International Journal For Technological Research In Engineering
Volume 7, Issue 12, August-2020 *ISSN (Online): 2347 - 4718*

A STUDY ON SHEER OF BFRP STRENGTHENED RC T-BEAMS

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ABSTRACT: This study explores the result of an experimental investigation for enhancing the shear capacity of reinforced concrete (RC) T-beams with shear deficiencies, strengthened with Basalt Fiber Reinforced Polymer (BFRP) sheets which are a relatively new and economic alternative to more expensive fibers commonly used in strengthening of RC beams. A total of 22 numbers of concrete T-beams are tested and various sheet configurations and layouts are studied to determine their effects on the shear capacity of the beams. the present study investigates the shear behaviour of RC T-beams with different types of transverse web openings. The various parameters investigated in this study included BFRP amount and distribution, bonded surface, number of layers of BFRP, fiber orientation, transverse web openings of different shape (i.e., circular versus square versus rectangular) and end anchor. The experimental results demonstrated that the use of the new mechanical anchorage scheme comprising of laminated composite plates increases the shear capacity of the beams significantly by preventing the debonding of BFRP sheets, so that the full strength of the BFRP sheets get utilized. An analytical study is also carried out to validate the experimental findings

I. INTRODUCTION

Strengthening using FRP

Concrete beams are the main element in structural engineering which are designed to carry both horizontal loads due to seismic or wind and vertical gravity loads. Like all other concrete elements they are susceptible for situations where there is an increase in structural loads. Generally reinforced concrete (RC) beams fail in two ways: flexure failure and diagonal tension (shear) failure. Flexural failure is generally preferred to shear failure as the former is ductile while the latter is brittle. A ductile failure permits stress redistribution and gives prior notice to occupants, whereas a brittle failure is sudden and thus catastrophic.The use of external FRP reinforcement may be classified as: flexural and shear strengthening.

Flexural strengthening using FRP

For flexural strengthening the laminates of FRP are used and applied with epoxy to the tension zone of the RCC members which acts as external tension reinforcements to increase the flexural strength of the RCC members.

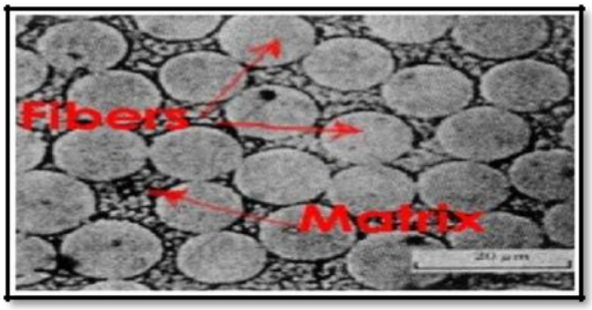

Figure 1.2 Macroscopic Structure of Fiber & Matrix

Structural members like beams, plates and columns can be strengthened in flexure through the use of FRP composites bonded to their tension zone using epoxy as a common adhesive for this purpose. The direction of fibers is kept parallel to that of the direction of high tensile stresses. Both prefabricated FRP strips and sheets are used.

Objective

The main objectives of the present research work may be summarized as follows:

- To analyse the structural behaviour of T-section RC beams under static loading condition.
- To investigate the shear behaviour and modes of failure of shear deficient RC T-beams strengthened with FRP composite sheets.
- To examine the effect of different parameters such as number of layers, bonding surface, different fiber orientation etc. on the shear capacity of the RC T-beams.
- To study the effect of strengthening with externally bonded FRP on the enhancement of strength in RC T-beams with web openings of different cross-section.
- To investigate the effect of an anchorage scheme on the improvement of shear capacity of the RC T-beams.

Experimental Setup Summary

In this experimental program, twenty two numbers of beams are investigated which are separated into two series (A and B). The detail descriptions of all the beams of two series (A and B) are presented in Table 3

