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Experimental Study of FRP Composites for Shear Strengthening Of RC T-Beams With Web Openings

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ABSTRACT: *Shear collapse of reinforced concrete (RC) members is catastrophic and occurs suddenly with no advance warning of distress. In several occasions existing RC beams have been found to be deficient in shear and in need of strengthening. 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.*

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 debonding 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 debonding 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.

KEYWORDS: *Shear strengthening, RC T-Beam, web opening, FRP composites.*

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I. INTRODUCTION:

Many natural disasters, earthquake being the most affecting of all, have produced a need to increase the present safety levels in buildings. The knowledge of understanding of the earthquakes is increasing day by day and therefore the seismic demands imposed on the structures need to be revised. As the complete replacement of such deficient structures leads to incurring a huge amount of public money and time, retrofitting has become the acceptable way of improving their load carrying capacity and extending their service lives. 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.

The retrofitting is one of the best options to make an existing inadequate building safe against future probable earthquake or other environmental forces. There are many other factors, considered in decision making for any retrofitting strategy.

Ghazi studied the shear repair of reinforced concrete (RC) beams strengthened with fiber glass plate bonding (FGPB) for structural and non-structural cracking behaviour due to a variety of reasons. Results from a study on strengthening of RC beams having deficient shear strength and showing major diagonal tension cracks have been presented. The beams with deficient shear strength were damaged to a predetermined level (the appearance of the first shear crack) and then repaired by fiber glass plate bonding (FGPB) techniques.Chaallal (1998) investigated a comprehensive design approach for reinforced concrete flexural beams and unidirectional slabs strengthened with externally bonded fiber reinforced plastic (FRP) plates. The approach complied with the Canadian Concrete Standard.Alex(2001) studied experimentally the effect of shear strengthening of RC beams on the stress distribution, initial cracks, crack propagation, and ultimate strength. Five types of beams with different strengthening carbon-fiber–reinforced plastic sheets are often strengthened in flexure. The experimental results show that it is not necessary to strengthen the entire concrete beam surface. The general and regional behaviors of concrete beams with bonded carbon-fiber–reinforced plastic sheets are studied with the help of strain gauges. Chen and Teng (2003) carried out an investigation on the shear capacity of FRP-strengthened RC beams. These studies have established clearly that such strengthened beams fail in shear mainly in one of the two modes, i.e., FRP rupture and FRP debonding, and have led to preliminary design proposals. This study was concerned with the development of a simple, accurate and rational design proposal for the shear capacity of FRP-strengthened beams which fail by FRP debonding. This new model explicitly recognises the non-uniform stress distribution in the FRP along a shear crack as determined by the bond strength between the FRP strips and the concrete.

EXPERIMENTAL PROGRAM:

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.

OBJECTIVE

The main objectives of the present work are:

- To study the structural behaviour of reinforced concrete (RC) T-beams with a transverse hole under static loading condition.
- To study the contribution of externally bonded Fiber Reinforced Polymer (FRP) sheets on the shear behaviour of RC T-beams.
- To know the suitability of the FRP composites as repair materials for deteriorated RC Structures.
- To examine the effect of different parameters such as steel stirrups, number of layers, different shear span to effective depth ratio etc. on enhancement of load carrying capacity and load deflection behaviour.
- To investigate the effect of a new anchorage scheme on the shear capacity of the beam.

II. MATERIAL PROPERTIES

Concrete

For conducting experiment, the proportions in the concrete mix are tabulated in Table 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 table 1.

Table 1:Nominal Mix Proportions of Concrete

Description	Cement	Sand (Fine Aggregate)	Coarse Aggregate	Water
Mix Proportion (by weight)	1	1.67	3.33	0.6
Quantities of materials for one specimen beam (kg)	44.4	74.11	147.85	22.5

Fine Aggregate

Fine aggregate/sand is an accumulation of grains of mineral matter derived from disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles, but is distinct from clays which contain organic material. Sand is used for making mortar and concrete and for polishing and sandblasting. Sands containing a little clay are used for making molds in foundries. Clear sands are employed for filtering water. Here, the fine aggregate/sand is passing through 4.75 mm sieve and having a specific gravity of 2.64. The grading zone of fine aggregate is zone III as per Indian Standard specifications IS: 383-1970.

Coarse Aggregate
Coarse aggregates are the crushed stone is used for making concrete. The commercial stone is quarried, crushed, and graded. Much of the crushed stone used is granite, limestone, and trap rock. The coarse aggregates of two grades are used one retained on 10 mm size sieve and another grade contained aggregates retained on 20 mm size sieve. The maximum size of coarse aggregate was 20 mm and is having specific gravity of 2.88 grading confirming to IS: 383-1970.

