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STUDY OF RC T-BEAMS WITH WEB OPENINGS USING FRP COMPOSITES

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Abstract: Conventional shear strengthening method such as external post tensioning, member enlargement along with internal transverse steel, and bonded steel plates are very costly, requiring extensive equipment, time, and significant labor. Conversely, the relatively new alternative strengthening technique using advanced composite materials, known as fiber reinforced polymer (FRP), offers significant advantages such as flexibility in design, ease of installation, reduced construction time, and improved durability.

The overall objective of this study was to investigate the shear performance and failure modes of RC T-beams strengthened with externally bonded GFRP sheets. In order to achieve these objectives, an extensive experimental program consisting of testing eleven, full scale RC beams was carried out. The variables investigated in this study included steel stirrups, shear span-to-depth ratio, GFRP amount.

The experimental results indicated that the contribution of externally bonded GFRP to the shear capacity is significant and depends on the variable investigated. The failures of strengthened beams are initiated with the deboning failure of FRP sheets followed by brittle shear failure. However, the shear capacity of these beams has increased as compared to the control beam which can be further improved if the deboning failure is prevented. An innovative method of anchorage technique by using GFRP plates has been used to prevent these premature failures, which as a result ensure full utilization of the strength of FRP.

INTRODUCTION

Retrofitting is specially used to relate to the seismic upgrade of facilities, such as in the case of the use of composite jackets for the confinement of columns. Retrofitting is making changes to an existing building to protect it from flooding or other hazards such as high winds and earthquakes.

The maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public amount and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives.

Fiber Reinforced Polymer (FRP):

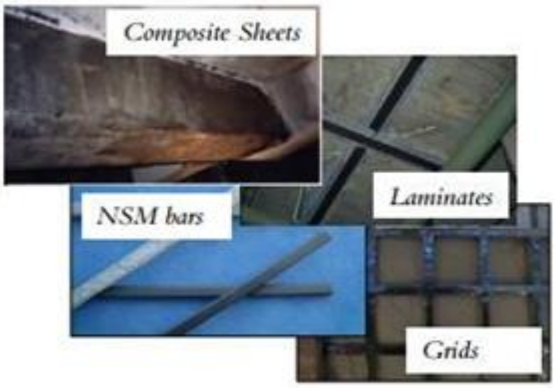

Figure 1. Various composite materials

Fiber Reinforced Polymer (FRP) composites comprise fibers of high tensile strength within a polymer matrix such as vinyl ester or epoxy. FRP composites have emerged from being exotic materials used only in niche applications following the Second World War, to common engineering materials used in a diverse range of applications such as aircraft, helicopters, space- craft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and civil infrastructure. The role of FRP for strengthening of existing or new reinforced concrete structures is growing at an extremely rapid pace owing mainly to the ease and speed of construction, and the possibility of application without disturbing the existing functionality of the structure. FRP composites have proved to be extremely useful for strengthening of RCC structures against both normal and seismic loads.

Flexural strengthening using FRP:
The laminates are generally made up of Carbon fibers blended in an epoxy matrix. These when applied with epoxy, act as external tension reinforcements to increase the flexural strength of the RCC members.
Beams, Plates and columns may 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 parallel to that of high tensile stresses. Both prefabricated FRP strips, as well as sheets (wet-lay up) are applied.

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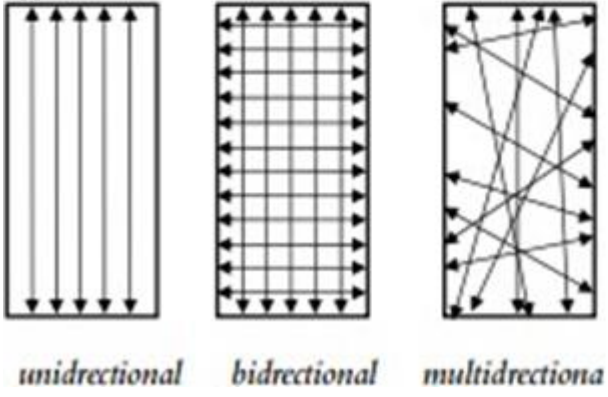


Figure 2. Fiber directions in composite materials

BRIEFREVIEW

The state of deterioration of the existing civil engineering concrete structures is one of the greatest concerns to the structural engineers worldwide. The renewal strategies applied to existing structures comprise of rehabilitation and complete replacement. The latter involves a huge expenditure and time; hence the rehabilitation is the only option available. Fiber reinforced polymers (FRP) are the promising materials in rehabilitation of the existing structures and strengthening of the new civil engineering structures.

