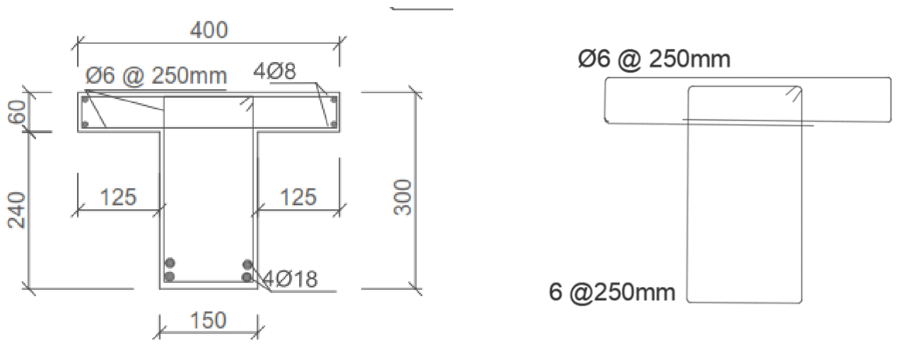

Figure 1: concrete dimensions for specimens& Reinforcement details for specimens

4.2 Material Properties

Test specimens were prepared from available local materials. These including cement CEMI (42.5 N), natural sand, crashed dolomite with maximum normal size of 10 mm, and steel reinforcement. Clean drinkable fresh water was used in all mixes and also for curing process. The mix proportions were designed to achieve target strength of 25 N/mm^2. Table 2 shows the design of the concrete mix. Deformed bars with diameters 10, and 12 mm were used as the main reinforcement diameters for both beam and column. Mild steel bars with 6, and 8 mm diameter were used for the column and beam stirrups. Table 3 shows the properties of the steel bars used in this study.

Table 2: Mix proportions by weight

Cement	Sand	Fine gravel	Water
1	1.5	3	0.45-0.50

4.3 Test Setup and Instrumentation:

The beams in the pilot study was simply supported with a clear span of 2500 mm and 800 mm space loading. Supports consisted of a pin and roller connections. Load was applied through a hydraulic jack mounted on the actuator. The test setup is shown Figure 3.