Table Beam material properties and test parameters

Beam ID	(MPa)	Tension Reinforcement	Yield Stress (MPa)	FRP Thickness (mm)	Strengthening Scheme using BFRP sheet
CB	23.1	2-16mmφ, 1-12mmφ	494, 578	–	Control Beam (without FRP sheets)
SB1	25.27	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers continuous bonded horizontally to the bottom and sides of shear span of beam (U-wrap)
SB2	24.67	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers continuous bonded horizontally only to the sides of shear span of beam (Side wrap)
SB3	24.33	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers strip bonded horizontally to the bottom and sides of shear span of beam (U-strip)
SB4	23.36	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers strip bonded horizontally only to the sides of shear span of beam (Side strip)
SB5	28	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers continuous bonded vertically to the bottom and sides of shear span of beam (U-wrap)
SB6	26.81	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers continuous bonded vertically only to the sides of shear span of beam (Side wrap)
SB7	26.07	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers strip bonded vertically to the bottom and sides of shear span of beam (U-strip)
SB8	24.45	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers strip bonded vertically only to the sides of shear span of beam (Side strip)
SB9	28.03	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers bonded in inclined strip (45^0) to the bottom and sides of shear span of beam (U-strip)
SB10	28.33	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers continuous bonded vertically to the bottom and sides with composite plate bolt arrangement i.e., anchoring system only in shear span of beam (U-wrap)
SB11	28.89	2-16mmφ, 1-12mmφ	494, 578	1.07	Four layers continuous bonded vertically to the bottom and sides with composite plate bolt arrangement i.e., anchoring system only in shear span of beam (U-wrap)
SB12	28	2-16mmφ, 1-12mmφ	494, 578	0.56	Two layers strip bonded vertically to the bottom and sides with composite plate bolt arrangement i.e., anchoring system only in shear span of beam (U-strip)
CB1	23.55	2-16mmφ, 1-12mmφ	494, 578	–	Control Beam with circular hole (without FRP sheets)
SB13	26.22	2-16mmφ, 1-12mmφ	494, 578	1.07	Four layers continuous bonded vertically to the bottom and sides of shear span excluding the circular hole part of beam (U-wrap)
SB14	28.65	2-16mmφ,	494,	1.07	Four layers continuous bonded vertically to the bottom and sides of shear span excluding the

		1-12mmφ	578		circular hole part with composite plate bolt arrangement i.e., anchoring system of beam (U-wrap)
CB2	26.14	2-16mmφ, 1-12mmφ	494, 578	–	Control Beam with rectangular hole (without FRP sheets)
SB15	28.14	2-16mmφ, 1-12mmφ	494, 578	1.07	Four layers continuous bonded vertically to the bottom and sides of shear span excluding the rectangular hole part of beam (U-wrap)
SB16	27.26	2-16mmφ, 1-12mmφ	494, 578	1.07	Four layers continuous bonded vertically to the bottom and sides of shear span excluding the rectangular hole part with composite plate bolt arrangement i.e., anchoring system of beam (U-wrap)
CB3	23.26	2-16mmφ, 1-12mmφ	494, 578	–	Control Beam with square hole (without FRP sheets)
SB17	29.04	2-16mmφ, 1-12mmφ	494, 578	1.07	Four layers continuous bonded vertically to the bottom and sides of shear span excluding the square hole part of beam (U-wrap)
SB18	25.18	2-16mmφ, 1-12mmφ	494, 578	1.07	Four layers continuous bonded vertically to the bottom and sides of shear span excluding the square hole part with composite plate bolt arrangement i.e., anchoring system of beam (U-wrap)

II. TEST RESULTS AND DISCUSSIONS

Introduction

This chapter interprets the results obtained from the experimental investigation which comprises of testing twenty two numbers of RC T-beams divided into two series (A and B). The series A comprises of the shear strengthening of the RC beams with T-shaped cross-section without transverse openings and the series B dealt with the shear strengthening of the RC T-beams with transverse openings of different shapes. The behaviour of the RC T-beams with respect to initial crack load, ultimate load carrying capacity, crack pattern, deflection is studied throughout the test and their failure modes are described Except the control beams, all the beams are strengthened with various configurations of unidirectional BFRP sheets/strips. All the beams are made as shear deficient ones. A comparison in ultimate load carrying capacity is made among the control beam CB2, SB15 (strengthened with four layers continuous U-wrap with 900 fiber direction with rectangular shape web opening) and SB16 (strengthened with four layers continuous U-wrap with 900 fiber direction with rectangular shape web opening with end anchorage) and is presented in Figure 4.68. It is noticed that the ultimate load carrying capacity of SB16 is 35.09% higher than the control beam CB2 and is 14.07% higher than the beam SB15

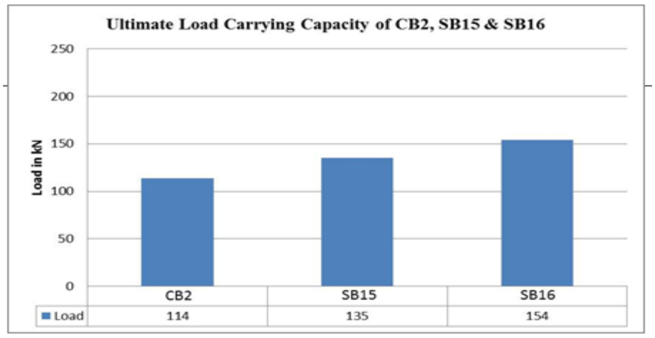

Figure Ultimate load carrying capacity of beams CB2, SB15 and SB16

The ultimate load carrying capacity of the control beam CB3, SB17 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with square shape web opening) and SB18 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with square shape web opening with end anchorage) beams are compared and is depicted in Figure 4.69. It is revealed that the ultimate load carrying capacity of SB18 is 36.67% higher than the control beam CB3 and is 13.89% higher than the beam SB17.

