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Experimental Investigation on the Study of RC-T Beam with Opening Strengthened with GFRP

Sivagandan.M[1], Dr.B.Shivakumaraswamy[2], Dr.S.Vijaya[3]
P.G Student[1], HOD & Professor[2], Professor[3]
Department of Civil Engineering
Dr.AIT, Bangalore

Abstract:
In this investigation the importance of web opening in Reinforced Concrete T- beam for the purpose of service lines into the buildings as per modern requirements are explained. The dimensions of the specimens cast were 1300 mm in length, width and depth of web was 100x125mm and having a flange of 300x75 mm. This experimental work includes the testing of beams with and without web openings. The beams were cast having circular opening of 50mm diameter in the shear portion of the beam and tested with the four point symmetrical loading. The ratio of shear span to depth was 2.188 and ratio of size of opening to depth was 0.40.This paper is mainly concentrated on strengthening techniques of RC T-Beam with web opening in shear region using glass fibre reinforced polymer (GFRP) i.e., U-Wrap and face wrap. From the experimental results it is observed that, the load carrying capacity decrease in the unstrengthened beam with opening compare to control beams and was increased in case of Strengthened beams compared to unstrengthened beams. The presence of openings leads to decrease in stiffness and improves in deflection of beams compared to control beam. This paper also explains about the effect of GFRP on the control of deflection, cracks propagation and failure pattern. Finally use of U wraps with one and two layer of GFRP gives the strength similar to that of the control beams without openings.

Keywords: Glass fiber reinforced polymer, circular opening, Strengthening, retrofitting, RC T-beam, bonding agents.

I. INTRODUCTION

The deterioration of the RC structure plays a major role in the reduction of strength and stiffness of the structural elements. Due to corrosion of reinforcing steel, concrete age, seismic activities, improper design and maintenance etc.The transverse opening in the beam is an important element to be considered in the modern day construction practice for the passage of utility ducts, sewerage and water supply pipes. Circular, Rectangular and Square are the common shapes of opening provided in the beams. The major reason behind this practise is to reduce dead space of the room, floor to floor height of the building and also increasing the numbers of storeys of the building in a structure. Another important advantage is reduction in the floor height helps in saving building material, which results in reduction of overall cost of the building. The presences of opening in the web in the beam also have some disadvantages, it leads to decreasing the stiffness of beam, increasing the deflection of the beam, decreasing the ultimate load carrying capacity of the beam and cause more cracks surrounding the opening. Presence of opening also develops cracks much faster than regular in the beam. To overcome from the above mentioned disadvantages, strengthening is one of the latest alternative techniques carried out in construction practice. Use of GFRP fabric as strengthening element leads to increase in the load carrying capacity and stiffness of the beam in the shear portion having openings. GFRP wrapping also reduces the development of cracks in the beams. The main advantages in the strengthening process by GFRP wrapping are it has low self weight, high strength to weight ratio, easy to transport, easy to install and requires less time. These are some of the limitations in this system is relatively less economical and pot life of resign will be less so the wastage will be more.

II. RELATED WORKS

Mehmet Mustafa Onal [1] studied on strengthening of Reinforced Concrete beams with CFRP and GFRP and concluded that there was a reduction in the deflection of the beam with CFRP is 41% and GFRP is about 53.6%. It was also observed that there is increase in strength of beam with CFRP is 42% and GFRP is about 38%.

M.A.Mansur [2] investigated on the design of reinforced concrete beams with web openings; the author gave brief information about the size and location of the openings. Also discussed types of failure of beams and explained the limitation of post opening in existing structure. It also includes the analysis and design of circular and large rectangular opening. The reinforcement detailing of beams having single and multiple opening are also provided.

Subhajit Mondal, J.N.Bandyapadya and Chandra Pal Gautham[3] researched on Strengthening and Rehabilitation of Reinforced Concrete beams with opening and concluded that the use of GFRP can enhance the ultimate load of small openings only and it is not capable to enhance the ultimate load effectively for large openings. Maximum deflection is observed at the midpoint of the beam not below the opening and FRP wrapping failed by tearing along the diagonal cracks.

