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Shear Strengthening of RC T Beam using CFRP Laminate: A Review

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Abstract**—**This paper presents the Literature Review of carbon fiber reinforced polymer (CFRP) strips to reinforced concrete (RC) as a strengthening solution for T-beams. Although a great deal of research has been carried out on Rectangular beams strengthened with Fibre-Reinforced Polymer composites (FRP), Fiber reinforced polymer (FRP) composites have been increasingly studied for their application in the flexural or shear strengthening of reinforced concrete (RC) members. A detailed discussion of the shear-strengthening repair with FRP is undertaken. This paper will be limited to research of CFRP material externally bonded to the tensile face of concrete beams. In particular, research studying the effect of externally applied CFRP materials on the shear performance of reinforced concrete beams will be reported.

Keywords**—**CFRP, Concrete, Flexural, FRP, Shear, Strengthening.

I. INTRODUCTION

THE growing interest in fiber-reinforced polymer (FRP) composite in strengthening and retrofit is becoming apparent in recent years because of the special properties of these composite materials.

The most efficient technique for improving the shear strength of deteriorated RC members is to externally bond fiber-reinforced polymer (FRP) plates or sheets [1]. FRP composite materials have experienced a continuous increase of use in structural strengthening and repair applications around the world in the last decade [2] .In addition, the FRP when compared with steel materials found and provided unique opportunities to develop the shapes and forms to facilitate their use in construction.

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Strengthening of beams and slabs in flexure and confinement of circular columns have been well documented. A review of research studies on shear strengthening, however, revealed that experimental investigations are still needed [3], [4].

There are many methods for shear strengthening option such as: Bonded surface configurations, end anchor, shear reinforcement spacing and fiber orientation. While many methods of strengthening structures are available, strengthening structures via external bonding of advanced fibre-reinforced polymer composite (FRP) has become very popular worldwide.

Although the materials used in FRP for example, fiber and resins are relatively expensive when compared with traditional materials, noting that the crises of equipment for the installation of FRP systems are lower in cost. FRP systems can also be used in areas with limited access where traditional techniques would be impractical. Commercially available FRP reinforcing materials are made of continuous aramid (AFRP), carbon (CFRP), and glass (GFRP) fibers. Possible failure modes of FRP strengthened beams are classified into two types:

The first type of failure includes the common failure modes such as concrete crushing and FRP rupture based on complete composite action. The second type of failure is a premature failure without reaching full composite action at failure. This type of failure includes: end cover separation, end interfacial delamination, flexural crack induced debonding and shear crack induced debonding. Different failure mechanisms in experimental tests were reported by [5]-[7].

In addition, several studies were conducted to identify methods of preventing premature failure with the aim of improving the load capacity and ductility of RC beams. Researchers studied the use of end anchorage techniques, such as U-straps, L-shape jackets, and steel clamps for preventing premature failure of RC beams strengthened with CFRP ([5], [7], [8]-[17].

Generally, the researchers were conducted on RC rectangular sections which are not representative because most RC beams would have a T- Section due to the presence of a top slab. This paper mainly focuses on T-beams strengthened with CFRP on shear.

II. PREVIOUS RESEARCH WORKS ON T- BEAMS

Although most research studies on shear strengthening with FRP composites are mainly focused on the properties and the performance of the FRP and often involve rectangular beams, there is little reported work on the behaviour of shear strengthened with FRP on T-beams. An exhaustive literature review revealed that a minimum amount of research work had

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been done for addressing the possibility of strengthening the T-beam using FRP materials.

Reference [18] shows tested 19 RC T3 beams with CFRP as L-strips to strengthen RC T-beams damaged in shear. All of these test beams have been previously loaded to failure and are consequently extensively damaged in shear. These test beams are variations on 50% scaled versions of beams found within the Kiewa Valley Highway Bridge in Victoria which is typical of many of the T-beam bridges built prior to the1950's. Detail of the standard T- beam that was only marginally deficient in shear before pre-loading.