Water
Water fit for drinking is generally considered good for making the concrete. Water should be free from acids, alkalis, oils, vegetables or other organic impurities. Soft water produces weaker concrete. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement. Ordinary clean portable tap water is used for concrete mixing in all the mix.

Reinforcing Steel
High-Yield Strength Deformed (HYSD) bars confirming to IS 1786:1985. The longitudinal steel reinforcing bars were deformed, high-yield strength, with 20 mm and 10 mm diameter. The stirrups were made from deformed steel bars with 8 mm diameter.Three coupons of steel bars were tested and yield strength of steel reinforcements used in this experimental program is determined under uniaxial tension an accordance with ASTM specifications. The proof stress or yield strength of the specimens are averaged and shown in Table 3.5. The modulus of elasticity of steel bars was 2×10^5 MPa.

Table 2:Tensile Strength of reinforcing steel bars

Sl. no. of sample	Diameter of bar (mm)	0.2% Proof stress (N/mm^2)	Avg. Proof Stress (N/mm^2)
1	20	475	470
2	20	472	
3	20	463	
4	10	530	529
5	10	535	
6	10	521	
7	8	520	523
8	8	527	
9	8	521	

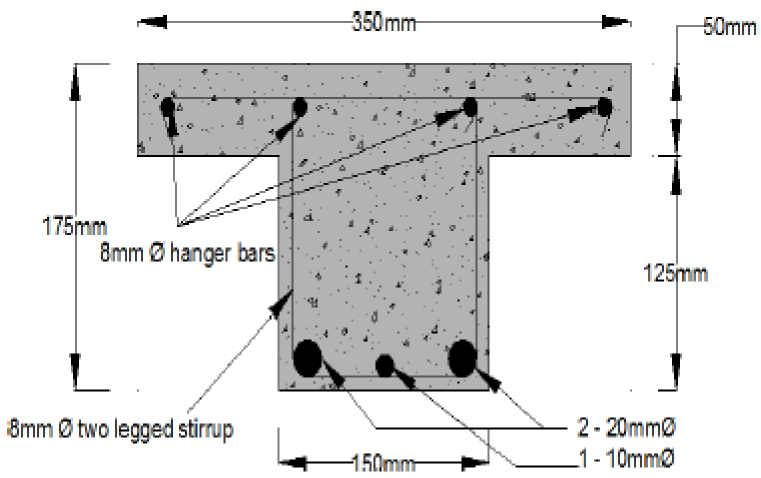

Figure 1:Detailing of Reinforcement

III. RESULTS:

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

Group-A:

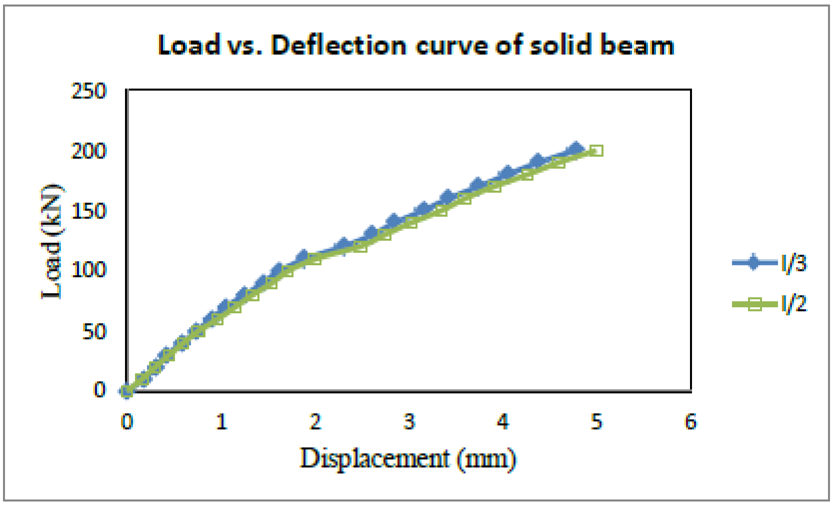

Figure 3. Load vs. Deflection Curve for Solid beam A

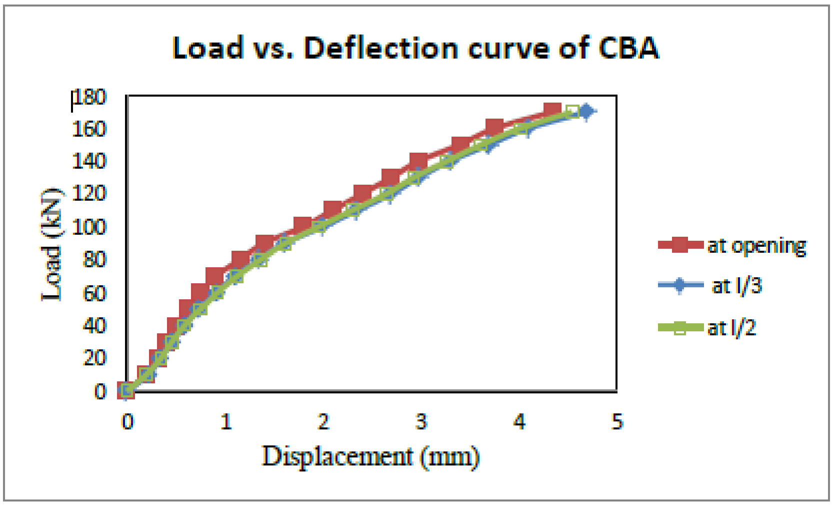

Figure 4. Load vs. Deflection Curve for CBA

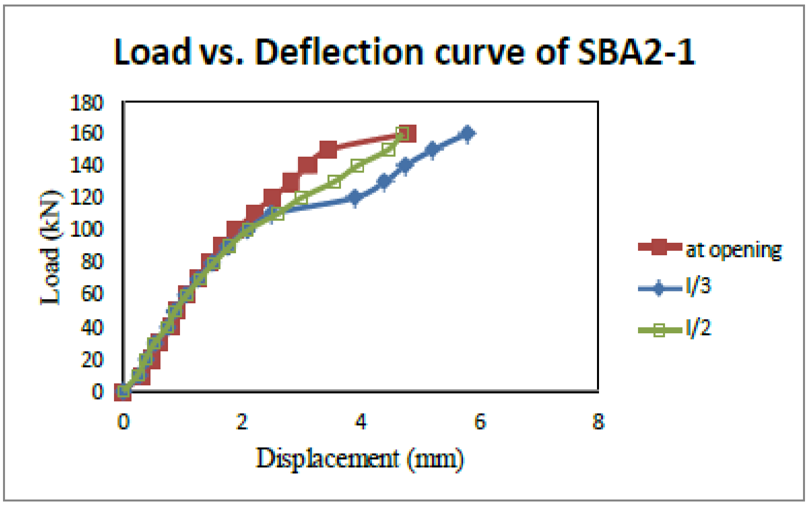

Figure 5. Load vs. Deflection Curve for SBA2-1