Surya sunder S, Nisha Babu, Dinu Paulose[4] reported on Experimental study on strengthening of openings in R.C Beams using BFRP fabric and they concluded that the beams with double circular opening gave the better strength when compared to that of the singular circular opening. The formation of initial crack is observed at higher load in strengthened beam compared to control beams and most of the beams were failed by shear during the experimental testing. S.A.G.ALY [5] investigated on Behaviour of RC Beams with strengthened openings in D-Region and they concluded that there was a gain in the shear capacity of the tested RC T- beam ranged from 48% to 100%. There was also increase in the ultimate load carrying capacity of beam with strengthened opening were 91%,107% and 123% of that of the beam without opening.

III. EXPERIMENTAL PROGRAM

This experimental work consists of thirteen beams were cast and tested with and without web openings. The dimension of the specimens was 1300 mm in length, width and depth of web was 100x125mm with a flange of 300x75 mm. The beams were cast having circular opening of 50mm diameter in the shear portion and tested with the four point symmetrical loading system. The ratio of shear span to depth was 2.188 and ratio of size of opening to depth was 0.40. All the beams were designed as under reinforced section having reinforcing steel as shown in figure 1(a) and 1(b).

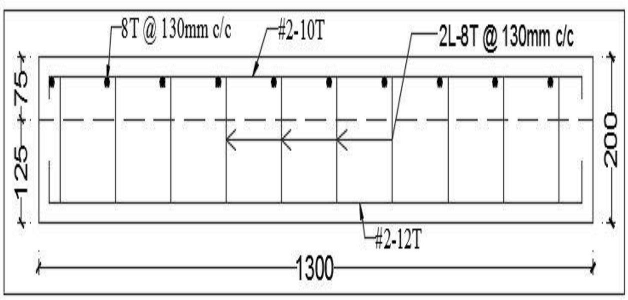

Figure.1.(a): Longitudinal section of the RC T – Beam

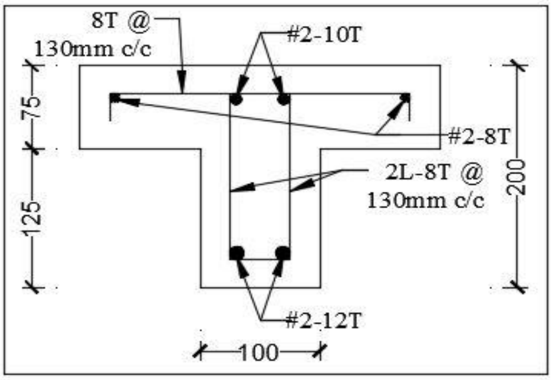

Figure.1.(b): Cross section of the RC T - Beam

The mix proportion for the M30 grade of concrete without addition of fly ash was 1: 1.68: 2.33 with w/c ratio of 0.436 and having a compressive strength of 36.57MPa which is tested after 28 days of curing. The experimental project also consists of 20 % replacement of fly ash in place of OPC in concrete mix without addition of chemical admixture. The mix proportion for the M30 grade of concrete with addition of fly ash was 0.8: 0.2: 1.64: 2.28 with w/c ratio of 0.45 and having a compressive strength of 34.97MPa. The grade of steel used was Fe 500 having yield strength of 500MPa for all reinforcement work. The fine aggregate are fully replaced by manufacturing sand is used throughout the project work. GFRP fabric was used for strengthening and retrofitting of beams. The bonding agents used for pasting of GFRP fabric to the concrete surface was Unsaturated Polyester (UP) resin with a mixture of Cobalt Naphthenate (CN) and Methyl Ethyl Ketone Peroxide (MEKP). The study of this research work consists of thirteen beams divided into three series like control beams are unstrengthened beams, strengthened beams and retrofitted beams. Out of which control beam were cast without fly ash (CB1), beams cast with addition of fly ash (CB2), unstrengthened beam with circular openings in web portion (UBO), beams strengthened with GFRP U- wrap one layer (SUSL) and with two layer (SUDL), beams strengthened with GFRP face wrap one layer (SFSL) and with two layer (SFDL), beams retrofitted with GFRP U- wrap one layer (RUSL) and with face wrap one layer (RFSL).

IV. TEST SETUP

The capacity of loading frame used for testing of the beams was 50 tonne. Loads are applied to the beams with the help of hydraulic jack at an increment of 10kN up to failure and were subjected to two concentrated loads. Bearing width of the beam was 75mm on either side so the clear span between the supports was 1150mm is maintained constant. Shear span was maintained at 380mm for all beam specimens. Linear variable displacement transducers (LVDT) were used to measure the deflection at the point below the loading and at the centre. The experimental test setup is shown in figure 2(a) and figure 2(b).