This chapter presents a brief review of the existing literature in the area of reinforced concrete (RC) beams strengthened with epoxy-bonded FRP. The major achievements and results reported in the literature are highlighted. The review of the literature is presented in the following three groups:

a) Strengthening of Reinforced Concrete (RC) Rectangular Beams
b) Strengthening of Reinforced Concrete (RC)T-Beams
c) Strengthening of RC Rectangular and T- Beams with web opening

EXPERIMENTAL PROGRAM

The objective of the experimental program is to study the effect of externally bonded (EB) fiber reinforced polymer (FRP) sheets on the shear capacity of reinforced concrete T-beam with a transverse opening in shear span under static loading condition. Eleven number of reinforced concrete T-beams are cast and tested up to failure by applying symmetrical four-point static loading system. These beams were divided into 2 groups designated as A and B. The difference between two groups was in transverse steel reinforcement. Out of eleven number of beams, four beams were not strengthened by FRP and in that two beams were considered as a control beams and two beams were solid beams without transverse opening, whereas all other seven beams were strengthened with externally bonded GFRP sheets in shear zone of thebeam. The variables investigated in this research study included steel stirrups (i.e., beams with and without steel stirrups), shear span-to depth ratio (i.e., a/d ratio 2.66 versus 2), and end anchor (i.e., U-wrap with and without end anchor).

TESTSPECIMENS

All eleven reinforced concrete T-beams had a span of 1300 mm, 150mm wide web, 350mm wide flange, 125mm deep web, 50mm deep flange and effective depth of 125mm.

The arrangement of reinforcement of beams under group-A consists of 2numbers of 20mm φ and 1number of 10mm φ HYSD bars as tension reinforcement, four bars of 8mm φ are also provided as hang up bars and without any shear reinforcement.

The arrangement of reinforcement of beams under group-B consists of 2numbers of 20mm φ and 1number of 10mm φ HYSD bars as tension reinforcement, four bars of 8mm φ are also provided as hang up bars and 8mm φ bars are provided as shear reinforcement at 200 mm spacing.

MATERIALPROPERTIES

Concrete

For conducting experiment, the proportions in the concrete mix are tabulated in Table 3.1 as per IS: 456-2000. The water cement ratio is fixed at 0.55. The mixing is done by using concrete mixture. The beams are cured for 28 days. For each beam six 150x150x150 mm concrete cube specimens and six 150x300 mm cylinder specimens were made at the time of casting and were kept for curing, to determine the compressive strength of concrete at the age of 7 days & 28 days are shown in table3.2.

Table 1 Nominal Mix Proportions of Concrete

Description	Cement	Sand (Fine Aggregate)	Coarse Aggregate	Wate
Mix Proportion (by weight)	1	1.67	3.33	0.60
Quantities of materials for one specimen beam (kg)	44.4	74.11	147.85	22.50

The compression tests on control and strengthened specimen of cubes are performed at 7 days and 28 days. The test results of cubes are presented in Table 3.2.

Table 2 Test Result of Cubes after 28 days

Specimen Name		Size of Cube Specimen	Size of Cylinder Specimen	Average Cube Compressive Strength (MPa)	Average Cylinder Compressive Strength (MPa
Group-A	Solid beam	150x150x150	150φ x300	35.23	25.15
	CBA	150x150x150	150φ x300	35.88	20.93
	SBA2-1	150x150x150	150φ x300	36.50	21.86
	SBA2-2	150x150x150	150φ x300	34.87	23.72
	SBA2-3	150x150x150	150φ x300	36.47	20.46
	SBA4-1	150x150x150	150φ x300	37.86	26.82
Group-B	Solid beam	150x150x150	150φ x300	30.83	21.08
	CBB	150x150x150	150φ x300	32.56	22.75
	SBB2-1	150x150x150	150φ x300	31.89	20.74
	SBB2-2	150x150x150	150φ x300	35.40	23.50
	SBB2-3	150x150x150	150φ x300	36.77	24.87

TEST RESULTS AND DISCUSSIONS

INTRODUCTION

In this chapter, the results obtained from the testing of eleven number RC T-Beams for the experimental program are interpreted. Their behaviors throughout the test are described with respect to initial crack load and ultimate load carrying capacity, deflection, crack pattern and modes of failure.