Loaded to failure, the beams have lost a considerable amount of their original shear strength. With significant slippage occurring between the stirrups and the concrete during loading, further shear resistance by the stirrups is unlikely. As a result, the stirrups are assumed to provide no shear contribution in the shear strengthening design also showed that L-shaped CFRP strips are the most effective elements for this kind of repair. The pre-loading would have largely reduced the uncracked concrete shear resistance in being extensively damaged. The shear contribution from the other two components is difficult to assess. Unable to assess the shear contribution's of these components, an upper and lower shear contribution bound is assumed.

Later, [19] presented the shear performance of reinforced concrete (RC) beams with T-section. Different configurations of externally bonded carbon fiber-reinforced polymer (CFRP) sheets were used to strengthen the specimens in shear. The experimental program consisted of six full-scale, simply supported beams. One beam was used as a bench mark and five beams were strengthened using different configurations of CFRP. The parameters investigated in this study included wrapping schemes, CFRP amount, 90°/ 0° ply combination, and CFRP end anchorage. The test results indicated that the externally bonded CFRP reinforcement can be used to enhance the shear capacity of the beams. For the beams tested in the experimental program, increase in shear strength of 35-145% was achieved. In addition, the results indicated that the most effective configuration was the U-wrap with end anchorage.

On the other hand, [20] tested 19 RC T3 conducted to address an important practical issue that is encountered in strengthening the negative moment regions of RC continuous beams and described the shear and flexural behavior of RC T-beams strengthened in the negative moment region with CFRP laminates. Three RC T-beams were cast. For all specimens, column stumps were also cast and used as the point of application of the load. One beam served as a control specimen, while one was strengthened for flexure (CFRP laminates applied besides the column) and the other one for flexure and shear (CFRP laminates in the form of U-wraps terminated at the flange intrados). Test results indicated externally bonded CFRP laminates are very effective in enhancing the strength, both flexural and shear, and stiffness of the negative moment region of T-beams. The increase in strength for all Beams except the control beam was observed to be 41 and 39%, respectively. The restraint offered to the application of strengthening system due to the presence of column did not affect the strength of the beams.

And contribution by, [21] described examples to strengthen concrete T-beams for shear and presented briefly the traditional strengthening methods, then the use of CFRP (Carbon Fibre reinforced Polymers) composites for shear strengthening. Tests on T-beams strengthened in shear with CFRP sheets are presented and a short presentation on how to design for shear strengthening with CFRP is give. Furthermore, a field application of a parking slab strengthened for shear with CFRP unidirectional fabric is presented. The laboratory tests show the importance of considering the principal directions of the shear crack in relation to the unidirectional fibre. The field application shows that it is easy to strengthen existing structures for shear with CFRP fabrics.

In another research, [22] tested 22 reinforcement concrete (RC) T-beams. The parameters investigated were as follows: 1) the CFRP ratio (that is, the number of CFRP layers); 2) the internal shear steel reinforcement ratio (that is, spacing); and 3) the shear length to the beam's depth ratio, a/d (that is, deep beam effect). The main objective of the study was to analyze the behavior of RC T-beams strengthened in shear with externally applied CFRP by varying the aforementioned parameters. The letters DB (deep beam) and SB (slender beam) are used to designate specimens with small and high a/d, respectively. Showed that the contribution of the CFRP to the shear resistance is not in proportion to the CFRP thickness (that is, the stiffness) provided, and depends on whether the strengthened beam is reinforced in shear with internal transverse steel reinforcement. Results also confirmed the influence of the ratio a/d on the behavior of RC beams retrofitted in shear with external fiber-reinforced polymer (FRP). The summary of their research is shown in Table I.

More recently, [23] experimental investigation on shear strengthening capacity and modes of failure of precracked and non-precracked RC beams bonded externally with bi-directional Carbon Fibre Reinforced Polymer (CFRP) fabric strips. Twelve RC T- beams were fabricated with different internal longitudinal and shear reinforcements. These beams were subjected to two types of loading; namely three point and four point bending systems. The beams were classified into three categories namely control, precracked-repaired, and initially strengthened (i.e. non-precracked) beams. The overall increase in shear enhancement of the precracked-repaired and initially strengthened beams ranged between 13% and 61% greater over their control beams. They were found that the application of CFRP strips in the precracked-repaired beams attained better performance as compared to the initially strengthened beams. The summary of their research is shown in Table I.