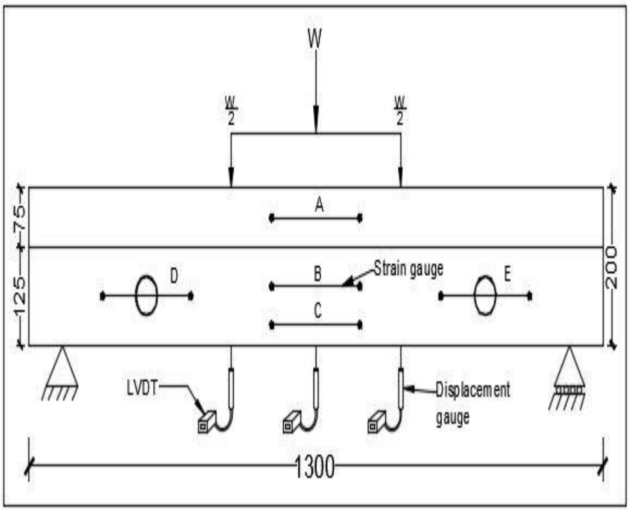

Figure.2.(a): Line Diagram of Experimental test setup

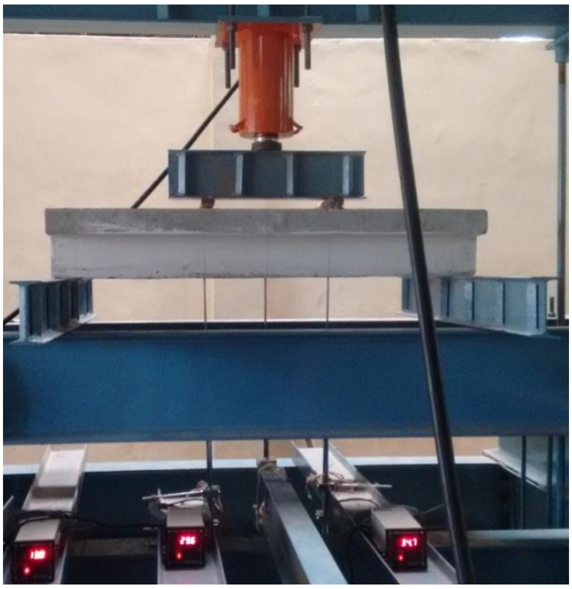

Figure.2.(b): Experimental test setup with loading frame

V. RESULTS AND DISCUSSION

The beams are tested after 28 days of curing to find out the deflection, load carrying capacity, failure modes and crack pattern. Load – deflection graphs are plotted for all beams to determine the deflection and stiffness of tested specimen. The deflection values of tested specimens are observed and presented in the table 1.

Table.1. Deflection values of tested specimen.

Specimen Name	Mid deflection (mm)
CB-1	26.50
CB-2	22.40
UBO	20.40
SUSL	19.90
SFSL	18.90
SUDL	19.28
SFDL	24.50
RUSL	18.00
RFSL	24.80

A. LOAD - DEFLECTION BEHAVIOUR OF BEAMS

The deflections of the beams were observed with the help of LVDT at the certain points i.e., at the distances of L/3, L/2 and 2L/3**.**

Control Beams

The beam CB-1 was cast without addition of fly ash, without circular in web opening and unstrengthened. Maximum deflection were observed at the midpoint 26.50mm, left point 21.90mm and right point 22.80mm as showed in fig 3. Bending stress of beam CB-1 was 23.57 N/mm^2.

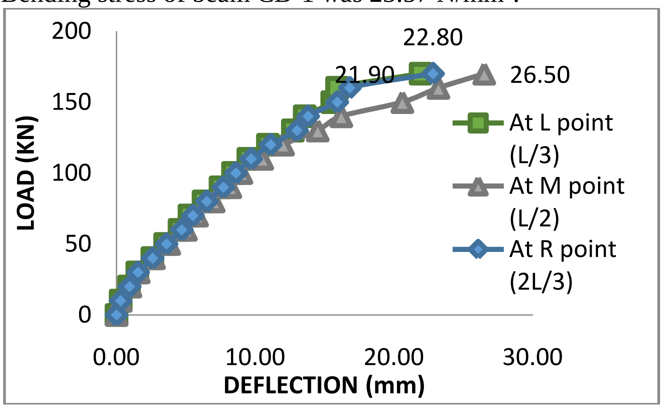

Figure.3. Load v/s Deflection Curve for Beam CB-1

The beam CB-2 was cast with 20% partial replacement of fly ash, without circular opening in web portion and unstreng thened. Maximum deflection were observed at the midpoint 22.40mm, left point 17.50mm and right point 19.38mm as showed in fig 4. Bending stress of beam CB-1 was 22.52 N/mm^2. Percentage decrease in stiffness was 3.85% when compared with beam CB-1.