All the beams except the control beams (CB) and solid beams are strengthened with various patterns of GFRP sheets. All the beams except SBA2-3 and SBB2-3 were in both the groups having shear span of 333.33 mm and SB3 having shear span of 250 mm. Specimens of group-A were cast without stirrups and group-B casted with stirrups at 200mm spacing. In both the groups the beam designated as SBA2-1 and SBB2-1 were strengthened with two layers of bi- directional GFRP sheets having U-wrap on shear of the beam where the transverse hole is provided. The beam SBA2-2 and SBB2-2 were strengthened with two layers of bi-directional GFRP sheets having U-wrap on shear span (0 to L/3 and L/3 to 2L/3) of the beam with flange anchorage system. The beam SBA2-3 and SBB2-3 were strengthened with two layers of bi- directional GFRP sheets in the form of U-wrap on shear span for a width of 250 mm with flange anchorage system. SBA4-1 was strengthened with four layers of bi-directional GFRP sheets having U-wrap on shear span (0 to L/3 and L/3 to 2L/3) of the beam with flange anchorage system by using GFRP plates instead of steel plates.

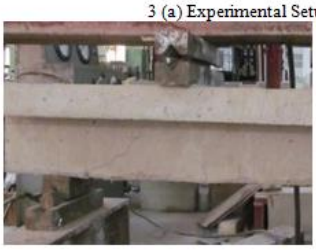
Crack Behavior and Failure Modes

The crack behavior and failure modes of the eleven number of beams tested in the experimental program are described below.

4.2.1. GROUP-A 4.2.1.1Solid Beam

The solid beam was cast with same reinforcement used for control beam but no transverse hole is provided. Figure 4-1 (a) shows the experimental test setup of solid beam under four point loading. The first hair crack was visible in the shear span at a load of 110 kN as shown in figure 4-1(b). With further increase in load, the beam finally failed in shear at a load of 208 kN exhibiting a wider diagonal shear crack as shown in figure 4-1 (c). The first shear crack became the critical crack for the ultimate failure of the solid beam. There is a 17.3% increase in shear capacity over the control beam.

3 (a) Experimental Setup of beam Solid beam



3 (b) Hair line crack startedat110kN

3 (c) Widened crack at ultimateload

Control Beam (CBA)

The control beam (CB) was cast with a reinforcement of two numbers of 20 mm bar and one number of 10 mm bar on tension face. The stirrups were not provided in the beam to make it shear deficient. The beam was tested by applying the point loads gradually. Figure 4-2 (a) shows the experimental test setup of control beam under four pointloading. The first hair crack was visible in the shear span at a load of 90 kN as shown in figure 4-2 (b). This crack appeared at the mid-height zone of the web of the beam. As the load increased beyond the first crack load, many inclined cracks were also developed and the first visible crack started widening and propagated With further increase in load, the beam finally failed in shear at a load of 172 kN exhibiting a wider diagonal shear crack as shown in figure 4-2 (c). The first shear crack became the critical crack for the ultimate failure of the control beam.

4(a) Experimental Setup of the CBA under four-point loading

Load-deflection history

The mid-span deflection of the control and strengthened beams were measured at different load steps and the deflections under the point loads and under centre of point load were also recorded. The load-deflection histories are illustrated in figures 4.12 to 4.22. It was observed that the deflection under the point load was less than that at the centre. These figures below show that the deflection curve was initially straight showing the linear relationship between the load and deflection and became non-linear with further increase in load.

Group-A:

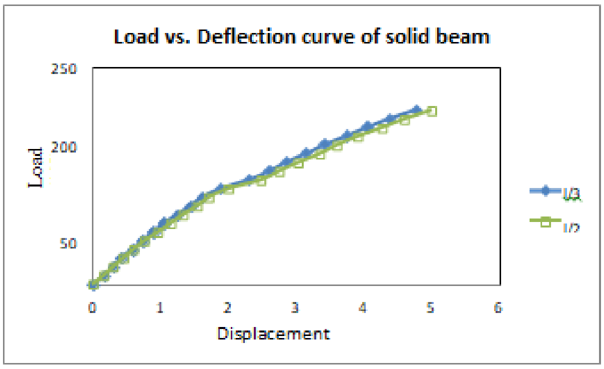


Figure 5. Load vs. Deflection Curve for Solid beam A

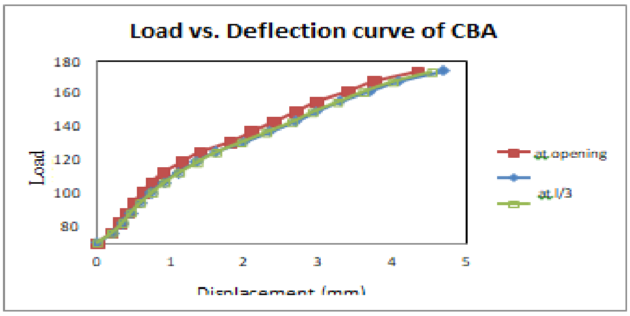
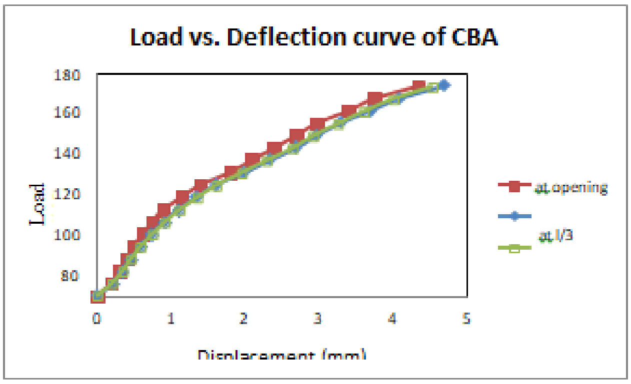