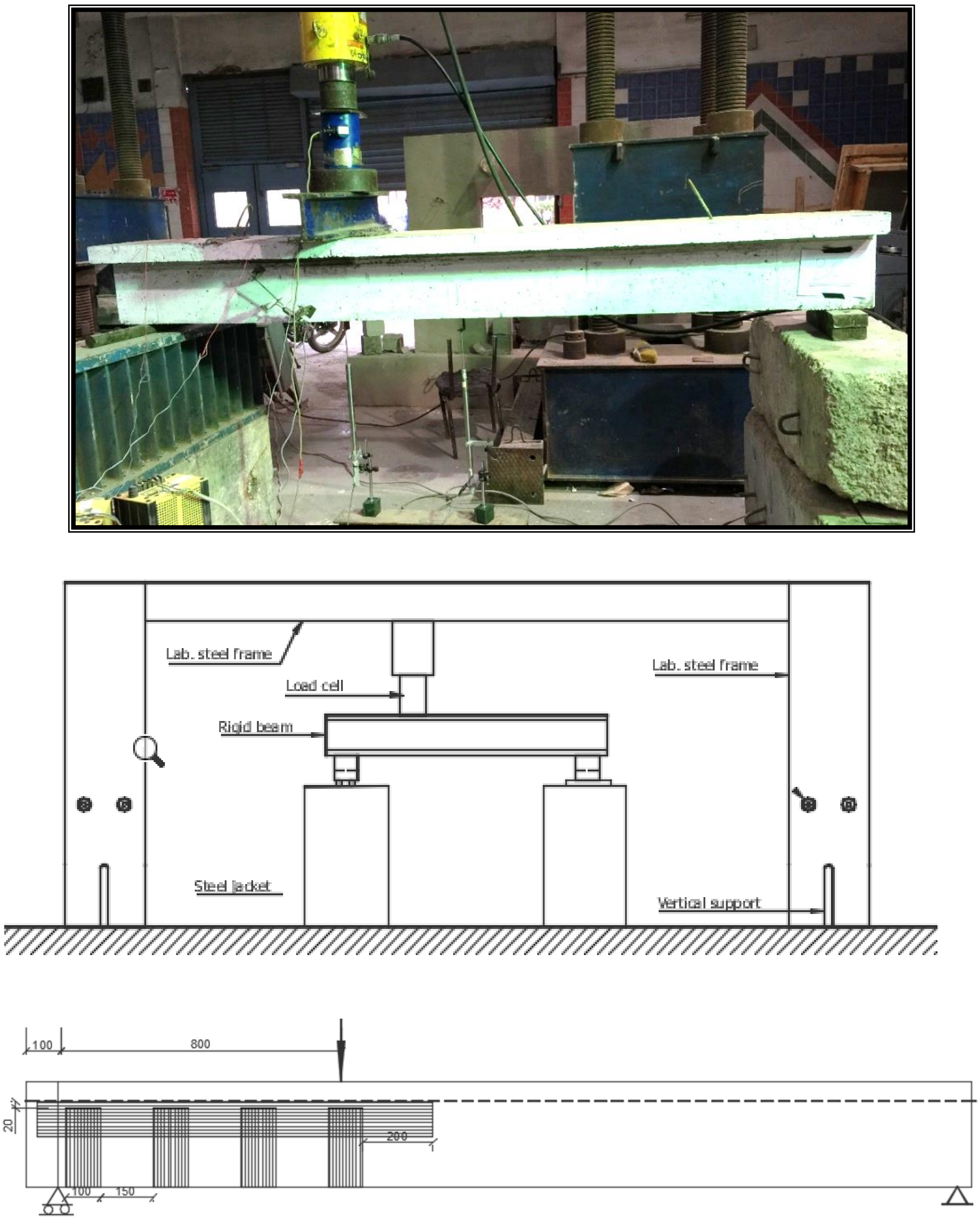

Figure 3: Test setup used for test specimens

4. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental program aimed to study the effect of anchors in th U-shaped wrapping of reinforced concrete T-beams strengthen in shear and compare the effectiveness of different anchor schemes. Results discuss the relation between load- deflection and load-strain for concrete, steel, and CFRP strains. The specimens were grouped according to different investigated parameters were shown in table 4.

Table 4 – Test specimen for T-section beams parameters

	Specimen	Wrap space (mm)	Anchor
	BC	Control	-----
Group (A)	BCU-100-NA	100	No anchor
	BCU-150-NA	150	
	BCU-200-NA	200	
Group (B)	BCU-100-CAH	100	anchor in web
	BCU-150-CAH	150	
	BCU-200-CAH	200	
Group (C)	BCU-100-CAI	100	anchor in flange
	BCU-150-CAI	150	
	BCU-200-CAI	200	
Group (D)	BCU-150-CSH	1500	horizontal sheet

5.1 General behavior and mode of failure

Figure 4 through figure 10 show the crack pattern for some specimens and the mode of failure for all specimens show in table 5. The failure mode of the control (BC) beam was by shear diagonal tension failure. Cracking initiated as flexural cracks between the two loading points with the first crack appearing at a load of 15 kN.As the load was increased, inclined cracks began to develop in the shear span and propagated between the support and loading points. A slight drop in the load was caused by crack development in the shear spans at a load of 85 kN.The beam failed suddenly in shear (diagonal tension) immediate after the peak load (118.7 kN) was reached indicating the brittle nature of shear failure.

Table **Error! No text of specified style in document.**5: Mode of failure of specimens

	Specimens Description	Failure Load(KN)	Max. deflection (mm)	Failure Mode
--	BC	118.7	15.673	• SF
Group (A)	BCU-100-NA	180.5	15.705	• FRP D- FRP R
	BCU-150-NA	150.5	13.557	• SF- FRP D
	BCU-200-NA	164.1	16.739	• SF - FRP D
Group (B)	BCU-100-CAH	213.6	12.837	• SF - FRP D- FRP R- EAF
	BCU-150-CAH	169.5	13.241	• SF - FRP D- EAF
	BCU-200-CAH	167.6	13.721	• SF - FRP D- EAF
Group (C)	BCU-100-CAI	211.7	17.216	SF - FRP D- FRP R -EAF
	BCU-150-CAI	158.1	13.117	• SF - FRP D- EAF
	BCU-200-CAI	166.3	13.360	• SF - FRP D- EAF
Group (D)	BCU-150-CSH	169.8	15.867	• SF - FRP R

* Where SF= shear failure, FRP D= FRP Deboning, FRP R= FRP Rupture, CC=Concrete crushing, DT= Diagonal tension and EAF= End anchorage failure.