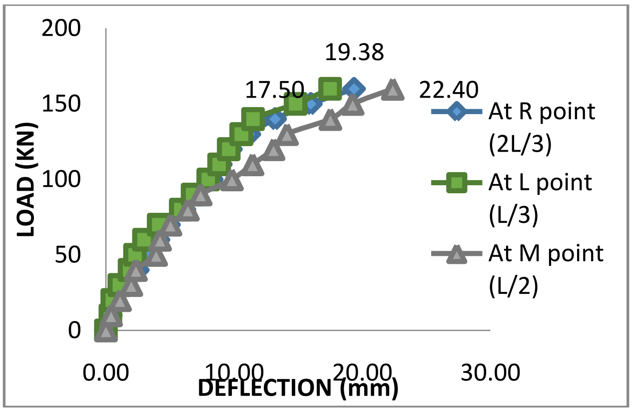

Figure.4. Load v/s Deflection Curve for Beam CB-2

Unstrengthened Beam

The beam UBO was cast with two circular openings in web portion at shear span. Maximum deflection were observed at the midpoint 20.40mm, left point 14.78mm and right point 17.23mm as showed in fig 5. Bending stress of beam UBO was 20.69 N/mm^2. Percentage decrease in stiffness was 44.38% when compared with beam CB-1.

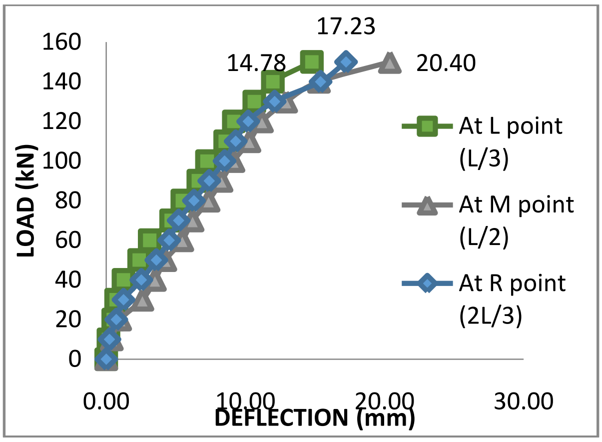

Figure.5. Load v/s Deflection Curve for Beam UBO

Strengthened Beam

All strengthened beams are cast with addition of fly ash and with two circular openings in web portion at shear span. Beams are strengthened with bi- directional GFRP sheets. The beam SUSL was strengthened with one layer of GFRP U-wrap. Maximum deflection were observed at the midpoint 19.90mm, left point 13.64mm and right point 15.80mm as showed in fig 6. Bending stress of beam SUSL was 22.26 N/mm^2. Percentage decrease in stiffness was 14.00% when compared with beam CB-1.

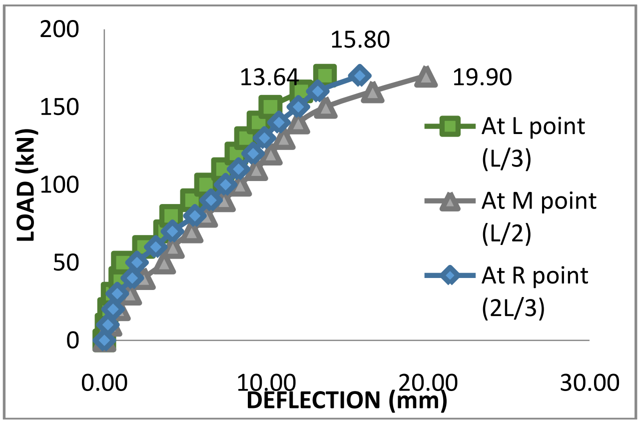

Figure.6. Load v/s Deflection Curve for Beam SUSL

The beam SFSL was strengthened with one layer of GFRP face wrap. Maximum deflection were observed at the midpoint 18.90mm, left point 11.42mm and right point 14.20mm as showed in fig 7. Bending stress of beam SFSL was 21.73 N/mm^2. Percentage decrease in stiffness was 18.77% when compared with beam CB-1.

