Strengthening of Shear Deficient RC T-Beams with Externally Bonded FRP Sheets

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***Abstract*— The rehabilitation of existing reinforced concrete (RC) bridges and building becomes necessary due to ageing, corrosion of steel reinforcement, defects in construction/design, demand in the increased service loads, and damage in case of seismic events and improvement in the design guidelines. Fibre-reinforced polymers (FRP) have emerged as promising material for rehabilitation of existing reinforced concrete structures. The rehabilitation of structures can be in the form of strengthening, repairing or retrofitting for seismic deficiencies. RC T-section is the most common shape of beams and girders in buildings and bridges. Shear failure of RC T-beams is identified as the most disastrous failure mode as it does not give any advance warning before failure. The shear strengthening of RC T-beams using externally bonded (EB) FRP composites has become a popular structural strengthening technique, due to the well-known advantages of FRP composites such as their high strength-to-weight ratio and excellent corrosion resistance.**

In this work the shear strengthening of shear deficient reinforced concrete T-beams using Glass fibre reinforced polymer (GFRP) sheets were carried out. Eighteen number of beams were cast, out of which two beam served as the control beam. The different configurations of GFRP sheets used in this work are U wrap, side wrap, U strip, inclined strip with single and double layers.

Based on the study it was observed that the FRP wrapped specimens showed improvement in shear capacity and first crack load. 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. Thus FRP wrapping was found to be an effective method for shear strengthening of beams.

***Keywords*— GFRP,Epoxy resin,Shear strength**

I. INTRODUCTION

The deterioration of civil engineering infrastructures such as buildings, bridge decks, girders, offshore structures, parking structures are mainly due to ageing, poor maintenance, corrosion, exposure to harmful environments. These deteriorated structures cannot take the load for which they are designed. A large number of structures constructed in the past using the older design codes in different parts of the globe are structurally unsafe according to the new design codes and hence need upgradation.

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. The design methodologies are also changing with the growing research in the area of seismic engineering. So the existing structures may not qualify to the current requirements. 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.

The conventional retrofitting techniques available are concrete-jacketing and steel-jacketing. The concrete-jacketing makes the existing section large and thus improves the load carrying capacity of the structure. But these techniques have several demerits such as construction of new formworks, additional weight due to enlargement of section, high installation cost etc. The steel-jacketing has proven to be an effective technique to enhance the performance of structures, but this method requires difficult welding work in the field and have potential problem of corrosion which increases the cost of maintenance.

The objectives of the work can be summarized as follows:

- To study the structural behavior of reinforced concrete (RC) T-beams under static loading condition.
- To study the contribution of externally bonded (EB) Fibre Reinforced Polymer (FRP) sheets on the shear behavior of RC T-beams.
- To examine the effect of different fibre orientations, number of layers etc. on the response of beam in terms of failure modes, enhancement of load carrying capacity and load deflection behavior.

II. EXPERIMENTAL INVESTIGATION

The objective of the experimental program is to study the effect of externally bonded (EB) fibre reinforced plastic (FRP) sheets on the shear capacity of reinforced concrete T-beam under static loading condition. Eighteen number of reinforced concrete T-beams are cast and tested up to failure by applying two-point loading system. Out of eighteen number of beams, two beams was not strengthened by FRP and was considered as a control beam, whereas all other sixteen beams were strengthened with externally bonded GFRP sheets in shear zone of the beam. The variables investigated in this research study included GFRP amount and distribution (i.e., continuous wrap versus strips), bonded surface (i.e., lateral sides versus U-wrap) and GFRP ratio (i.e., no. of layers).

A. Test on constituent materials

Cement : Ordinary Portland cement of 53 grade confirming to IS 12269:1987 was used for the study. For the cement the standard consistency test, initial setting time test, final setting time test and specific gravity test were conducted. The standard consistency of cement used is 36.25%.

Fine aggregate : M sand is used as fine aggregate. M sand passing through 4.75mm IS sieve conforming to grading zone II of IS 383:1970 was used. Specific gravity and fineness modulus of Sand used were 2.38 and 2.84 respectively.

Coarse aggregate : Coarse aggregate of maximum size 20 mm from local source was used.

GFRP: Glass fibre was used for strengthening of the shear deficient reinforced concrete beams. These strips were bonded externally to the beams using epoxy resins using the wet layup technique. Both side wrapping and U wrapping of the beams with GFRP strips were done.

Fig 1 GFRP Sheet

Water: Potable water is generally considered as being acceptable. Hence water available in the college water supply system was used for casting as well as curing of the test specimens.

Reinforcing bars : Main reinforcement consists of 10mm ϕ and 8mm ϕ HYSD steel bars of Fe 415 grade. 6mm ϕ steel bars were used as stirrups.

B. Mix Design

M25 mix was designed as per IS 10262:2009 and the mix proportion was obtained as 1:1.78:3.14. Water-cement ratio was 0.50.

C. Specimen details

The experimental program consists of 18 number of simply supported RC T-beams. The cross section of the beam is shown in the Fig 2. The length of the beam is 1.2m.