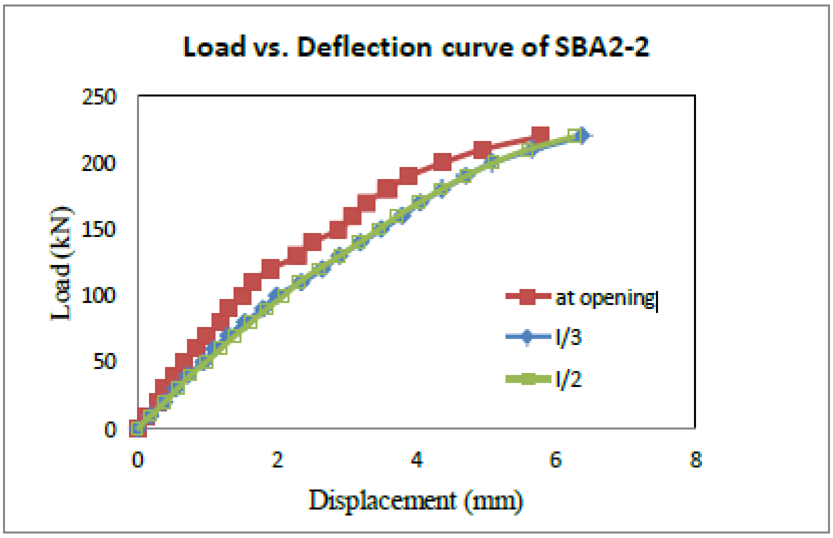

Figure 6. Load vs. Deflection Curve for SBA2-2

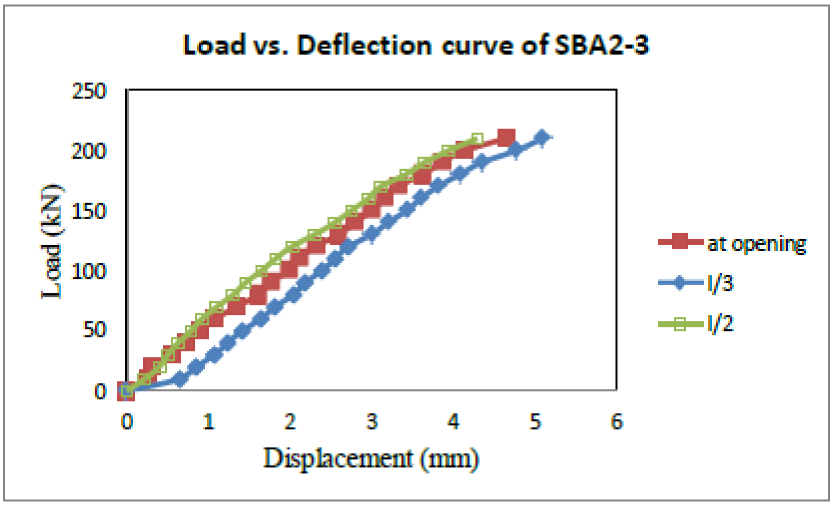

Figure 7. Load vs. Deflection Curve for SBA2-3

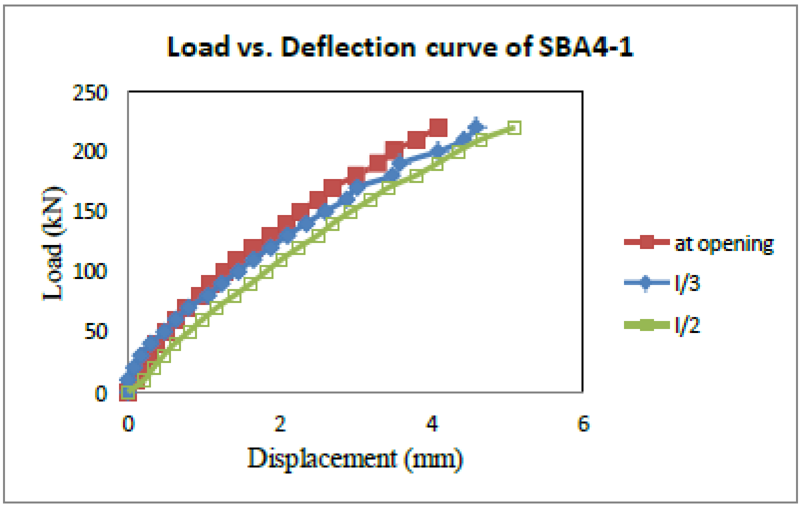

Figure 8. Load vs. Deflection Curve for SBA4-1

GROUP-B:

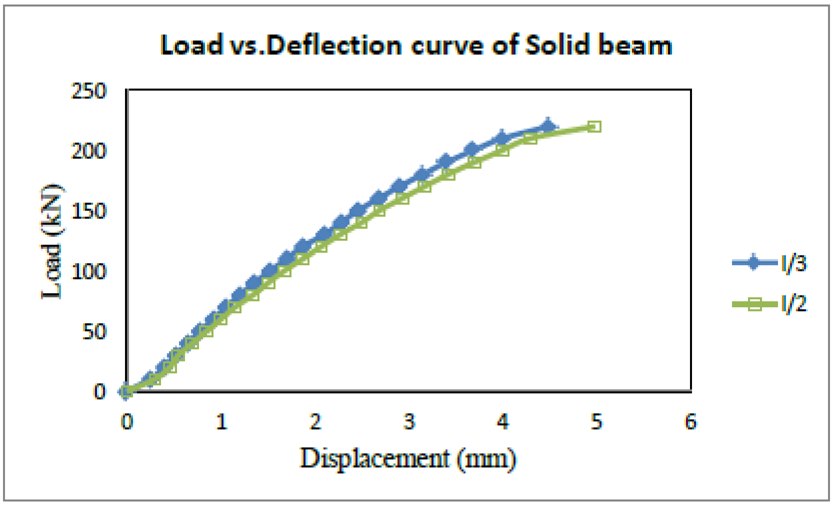

Figure 9. Load vs. Deflection Curve for Solid beam B

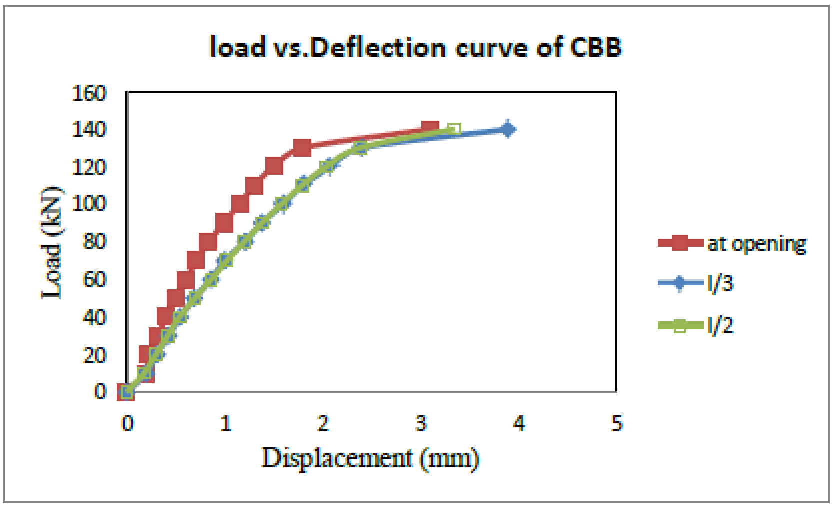

Figure 10. Load vs. Deflection Curve for CBB

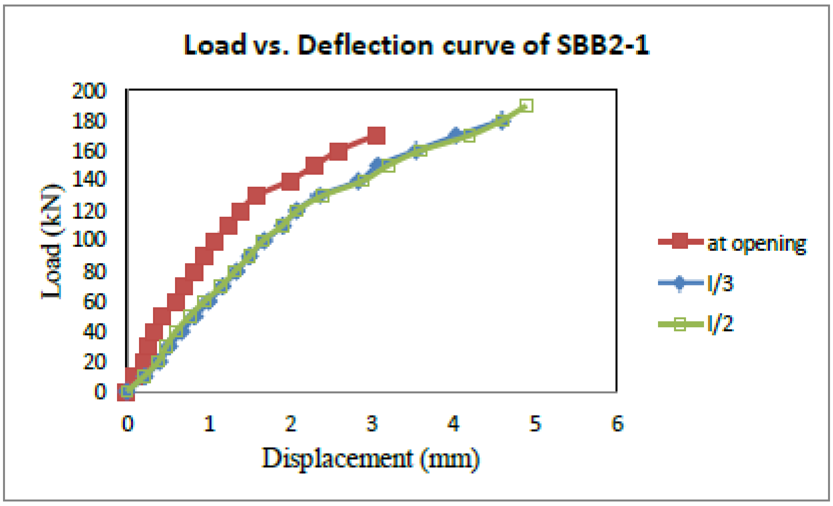

Figure 11. Load vs. Deflection Curve for SBB2-1

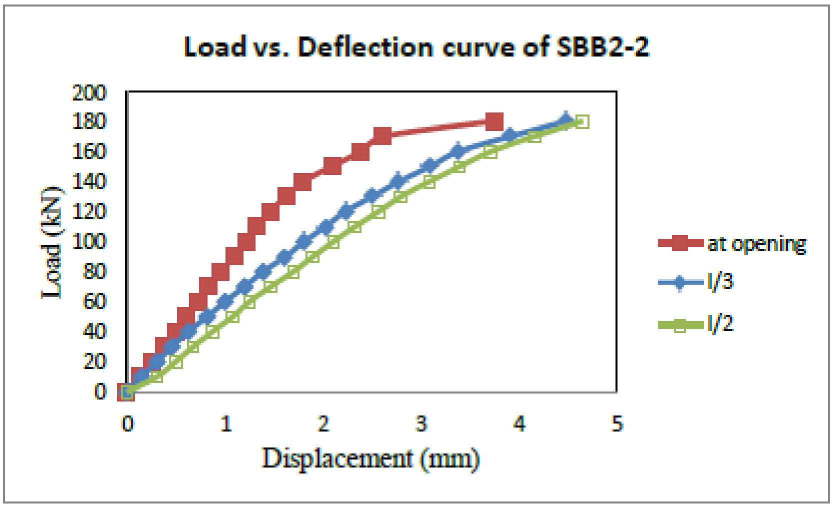

Figure 12. Load vs. Deflection Curve for SBB2-2

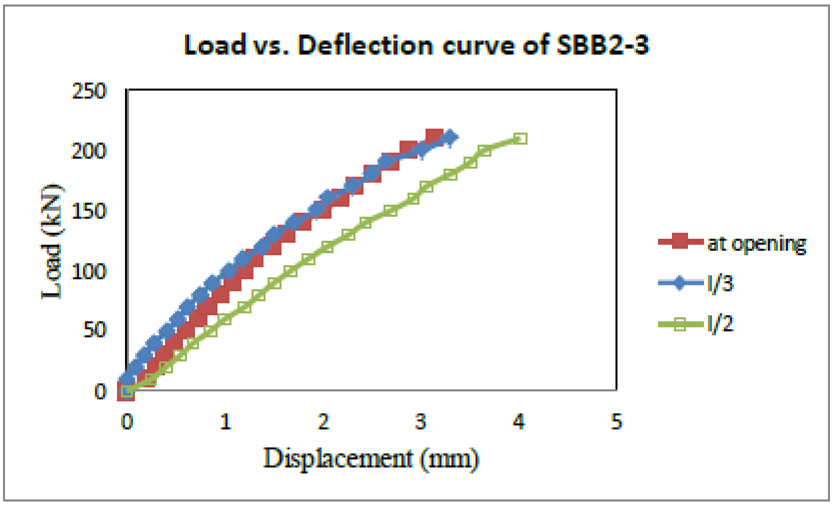

Figure 13. Load vs. Deflection Curve for SBB2-3

The deflection profile for the control beam CBA and beams SBA2-1 (strengthened with two layers continuous U-wrap on hole side), SBA2-2 (strengthened with two layers continuous Uwrap on both sides with flange anchorage system) and SBA4-1 (strengthened with four layers continuous U-wrap on both sides with flange anchorage system) are