Figure 4: Crack pattern of the control beam (BC)

Figure 5 Showing Beam (BCU-100-CAH) was strengthened with Sikawrap 230 C-CFRP sheets u-wraps (100 mm wide at a spacing of 100 mm).CFRP Sheet was strengthened with CFRP anchors was embedded in concrete perpendicularly in beam web. The failure mode of beam BCU-100-CAH was shear failure (diagonal tension) interlock with FRP debonding, FRP Rupture and End anchorage failure.

Figure 5: Crack pattern of specimen BCU-100-CAH

Figure 6 Showing Beam (BCU-150-CAH) was strengthened with Sikawrap 230 C-CFRP sheets u-wraps (100 mm wide at a spacing of 150 mm) .CFRP Sheet was strengthened with CFRP anchors was embedded in concrete perpendicularly in beam web. The failure mode of beam BCU-150-CAI was shear failure (diagonal tension) interlock with FRP debonding and End anchorage failure.

Figure 6: Crack pattern of specimen BCU-150-CAH

Figure 7 Showing Beam (BCU-200-CAH) was strengthened with Sikawrap 230 C-CFRP sheets u-wraps (100 mm wide at a spacing of 200 mm). CFRP Sheet was strengthened with CFRP anchors was embedded in concrete perpendicularly in beam web. The failure mode of beam BCU-200-CAH was shear failure (diagonal tension) interlock with FRP debonding and End anchorage failure

Figure 7: Crack pattern of specimen BCU-200-CAH

5. Analysis of test variables

In this section, the effect variables used to strengthen a shear critical beam on the load, stiffness, deflection and the strain response is discussed.

Effect of installation end anchors in web beam

In this section, the effect of end anchors which installation in web beam and wrapping with CFRP sheet. The comparisons include spacing between partial wrappings in beams.

Beams BCU-100-CHA, BCU-150- CHA and BCU-200- CHA of Group "B", strengthened with CFRP sheets and CFRP anchors strip spacing of 100 mm, 150mm and 200 mm respectively, failed in conventional ductile shear mode with debonding CFRP anchors and yielding of the main reinforcing steel followed by crushing of concrete and the strength of beams increased by 78%, 42% and 41% as the CFRP strip sacing 100 mm, 150mm, 200mm respectively. It was observed in the case of all the beams of Group "B" that failure was initiated by extensive diagonal tension cracking in the shear zone leading to rupture of CFRP anchor. This is also reflected by sudden drop in load carrying capacity in load-deflection curves as shown in Figure 8.

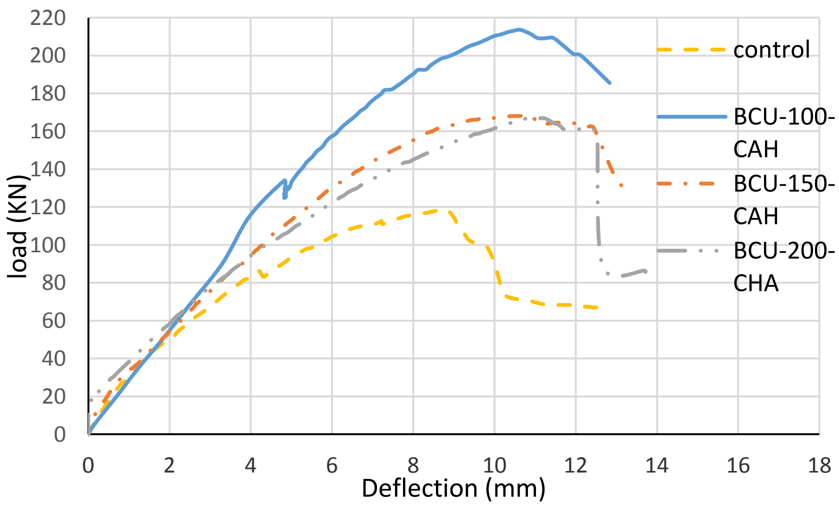

Figure 8 – Effect of anchors on deflection behavior of T-section specimens with partial wrapping

Strain Response in sheets

The load vs. strain response of the strengthened beams is shown in Figure 9. Additional strength was provided in the beams which contained FRP anchors. All three beams failed in shear. The beams with CFRP anchors had an enhanced ductility at failure with a much smaller drop in load compared to beams without CFRP anchors. The strain response in the sheets (Figure 9) showed that sheet had strains reaching maximum strains of 4150 με in BCU-100-CAH and the sheet start effect at load at 115 KN, however at BCU-150-CAH and BCU-200-CAH the sheets effect at load 80 KN and reach to maximum strain 1100 με, 1650 με respectively.