Figure 6. Load vs. Deflection Curve for CBA



GROUP-B:

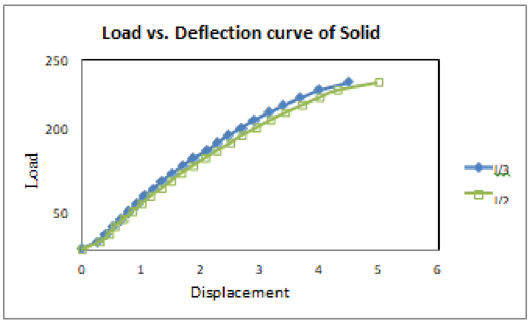


Figure 8. Load vs. Deflection Curve for Solid beam B

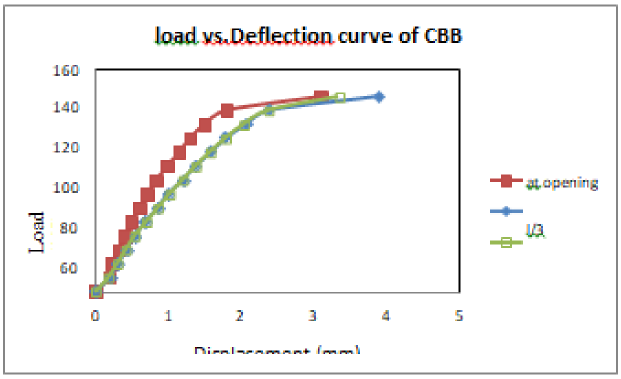


Figure 9. Load vs. Deflection Curve for CBB

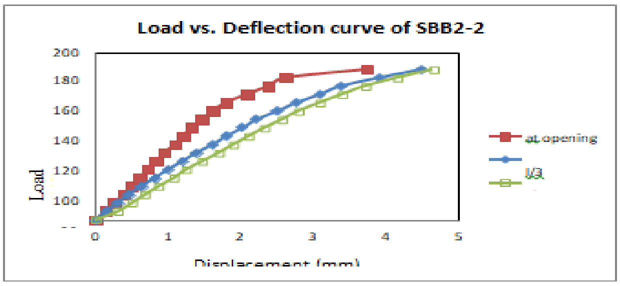


Figure 11. Load vs. Deflection Curve forSBB2-2

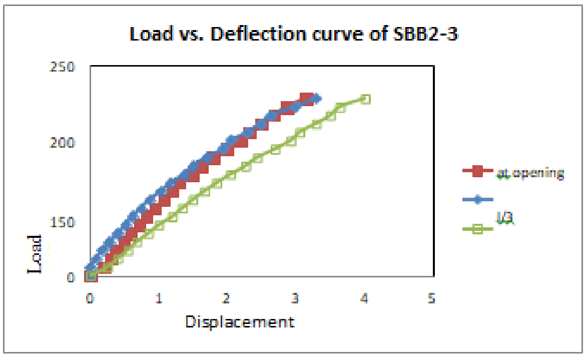


Figure 12. Load vs. Deflection Curve for SBB2-3

CONCLUSIONS

In this experimental investigation the shear behavior of RC T-beams strengthened by GFRP sheets are studied. The use of Fiber reinforced polymer (FRP) composites as external reinforcement leads to improve structural performance and FRP materials have high ultimate strength. This paper improves the application and performance of beams by using FRP sheets.
Based on the experimental and theoretical results, the following conclusions are drawn:

- The experimental verification of the flange anchorage system shows the effectiveness in increasing the shear capacity of RC beams.
- Existing evidence clearly indicates that the anchorage system can make FRP strengthening even more attractive and economical for concrete repair and strengthening.
- The test results indicates that the contribution of GFRP benefits the shear capacity to a greater degree for beams without steel shear reinforcement than for beams with adequate steel shear reinforcement.
- The contribution of externally bonded GFRP reinforcement to the shear capacity is influenced by the shear span-to-depth ratio (a/d) and it increases with a decrease in a/d ratio.

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