presented in figure 14.From the figure14, it is observed that SBA2-2 and SBA4-1 performs well compared to CBA and SBA2-1. The reduction in mid-span deflection of the beam SBA4-1 compared to CBA and SBA2-1 are 20.39% and 31.91% respectively under the applied load of 160 kN.

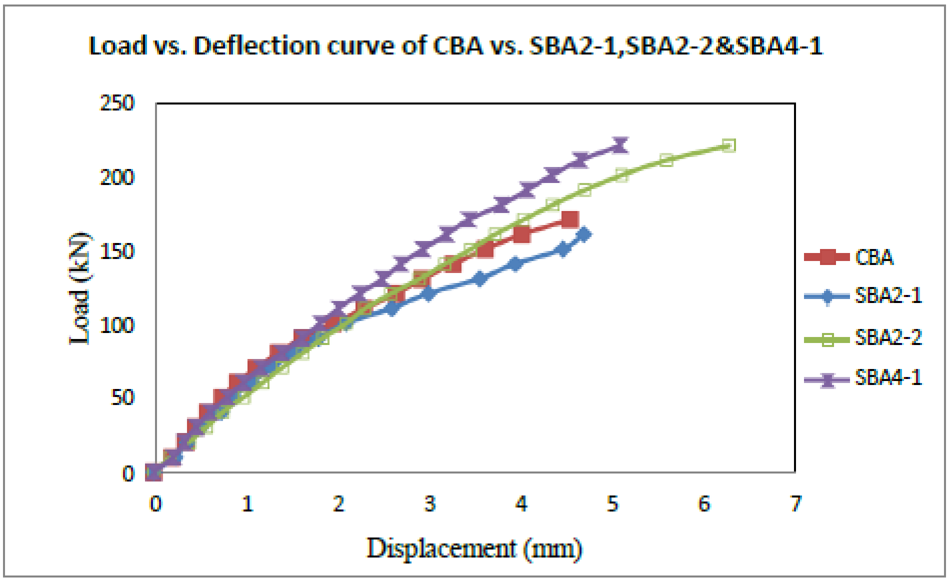

Figure 14. Load vs. Deflection Curve for CBA vs. SBA2-1, SBA2-2 and SBA4-1

The deflection profile for the control beam CBA and SBA2-3 (strengthened with two layers continuous U-wrap on both sides with flange anchorage system having a shear span of 250mm) are presented in figure 4-24. From the figure 15, it is observed that SBA2-3 performs well compared to CBA. The reduction in mid-span deflection of the beam SBA2-3 compared to CBA is 26.36% under the applied load of 160 kN.