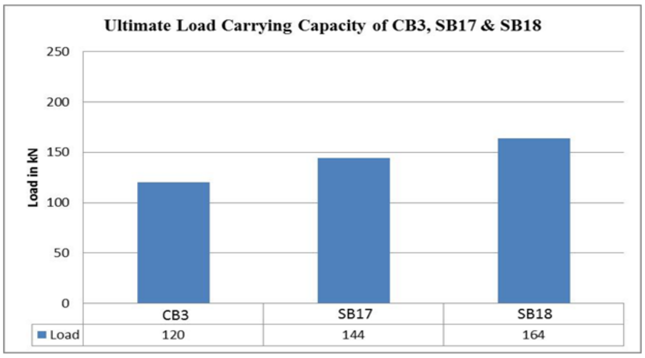

Figure 4.69 Ultimate load carrying capacity of beams CB3, SB17 and SB18

Among the beams SB13 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with circular shape web opening), SB15 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with rectangular shape web opening) and SB17 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with square shape web opening), the ultimate load carrying capacity of SB17 is 9.09% and 6.67% higher than SB13 and SB15, respectively and is shown in Figure 4.70.

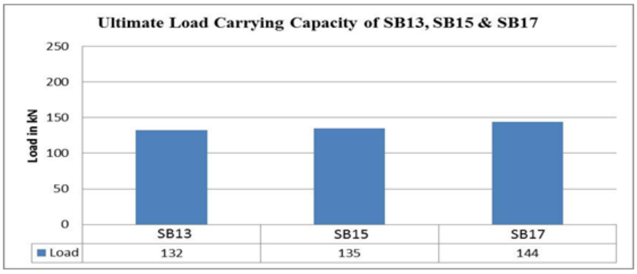

Figure 4.70 Ultimate load carrying capacity of beams SB13, SB15 and SB17

A comparison in ultimate load carrying capacity is drawn among the beams SB14 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with circular shape web opening with end anchorage), SB16 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with rectangular shape web opening with end anchorage) and SB18 (strengthened with four layers continuous U-wrap with 90^0 fiber direction with square shape web opening with end anchorage) and is given in Figure 4.71. It is observed that the ultimate load carrying capacity of SB18 is 1.23% higher than the beam SB14 and is 6.49% higher than the beam SB16.

From the above comparisons, it is observed that the shear capacity of the beams strengthened with BFRP sheets/strips is higher than the beam without FRP strengthening. There is an appreciable increase in the ultimate shear carrying capacity of the beam with the introduction of new anchorage system. There is also a considerable improvement in the shear capacity observed for the beams with web opening by using the end anchorage. The ultimate load carrying capacities of all the beams along with the nature of failure are summarized in Table 4.1. The ratio of ultimate load carrying capacity of strengthened beam to control beam are computed for Series A & B and presented in Table 4.1. From the Table, it is observed that the ratio is highest for the beam SB11 (strengthened with four layers continuous U-wrap with end anchorage) in Series A. The crack patterns and failure modes have been observed for all the beams. It is observed that all the tested beams predominantly failed in shear exhibiting a wider shear crack. The bending-shear crack pattern has not been observed in any tested beams.

It is observed from the curves 4.56-4.62 that, the percentage increase in the load carrying capacity is within 25%. This is due to the premature failure of the BFRP sheets i.e. due to the debonding of the BFRP sheets from the concrete surface, hence full strength of the BFRP has not been utilised. But, it is observed from the curve 4.63-4.69 that the increase in the load carrying capacity is within 62%. This effect is due to the use of anchorage system, which prevents the debonding of the BFRP sheets from the concrete surface. From the curves 4.70-4.71, it is noticed that, the percentage increase in load carrying capacity is within 10%. This is due to the effect of different shapes of the transverse holes.

In the cited literature [43], shear strengthening of RC T-beams using woven GFRP sheets with circular web openings have been studied. From the literature it has been observed that by using woven GFRP sheets provided with anchorage system the percent increase in the ultimate load carrying capacity is only 8.60% as compared to the beam with GFRP sheets without anchorage system. In the present study, different types of transverse web openings have been studied, such as circular, rectangular and square. For circular web opening, it is observed that, there is 22.67% increase in the load carrying capacity for the beam strengthened with BFRP sheets with anchorage system as compared to the beam strengthened with BFRP sheets without anchorage system. But, in the present research work, unidirectional BFRP sheets have been used throughout the experiment. Hence, it cannot be compared with the cited literatures in which woven GFRP have been used.