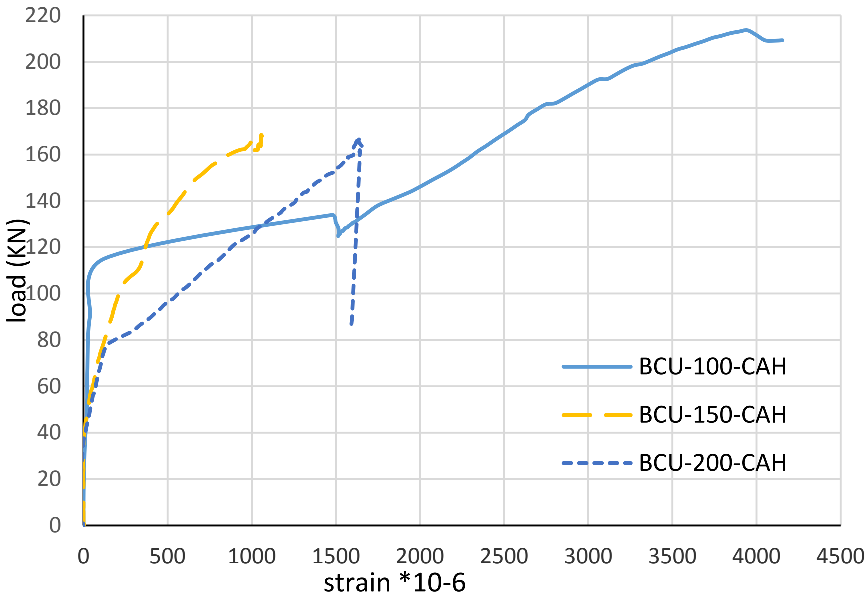

Figure 9– Effect of horizontal anchor on strain in sheet of specimens with partial wrapping

Effect on Deflection

Table 6 compares Decreases maximum deflection at beams strengthened with Sikawrap 320C sheets and anchors which embedded horizontally in web beam.

Table 6: Effect wrapping in deflection of Group B over control

	Specimens Description	Failure Load(KN)	Max. deflection (mm)	Effect in deflection
--	BC	118.7	15.673	---
Group (B)	BCU-100-CAH	213.6	12.837	decreases 18%
	BCU-150-CAH	169.5	13.241	decreases 20%
	BCU-200-CAH	167.6	13.721	decreases 14%

A comparison of deflection decrease over the control of beams strengthened with Sikawrap 230 C sheets is shown in Figure 10. The decrease in deflection for beam BCU-200-CAH was 14%, over the control because it failed in load 167.6 KN which the minimum failure load in group (B).