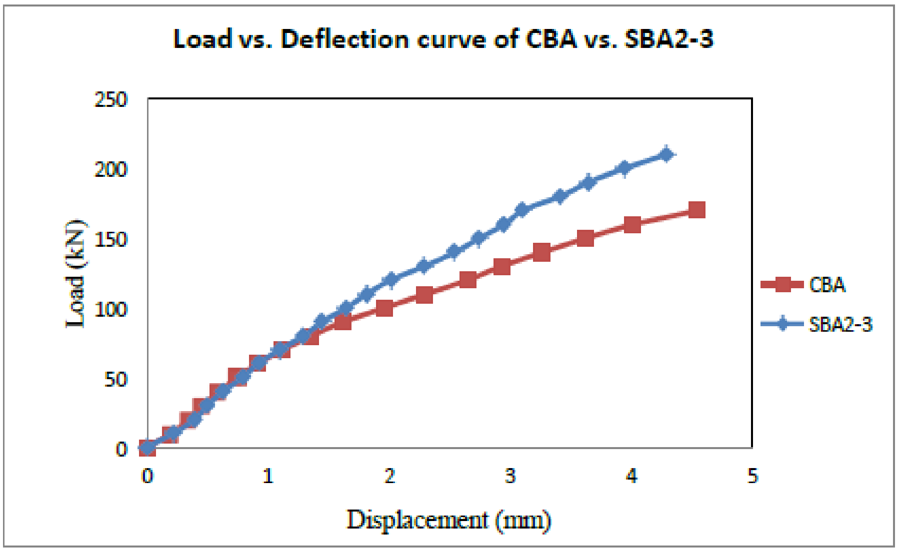

Figure 15. Load vs. Deflection Curve for CBA vs. SBA2-3

The deflection profile for the control beam CBA and solid beam (without transverse hole and no strengthening) are presented in figure 16. From the figure 16, it is observed that solid beam performs well compared to CBA. The reduction in mid-span deflection of the beam Solid beam compared to CBA is 10.44% under the applied load of 160 kN.

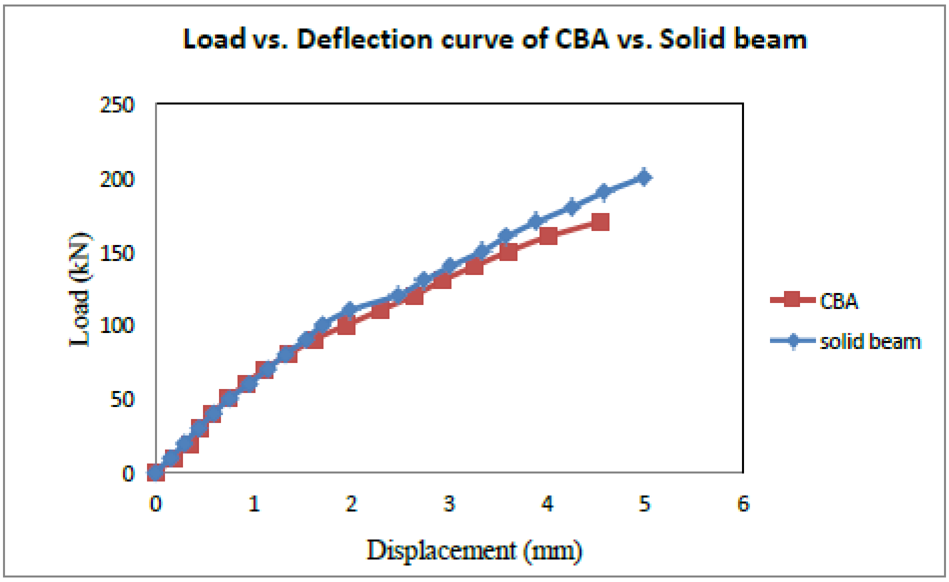

Figure 16. Load vs. Deflection Curve for CBA vs. Solid beam

The deflection profile for the control beam CBB and beams SBB2-1 (strengthened with two layers continuous U-wrap on hole side) and SBB2-2 (strengthened with two layers continuous Uwrap on both sides with flange anchorage system) are presented in figure 17. From the figure 17, it is observed that SBB2-1 and SBB2-2 performs well compared to CBB. The reduction in mid-span deflection of the beam SBB2-1 and SBB2-2 compared to CBB are 13.43% and 7.76% respectively under the applied load of 140 kN.