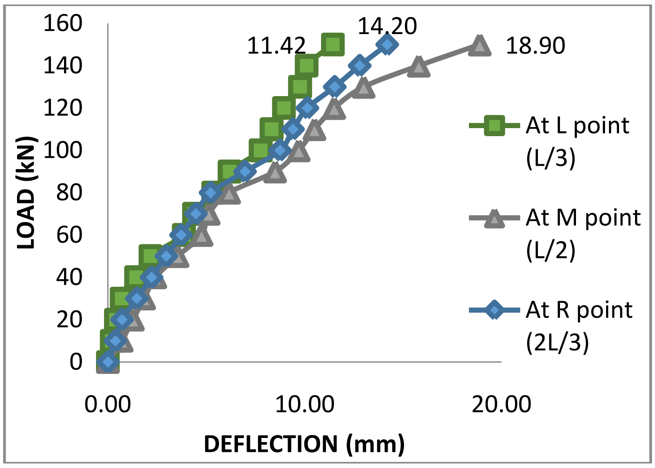

Figure.7. Load v/s Deflection Curve for Beam SFSL

The beam SUDL was strengthened with two layer of GFRP U-wrap. Maximum deflection were observed at the midpoint 19.28mm, left point 15.40mm and right point 11.89mm as showed in fig 8. Bending stress of beam SUDL was 23.57 N/mm^2. Percentage decrease in stiffness was 9.69% when compared with beam CB-1.

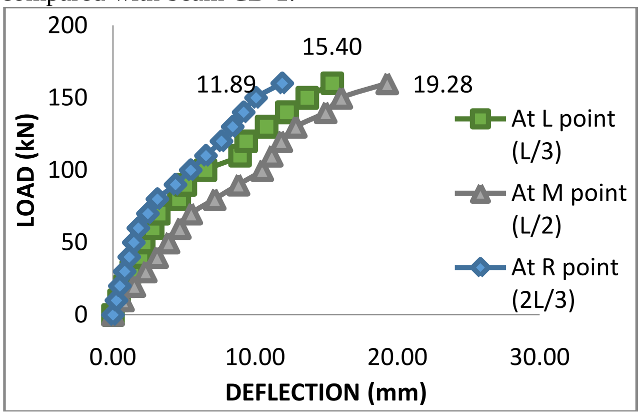

Figure.8. Load v/s Deflection Curve for Beam SUDL

The beam SFDL was strengthened with two layer of GFRP face wrap. Maximum deflection were observed at the midpoint 18.90mm, left point 11.42mm and right point 14.20mm as showed in fig 9. Bending stress of beam SFDL was 22.52 N/mm^2. Percentage decrease in stiffness was 16.46% when compared with beam CB-1.

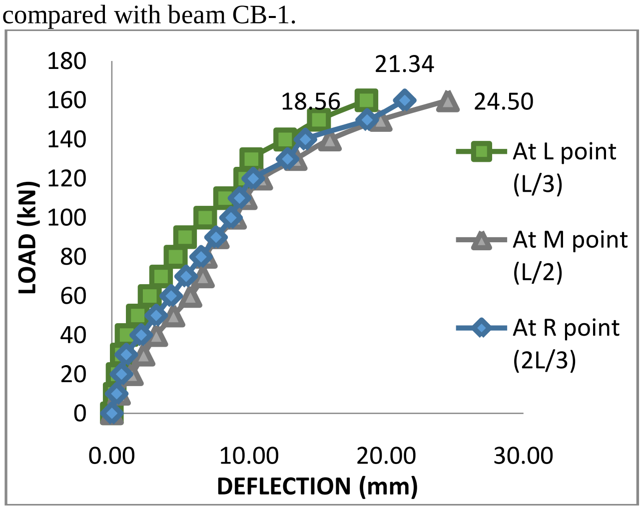

Figure.9. Load v/s Deflection Curve for Beam SFDL

Retrofitted Beams

All retrofitted beams are cast with addition of fly ash and with two circular openings in web portion at shear span. Beams are retrofitted with bi- directional GFRP sheets. The beam RUSL was retrofitted with one layer of GFRP U- wrap. Maximum deflection were observed at the midpoint 18.00mm, left point 13.85mm and right point 16.80mm as showed in fig 10. Bending stress of beam RUSL was 22.52 N/mm^2. Percentage decrease in stiffness was 17.31% when compared with beam CB1.