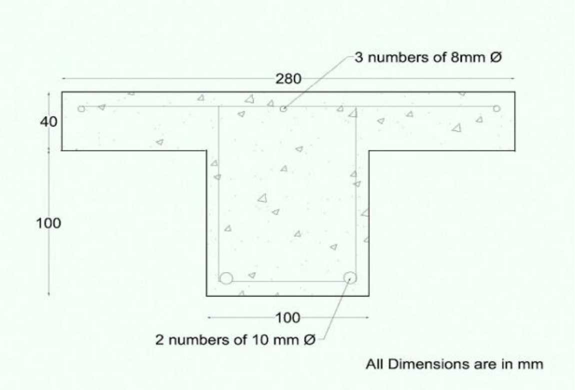

Fig 2 Cross section of T beam

All the beams were tested under simply supported end conditions. Two point loading was adopted for testing the specimens. The testing of the beams were done on the loading frame of 200 tonne capacity. The test set up is as shown in Fig 3. The load was increased in stages till the failure of the beam specimen occurs in the case of monotonic loading and at each stage of loading the deflection at midspan was recorded using a dial gauge of least count 0.01mm and 25mm travel. The first crack loads were also noted.

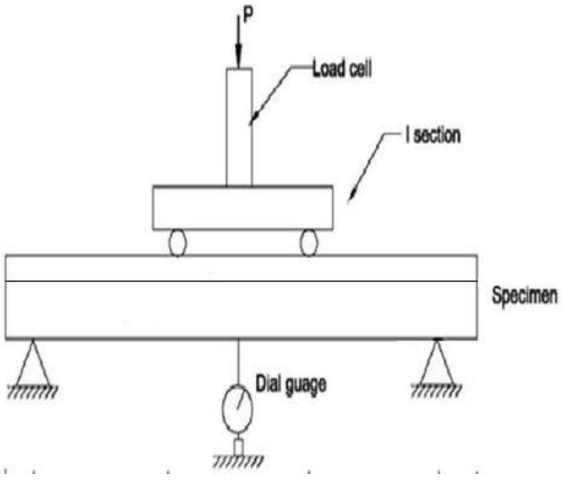

Fig 3 Schematic diagram of test setup

D. *Experimental variables*

TABLE 1 EXPERIMENTAL VARIABLES

Sl. No.	Beam designation	Wrapping style	No. of layers
1	CB	Control beam	
2	SB1	U-wrap	Single
3	SB2	Side wrap	Single
4	SB3	U-strip	Single
5	SB4	45° inclined strip	Single
6	SB5	U-wrap	Double
7	SB6	Side wrap	Double
8	SB7	U-strip	Double
9	SB8	45° inclined strip	Double

All the beams except the control beam (CB) are strengthened with various patterns of GFRP sheets. All of the specimens were cast without stirrups. The beam designated as SB1 was strengthened with one layer of GFRP having U-wrap on bottom and web portions of the shear spans of the beam. The beam SB2 was strengthened by applying one layer of GFRP on web portions on shear span region only on the sides of the beam. The beam SB3 was strengthened by applying one layer of GFRP U-strips on web portions and bottom on shear span region with three equal strips on both sides of the beam, each strip of size thickness as 50mm and the spacing between the strips is 50mm.

The beam SB4 was strengthened by applying one layer of GFRP strips on shear span region with three equal strips on both sides of the beam which is inclined to 45°. The beam SB5 is modeled with two layers of GFRP having U-wrap on bottom and web portions of the shear span. The same two-point loading is applied. The beam SB6 was strengthened by applying two layers of GFRP on web portions on shear span region only on the sides of the beam. The beam SB7 was strengthened by applying two layers of GFRP U-strips on web portions and bottom on shear span region with three equal strips on both sides of the beam, each strip of size thickness as 50mm and the spacing between the strips is 50mm. The beam SB8 was strengthened by applying two layers of GFRP strips on shear span region with three equal strips on both sides of the beam which is inclined to 45°.

E. *FRP Wrapping of specimen*

Totally 18 beams were cast for the experimental work. Out of this two beam served as the control beam. While doing the wrapping process first the required region of concrete surface was made rough using a coarse sand paper texture and cleaned with an air blower to remove all dirt and debris particles. Once the surface was prepared to the required standard, the epoxy resin was mixed in accordance with manufacturer's instructions. The mixing is carried out in a plastic container (100 parts by weight of GP Resin1102 to 10 parts by weight of Hardener Ketone Peroxide) and was continued until the mixture was in uniform.

After their uniform mixing, the fabrics are cut according to the size then the epoxy resin is applied to the concrete surface. Then the GFRP sheet is placed on top of epoxy resin coating and the resin is squeezed through the roving of the fabric with the roller. Air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface are eliminated. Then the second layer of the epoxy resin was applied and GFRP sheet was then placed on top of epoxy resin coating and the resin was squeezed through the roving of the fabric with the roller. This operation is carried out at room temperature. Concrete beams strengthened with glass fibre fabric were cured for 48 hrs at room temperature before testing.