In the present research work circular, rectangular and square shape transverse holes having same cross-sectional area have been considered. The diameter of the circular hole is 7cm and the size of the rectangular and square holes are 8cmx4.8cm and 6.2cmx6.2cm respectively. Since circular hole has a greater depth as compared to the other shapes of holes, it is more susceptible to failure and the load carrying capacity of the beams with rectangular and square holes is higher than the beam with circular hole. The load carrying capacity of beam with a rectangular hole is lower than that of the beam with a square hole as the edge of the rectangular opening is closer to the support.

Table 4.1 Ultimate load and nature of failure for various beams

Beam ID	**Nature of Failure**	**(kN)**	
CB	Shear failure	158	-
SB1	Splitting and Debonding of BFRP + Shear failure	178	1.13
SB2	Splitting and Debonding of BFRP + Shear failure	167	1.06
SB3	Debonding of BFRP + Shear failure	170	1.08
SB4	Debonding of BFRP + Shear failure	163	1.03
SB5	Splitting and Debonding of BFRP + Shear failure	200	1.27

SB6	Splitting and Debonding of BFRP + Shear failure	175	1.11
SB7	Debonding of BFRP + Shear failure	185	1.17
SB8	Debonding of BFRP + Shear failure	166	1.05
SB9	Debonding of BFRP + Shear failure	192	1.21
SB10	Tearing of BFRP + Shear failure	219	1.39
SB11	Tearing of BFRP + Shear failure	232	1.47
SB12	Tearing of BFRP + Shear failure	200	1.27
CB1	Shear failure	100	-
SB13	Debonding of BFRP + Shear failure	132	1.32
SB14	Tearing of BFRP + Shear failure	162	1.62
CB2	Shear failure	114	-
SB15	Splitting and Debonding of BFRP + Shear failure	135	1.18
SB16	Tearing of BFRP + Shear failure	154	1.35
CB3	Shear failure	120	-
SB17	Splitting and Debonding of BFRP + Shear failure	144	1.2
SB18	Tearing of BFRP + Shear failure	164	1.37

III. CONCLUSIONS

Based on the experimental investigation and analytical study of shear strengthening of RC T-beams with externally bonded unidirectional BFRP composites, the following conclusions are drawn:

- The ultimate load carrying capacity of all the strengthen beams were enhanced as compared to the Control Beam.
- Initial cracks appear for higher loads in case of strengthened beams.
- Among all the BFRP strip configurations (i.e., horizontal strips, vertical strips and strips inclined at 45^{0}), the U-strip with 45^{0} fiber orientations is more effective.
- The performance of externally bonded BFRP composites can be improved significantly by using adequate anchoring system.
- A proportional increase in the shear capacity with the increasing BFRP amount cannot be achieved when debonding is not prevented.
- Beam has minimum deflection values on same loads as compared to other strengthened beams and the control beam. The midspan deflection of beam 6decreased to 23.5 % less than the control beam at load 220 KN.
- Formation of crack gets delayed due to the use of BFRP sheets and also by introduction of end anchorage.
- U-wrap with end anchorage is found to be the most effective configuration among all the configurations.
- The load carrying capacity of the strengthened beams are found to be greater than that of the control beams, thus the externally bonded BFRP composites enhances the load carrying capacity.
- The shear strength of the T-beam strengthened with the U - wrap is found to be more in case of the beam without transverse web openings.
- The T-beam with transverse web openings strengthened with anchored U-wrap performs superior than the beam without anchorage.
- Among different shapes of transverse web openings, square hole is found to be more effective as compared to other ones.
- Finally, BFRP composite is proven to be a promising material for shear strengthening of RC T-beams with or without opening.

Recommendations for Future Studies

Based on the finding and conclusions of the present study, the following recommendations are made for further research in FRP shear strengthening:

- Study of the bond mechanism between BFRP composite and concrete substrate.
- FRP strengthening of RC T-beams using carbon and aramid composites.
- Strengthening of RC T-beams using woven basalt fiber.
- Strengthening of RC L-section beams with FRP composites.
- Strengthening of RC L-section beams with transverse web openings.
- Effect of transverse web openings of different shape and size on the shear behaviour of RC L-section beams.
- Effects of shear span to effective depth ratio on the

shear capacity of beams.

- Numerical modelling of RC T & L-beams strengthened with FRP sheets with end anchorage.

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