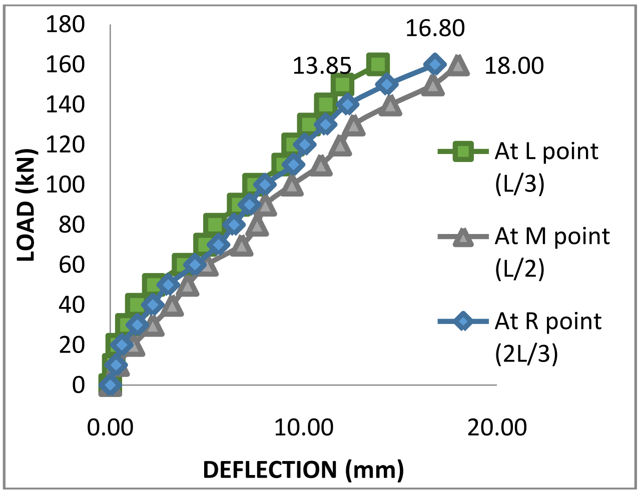

Figure.10. Load v/s Deflection Curve for Beam RUSL

The beam RFSL was retrofitted with one layer of GFRP face wrap. Maximum deflection were observed at the midpoint 18.00mm, left point 13.85mm and right point 16.80mm as showed in fig 11. Bending stress of beam RFSL was 21.99 N/mm^2. Percentage decrease in stiffness was 20.92% when compared with beam CB1.

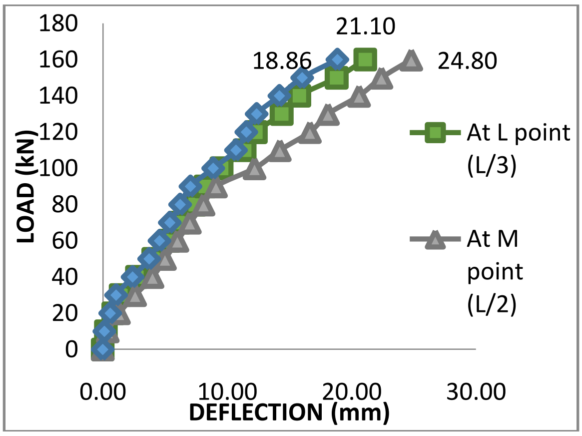

Figure.11. Load v/s Deflection Curve for Beam RFSL

Increase in deflection of beam UBO is 5.86% compared to beam CB-2. Decrease in deflection of beam SUSL was 32.84% compared to UBO. Decrease in deflection of beam SFSL was 7.35% compared to UBO. Decrease in deflection of beam SUDL was 21.32% compared to UBO. Decrease in deflection of beam SFDL was 3.92% compared to UBO. Decrease in deflection of beam RUSL was 18.13% compared to UBO. Increase in deflection of beam RFSL was 9.80% compared to beam UBO.

B. ULTIMATE LOAD

The beams are tested after 28 days of curing, were loaded to determine the ultimate load carrying capacity of the control, strengthened and retrofitted beams. Fig 12 shows Load comparison of various beams like control beam, beams with circular opening, strengthened and retrofitted beams.

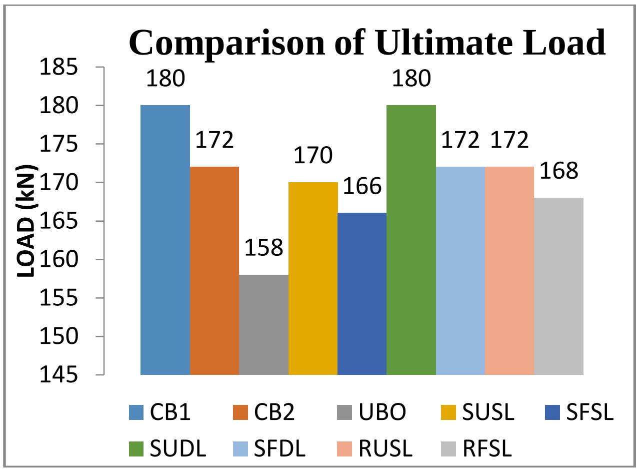

Figure.12. Load comparison of various beams

Table.2. Ultimate Load carried by various beams

Beam Notation	Ultimate load (kN)	Increase in load (%)	Decrease in load (%)	Comparison with Beam
CB1	180	4.65	-	CB-2
CB2	172	-	4.44	CB-1
UBO	158	-	8.86	CB-2
SUSL	170	7.59	-	UBO
SFSL	166	5.06	-	UBO
SUDL	180	13.92	-	UBO
SFDL	172	8.86	-	UBO
RUSL	172	8.86	-	UBO
RFSL	168	6.33	-	UBO

Table 2 shows increase or decrease in ultimate load of various beam specimens. The beams were tested up to failure load and almost all beams failed by frame type failure only.