Finally, [24] examined 14 RC T-section deep beams were designed to be deficient in shear with a shear span to effective depth ratio (a/d) of 1.22. Key variables evaluated in this study were strengthening length, fiber direction combination of

CFRP sheets, and an anchorage using U-wrapped CFRP sheets. Failure modes of the tested deep beams are observed from the four-point loading tests. The failure mode of the control beam was observed to be with a shear–compression failure. For the strengthened T-section deep beams with CFRP sheets, two different types of failure modes, such as rupture and partial delamination of CFRP sheets between concrete surface and CFRP sheets. Almost all strengthened deep beams except the CS-FL-HP specimen exhibited a shear–compression failure due to partial delamination of CFRP sheets. It was concluded from the test results that the key variables of strengthening length, fiber direction combination, and anchorage have significant influence on the shear performance of strengthened deep beams. In addition, a series of comparative studies between the present experimental data and theoretical results in accordance with the commonly applied design codes were made to evaluate the shear strength of a control beam and deep beams strengthened with CFRP sheets the summary of their research is shown in Table III.

TABLE I
BEHAVIOR OF REINFORCED CONCRETE T-BEAMS STRENGTHENED IN SHEAR WITH CFRP

Beams type	Beams No.	CFRP Properties			Failure Mode
		Layers	Thick. (mm)	Selecting Size	
Deep	S0	0L	-	-	shear
		0.5L	0.060	Arbitrary	shear
		1L	0.107	Arbitrary	shear
		2L	0.214	Arbitrary	shear
	S1	0L	-	-	shear
		0.5L	0.060	Arbitrary	Test stopped
		1L	0.107	Arbitrary	shear
		2L	0.214	Arbitrary	shear
	S2	0L	-	-	shear
		1L	0.107	Arbitrary	shear
		2L	0.214	Arbitrary	shear
Slender	S0	0L	-	-	shear
		0.5L	0.060	Arbitrary	shear
		1L	0.107	Arbitrary	shear
		2L	0.214	Arbitrary	shear
	S1	0L	-	-	shear
		0.5L	0.060	Arbitrary	shear
		1L	0.107	Arbitrary	shear
		2L	0.214	Arbitrary	shear
	S2	0L	-	-	flexure
		1L	0.107	Arbitrary	flexure
		2L	0.214	Arbitrary	flexure

TABLE II
EXPERIMENTAL INVESTIGATION ON SHEAR RESISTANCE BEHAVIOUR OF RC PRECRACKED AND NON-PRECRACKED T-BEAMS USING DISCRETE CFRP STRIPS

Beams No.	End of Anchorage	CFRP Properties			Failure Mode
		Width and spacing	Thick (mm)	Selecting Size	
TT1a (C)	None	-	-	-	Shear
TT1-1(P-R)	None	80mm U-Strips@150mm c/c	0.09	Arbitrary	Flexural
TT1-1I (I)	None		0.09	Arbitrary	Flexural
TS1a (C)	None	-	-	-	Shear
TS1-1 (P-R)	None	80mm U-strips@150mm c/c	0.09	Arbitrary	Flexural
TS1-1I (I)	None		0.09	Arbitrary	Flexural
TT2a (C)	None	-	-	-	Shear
TT22 (P-R)	None	80mm L-strips@150mm c/c	0.09	Arbitrary	Flexural
TT2-2I (I)	None		0.09	Arbitrary	Flexural
TS2a (C)	None	-	-	-	Shear
TS2-1 (P-R)	None	80mm U-strips@150mm c/c	0.09	Arbitrary	Flexural
TS2-1I (I)	None		0.09	Arbitrary	Flexural

P= internal tensile reinforcement ratio: P-R – Precracked-Repaired Beam: I-Initially strengthened beam. L: 45/135, U: 0/90