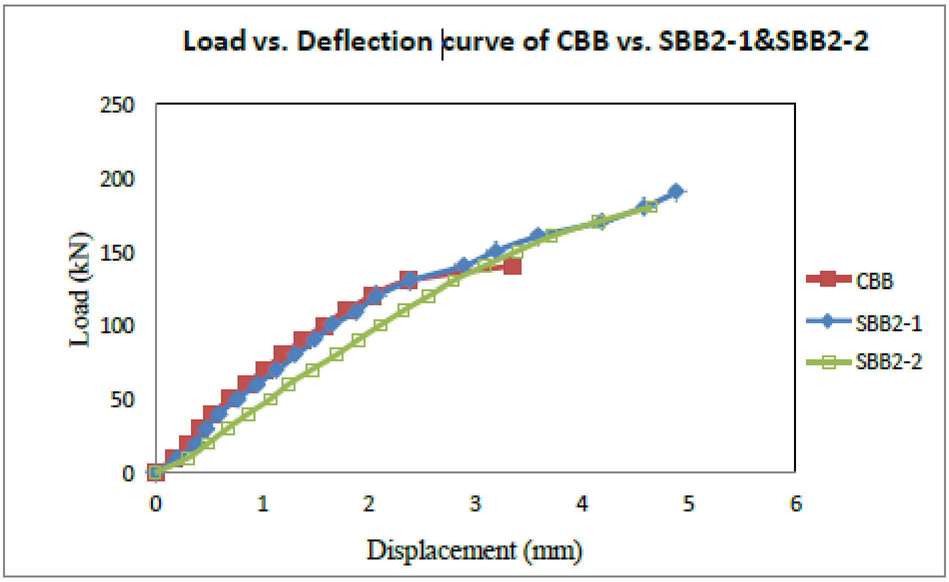

Figure 17. Load vs. Deflection Curve for CBB vs. SBB2-1 and SBB2-2

The deflection profile for the control beam CBB and SBB2-3 (strengthened with two layers continuous U-wrap on both sides with flange anchorage system having a shear span of 250mm) are presented in figure 4-27. From the figure 18, it is observed that SBB2-3 performs well compared to CBB. The reduction in mid-span deflection of the beam SBB2-3 compared to CBB is 27.16% under the applied load of 140 kN.

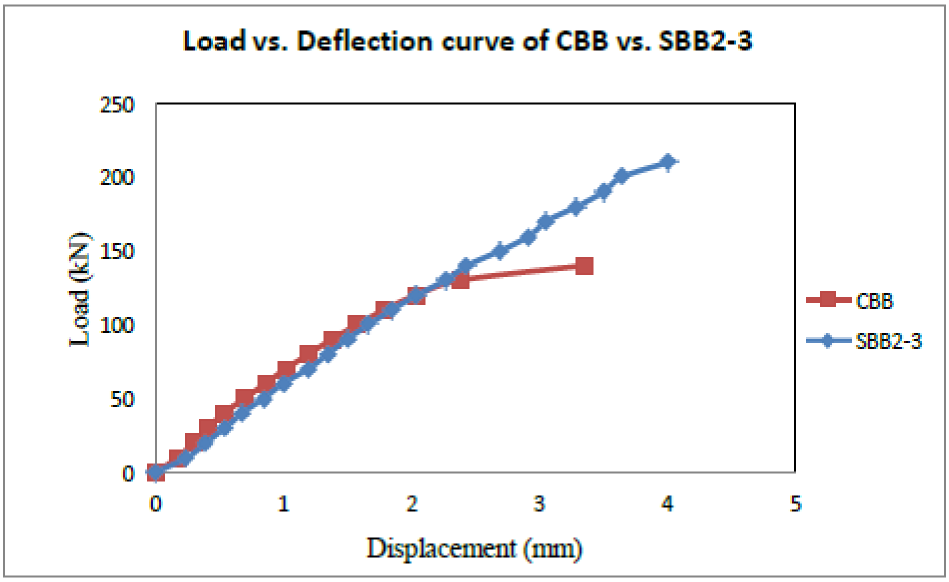

Figure 18. Load vs. Deflection Curve for CBB vs. Solid beam B

The ultimate load carrying capacities of all the beams along with the nature of failure are summarized in Table 3. The ratio of ultimate load carrying capacity of strengthened beam to control beam are computed and presented in Table 3.

Table3:Ultimate load and nature of failure for various beams

Beam Designation		Nature of Failure	P_u (kN)	$\lambda = \frac{Pu(Strengthened\ Beam)}{Pu(Control\ Beam)}$
Group-A	Solid beam	Shear failure	208	1.2
	CB	Shear failure	172	-
	SB1	Shear failure	180	1.04
	SB2	Tearing and Debonding of GFRP + Shear failure	220	1.28
	SB3	Tearing and Debonding of GFRP + Shear failure	210	1.22
	SB4	Debonding failure + Shear failure	230	1.33
Group-B	Solid beam	Shear crack shifted to the non-strengthened zone of shear span	240	1.71
	CB	Shear failure	140	-
	SB1	Tearing and Debonding failure + Shear failure	198	1.41
	SB2	Tearing of GFRP + Shear failure	204	1.45
	SB3	Tearing of GFRP + Shear failure	214	1.53

IV. CONCLUSIONS:

Based on the experimental and theoretical results, the following conclusions are drawn:

- The test results confirm that the strengthening technique of FRP system is applicable and can increase the shear capacity of T-beams.
- The experimental verification of the flange anchorage system shows theeffectiveness 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 andstrengthening.
- 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 beamswith 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 adecrease in a/d ratio.
- The use of anchorage system eliminates the debonding of the GFRP sheet, andconsequently results in a better utilization of the full capacity of the GFRP sheet.

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