C. SHEAR CONTRIBUTION GIVEN BY GFRP WRAPPING

The beam having opening in the shear portion leads to reduction of shear capacity of beams. Use of GFRP wrapping around the web opening as a strengthening element of beam helps in increasing the shear capacity of the beams. The Table 3 shows increase in shear contribution given by GFRP wrapping.

Table.3. Shear contribution by GFRP wrapping

Sl no	Beams	Ultimate load carried by beams (kN)	Shear force (kN)	Shear contribution given by GFRP wrapping (kN)
1	CB1	180	90	-
2	CB2	172	86	-
3	UBO	158	79	-
4	SUSL	170	85	6
5	SFSL	166	83	4
6	SUDL	180	90	11
7	SFDL	172	86	7
8	RUSL	172	86	7
9	RFSL	168	84	5

The amount of increase in shear capacity of beams by GFRP wrapping was 6kN for strengthened beam SUSL, 4kN for strengthened beam SFSL, 11kN for strengthened beam SUDL, 7kN for strengthened beam SFDL, 7kN for retrofitted beam RUSL, 5kN for retrofitted beam RFSL. The beam strengthened by U wrap with one and two layer gave better result than face wrap.

D. FAILURE PATTERN

Generally the RC beams when subjected to loading tend to fail by flexure, shear and flexure shear cracks. But in case of RC beams with openings in the web portion will fail by Beam type or Frame type failure. The control beams were cast without circular opening are tested up to failure to determine the ultimate load carrying capacity and failure pattern of the beam as shown in fig 13. It was noticed that the control beam was failed at left support by shear failure.

Figure.13. Failure Pattern of Control Beam at ultimate load

The unstrengthened beams were cast with circular opening are tested up to failure to determine the ultimate load carrying capacity and failure pattern of the beam as shown in fig 14. It was noticed that the unstrengthened beam was failed at right support by frame type failure.

Figure.14. Failure Pattern of Unstrengthened Beam at ultimate load

The strengthened beams were cast with circular opening and strengthened with GFRP at shear portion were tested up to failure to determine the ultimate load carrying capacity and failure pattern of the beam as shown in fig 15. Popping sound was observed during testing at the time of failure and de-lamination of GFRP was observed as shown in fig 16. It was noticed that the strengthened beam was failed at left support by frame type failure as shown in fig 17.

Figure.15. Failure Pattern of strengthened Beam at ultimate load

Figure.16. De-lamination of GFRP of Strengthened Beam

Figure.17. Frame type of failure of Strengthened Beam

V. CONCLUSION

The experimental study was carried out on strengthening of RC T- beam with GFRP. The following conclusions were made by the results obtained from the experimental study.

- It was observed that, increase in the ultimate load of strengthened beams with GFRP U-wrap was 7.59% to 13.92% when compared to unstrengthened beam with openings.
- It was noticed that, increase in the ultimate load of strengthened beams with GFRP face wrap was 5.06% to 8.86 % when compared to unstrengthened beam with openings.
- Application of GFRP helps in decreasing the deflection of strengthened beams of about 3.92% to 32.84% compared to unstrengthened beam with opening UBO.
- Use of GFRP enhance the shear capacity of the strengthened beams was 4kN to 11kN compared to unstrengthened beam.
- Unstrengthened beam UBO with opening in shear portion shows increase in the deflection of 5.86% compared to control beam CB-2.
- Addition of GFRP fabric in the openings resulted in the increase in stiffness and reduction in the formation of cracks.
- The beams strengthened with GFRP U-wrap gives more strength and shear capacity compared to beams strengthened with face wrap.
- The externally bonded GFRP composite enhances the load carrying capacity.
- Among the two types of failure, shear failure was observed in most of beams but beam SUDL was failed due to flexure during experimental testing.

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VII. ACKNOWLEDGEMENT

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