TABLE III
BEHAVIOR AND PERFORMANCE OF RC T-SECTION DEEP BEAMS EXTERNALLY STRENGTHENED IN SHEAR WITH CFRP SHEET

Beams No	End of Anchor	CFRP Properties			Failure Mode
		Strengthen Scheme	Length	Selecting Size	
CT	-	-		-	1
CS-QL-HP	None	Side only	Quarter length	Arbitrary	2
CS-QL-VP	None	Side only	Quarter length	Arbitrary	2
CS-QL-CP	None	Side only	Quarter length	Arbitrary	2
CS-QL-AP	None	Side only	Quarter length	Arbitrary	2
CS-HL-HP	None	Side only	Half length	Arbitrary	2
CS-HL-VP	None	Side only	Half length	Arbitrary	2
CS-HL-CP	None	Side only	Half length	Arbitrary	2
CS-HL-AP	None	Side only	Half length	Arbitrary	2
CS-FL-HP	None	Side only	Full length	Arbitrary	3
CS-FL-VP	None	Side only	Full length	Arbitrary	2
CS-FL-CP	None	Side only	Full length	Arbitrary	2
CS-FL-AP	None	Side only	Full length	Arbitrary	2
CSU-FL-CP	Yes	U-wrap	Full length	Arbitrary	2

(1)-Failure mode: shear -compression failure. (2)-Failure mode: shear-compression failure due to partial delamination of CFRP sheet. (3)-Failure mode: shear-compression failure due to rupture of CFRP sheets

III. COMMENTS ON THE ACTUAL STATE OF ART

In all the above cases (Tables I, II, III,), it is seen that the sizes of CFRP laminates were chosen arbitrarily. There is no design guideline for optimizing the length or thickness of CFRP sheet/laminate for strengthening continuous RC beams. Most of the researches were conducted on RC rectangular sections which are not representative of the fact that most RC beams would have a T- Section due to the presence of a top slab. In all the above cases, the restraint caused by the columns in the application of the strengthening system was not considered. Literature review on strengthening RC beams in the presence of RC slabs also reveals that the strengthening system is applied in the positive moment region and the restraint caused by the column in the application of the strengthening system is not considered [25]-[32].

IV. SHEAR STRENGTHENING IN THE NEGATIVE MOMENT REGION OF T BEAM

Shear strengthening of negative moment region has received very little attention among the researchers. In negative moment region, the shear stress capacity is also an important element as this critical section involves a maximum bending moment and shear force. In the negative moment region, the strengthening is not as simple as in the case of the positive moment region because the columns prevent the application of FRP system over the web portion of the beam. From previous study showed that the use of CFRPs to strengthened in the negative moment region were effective in enhancing the strength of shear as well as the stiffness of the negative moment region.

V. FUTURE NEEDS

A review on existing research works shows that strengthening RC beams, especially T beams is still very young compare with rectangular beams. The parameters like effective length, width, thickness and appropriate anchorage system of CFRP for strengthening RC T-beams are in the need of extensive research. In other words, to prepare a complete design guideline for strengthening RC T- beam with CFRP, further research is necessary. In addition, an extensive study needs to be done in order to determine the shear contribution of externally bonded FRP composites in negative moment region.

VI. CONCLUSION

This paper reviewed the research works on shear of RC T-beams strengthening by CFRP. The review given in this research is based on CFRP composite and has been covered extensively but not exhaustively. The importance to study the strengthening of the T-beams is due more practical in the site compare with rectangular beams.

A primary concern is the long term durability of these materials under natural weathering and corrosive environments coupled with mechanical stresses. A working knowledge of how material properties change as a function of climate, time and loading will also be of great value to the engineering and design communities. In addition FRP in concrete and allows engineers to increase or decrease margins of safety depending on environmental and stress conditions, generic FRP type and required design life. The approach can became less conservative as more data, particularly from real life structures, are acquired. In addition, an extensive study needs to be done in order to determine the shear contribution of externally bonded FRP composites in negative moment region.

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