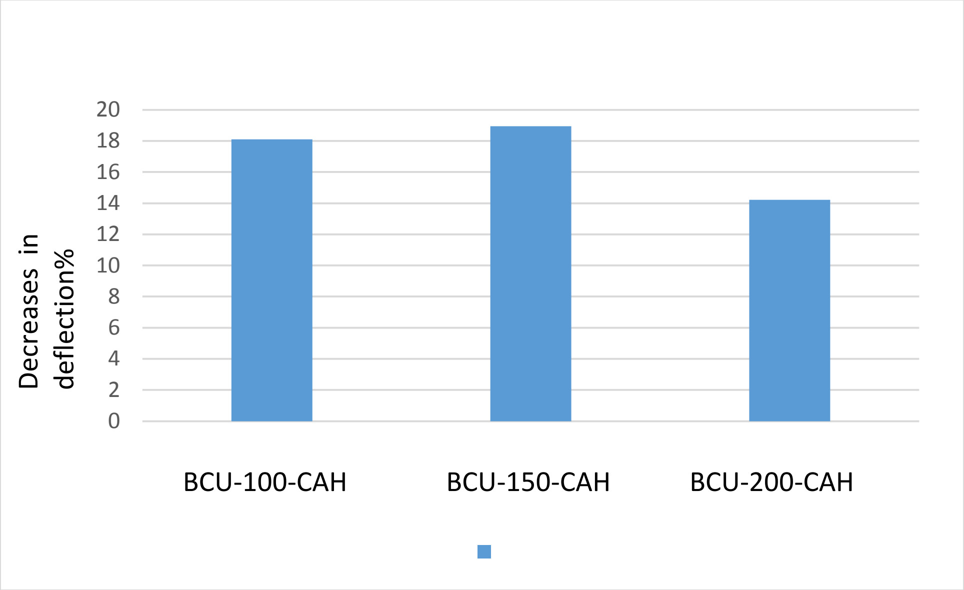

Figure 10: Decreases in deflection of Group B over control

6. CONCLUSIONS

1. Shear Strength was increased when installation CFRP anchors to secure CFRP sheet over than beams didn't have anchors in shear strengthened beams.as well, beams were installation the CFRP anchors experienced a 10% development in maximum deflection on a companion unanchored beams.
2. U-wrapped CFRP sheets with small spacing improved larger strength increases compared to large space strips in shear strengthening, As well as, the increases in strength small intermittent strips were economic than the continuous sheets.
3. The shear capacity of beams was increased when CFRP strengthening was provided (u-wraps), strength was increases by 52% at space 100mm while at space 200 mm increase only 38%.
4. FRP strengthening improve the ductility of failure. In addition, providing shear strengthening using anchors in web with space 100 mm can change the mode of failure in shear critical beams from a brittle shear failure and carried an additional load by 78%,.
5. Debonding failure evented in the concrete substrate and not in the FRP epoxy interface for all beams, it’s happened in the aggregate interlock in concrete.
6. Debonding of unanchored CFRP sheets in the concrete substrate happened at CFRP strains between 3000 $\mu\varepsilon$ to 5000 $\mu\varepsilon$, in the u-wrapped CFRP sheets. CFRP sheets debonding in the concrete substrate can be determined by using higher concrete strength. The strength of the process was more dependent on the tensile strength of the concrete, not the FRP/epoxy interface.
7. Using horizontal sheet to anchorage a CFRP strips increased shear strength for RC beams almost 13 % and this ratio largest than using anchors in flange method.
8. Using anchors in flange at the end of a CFRP strips increased shear strength for RC beams nearly 78%, 33% and 40% for spacing 100mm, 150mm and 200 mm respectively.

9. Using anchors in web at the end of a CFRP strips increased shear strength for RC beams almost 80%, 42% and 41% for spacing 100mm, 150mm and 200 mm respectively.

7. REFERENCE

1. Cao, S. Y. et al., 2005. Debonding in RC Beams Sher Strengthened with Complete FRP Wraps.Journal of Composites for Construction, 9(5), pp. 417-428.
2. Triantafillou, Thanasis C. and Antonopoulos, Costas P. (2000). "Design of Concrete Flexural Members Strengthened in Shear with FRP," Journal of Composites for Construction, Vol. 4, No. 4, pp. 198-205.
3. Noel, M. & Soudki, K., 2011. Evaluation of FRP posttensioned slab bridge strips using AASHTO-LRFD Bridge design specifications. Journal of Bridge Engineering, Volume 16, pp.839-846.
4. Kim, I. (2008). Use of CFRP to Provide Continuity in Existing Reinforced Concrete Members Subjected to Extreme Loads. Deparment of Civil, Environmental and Architectural Engineering. Austin, Texas, the University of Texas at Austin. Ph.D Dissertation.
5. Orton, S. L. (2007). Development of a CFRP System to Provide Continuity in Existing Reinforced Concrete Structures Vulnerable to Progressive Collapse. Department of Civil, Environmental and Architectural Engineering. Austin, Texas, The University of Texas at Austin. Ph.D Dissertation.
6. Chaallal, O., Shahawy, M. & Hassan, M., 2002. Performance of Reinforced Concrete T-Girders Strengthened in Shear with Carbon Fiber-Reinforced Polymer Fabric. ACI Structural Journal, 99(3), pp. 335-343.
7. Chen, G. M., Teng, J. G. & Chen, J. F., 2012. Shear Strength Model for FRP-Strengthened RC Beams with Adverse FRP-Steel Interaction. Journal of Composites for Construction
8. Chen, G. M., 2010. Shear Behaviour and Strength of RC Beams Shear-Strengthened with Externally Bonded FRP Reinforcement. Hong Kong: The Hong Kong Polytechnic University.
9. Khalifa, A., Gold, W., and Nanni, A., (2000), “Shear Performance of RC Members Strengthened with Externally Bonded FRP Wraps,” Proceedings, 12275 th World Conference onEarthquake Engineering, Auckland, New Zealand.
10. Orton, S. L., Jirsa, J. O. et al. (2008). "Design Considerations of Carbon Fiber Anchors," Journal of Composites for Construction, Vol. 12, No. 6, pp. 608-616.
11. Kim, S. J., and Smith, S. T. (2009). “Shear Strength and Behavior of FRP Spike Anchors in Cracked Concrete,” Ninth International Symposium on Fiber Reinforced Polymer Reinforcement for Concrete Structures, Sydney, Australia, FRPRCS-9: pp. 1-4 (CDROM).