Fig 4 Wrapping of specimen

III. RESULTS AND DISCUSSIONS

In the present study the results obtained from the testing of eighteen number RC T-Beams for the experimental program are interpreted. Their behaviors throughout the test are described with respect to initial crack load, ultimate load carrying capacity and deflection.

The control beam (CB) was cast with a reinforcement of two numbers 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. The first hair crack was visible in the shear span at a load of 18 kN. As the load increased beyond the first crack load, many inclined cracks were also developed and the first visible crack started widening. With further increase in load, the beam finally failed in shear at a load of 45 kN exhibiting a wider diagonal shear crack.

The beam SB1 is strengthened with one layer of GFRP having U-wrap on bottom and web portions of the shear span (0 to L/3 and 2L/3 to L distance from left support).The same two-point loading is applied. The initial crack in concrete as appeared in case of control beam could not be traced out because the shear zones were fully wrapped with GFRP sheets. The failure was initiated by the debonding of GFRP sheets. As the load was enhanced, the debonding failure was followed by a shear failure at an ultimate load of 64 kN. The strengthening of beam SB1 with GFRP U-wraps resulted in a 42.2% increase in shear capacity over the control beam.

The beam SB2 was strengthened by applying one layer of GFRP on web portions on shear span region only on the sides of the beam. The initial crack in concrete as appeared in SB2 could not be observed because the shear zones were fully wrapped with GFRP sheets. The failure mode was initiated by the debonding of GFRP sheets. The debonding failure of GFRP sheet was followed by shear failure and the beam finally failed at load of 58 kN. There is no noticeable increase in shear capacity compared to beam SB1. However, there is a 28.8% increase in shear capacity over the control beam.

The beam SB3 was strengthened by applying one layer of GFRP U-strips on web portions and bottom on shear span region with three equal strips on both sides of the beam, each strip of size thickness as 50mm and the spacing between the strips is 50mm. The initial diagonal shear crack started at a load of 22 kN. The failure mode was initiated by the debonding of GFRP sheets. Sudden failure of beam SB3 occurred at an ultimate load of 60 kN. The strengthening of beam SB3 with GFRP U-wrap strips on the beam resulted in a 33.33% increase in the shear capacity over the control beam.

The beam SB4 was strengthened by applying one layer of GFRP strips on shear span region with three equal strips on both sides of the beam which is inclined to 45° and each strip of width 50mm and the spacing is 50mm. The initial diagonal shear crack was formed at a load of 24 kN on the concrete surface and failed by tearing the GFRP sheets and debonding of GFRP sheets. The brittle failure occurred at an ultimate load of 61 kN. The strengthening of beam SB4 with GFRP inclined strips on the beam sides resulted in a 35.55% increase in the shear capacity over the control beam.

The beam SB5 is strengthened with two layer of GFRP having U-wrap on bottom and web portions of the shear span (0 to L/3 and 2L/3 to L distance from left support). The same two-point loading is applied. The failure was initiated by the debonding of GFRP sheets. As the load was enhanced, the debonding failure was followed by a shear failure at an ultimate load of 66 kN. The strengthening of beam SB5 with GFRP U-wraps resulted in a 46.67% increase in shear capacity over the control beam.

The beam SB6 was strengthened by applying two layer of GFRP on web portions on shear span region only on the sides of the beam. The initial crack in concrete as appeared in SB6 could not be observed because the shear zones were fully wrapped with GFRP sheets. The failure mode was initiated by the debonding of GFRP sheets. The debonding failure of GFRP sheet was followed by shear failure and the beam finally failed at load of 60 kN. There is an increase in shear capacity compared with SB2. However, there is a 33.33% increase in shear capacity over the control beam.

The beam SB7 was strengthened by applying two layers of GFRP U-strips on web portions and bottom on shear span region with three equal strips on both sides of the beam, each strip of size thickness as 50mm and the spacing between the strips is 50mm. The initial diagonal shear crack started at a load of 24 kN. The failure mode was initiated by the debonding of GFRP sheets. The beam finally failed at load of 61 kN. The strengthening of beam SB7 with GFRP U-wrap strips on the beam resulted in a 35.55% increase in the shear capacity over the control beam.

The beam SB8 was strengthened by applying two layer of GFRP strips on shear span region with three equal strips on both sides of the beam which is inclined to 45° and each strip of width 50mm and the spacing is 50mm. The initial diagonal shear crack was formed at a load of 25 kN on the concrete surface and failed by tearing the GFRP sheets and debonding of GFRP sheets. The brittle failure occurred at an ultimate load of 63 kN. The strengthening of beam SB8 with GFRP inclined strips on the beam sides resulted in a 40% increase in the shear capacity over the control beam.

The results showed that the shear capacity of the wrapped specimen increased compared with the CB. Also, as the number of layers of FRP increased the shear capacity improved. The U wrapped beams showed better improvement in shear capacity compared to side wrapped specimens and the angle strip beams showed better improvement in shear capacity compared to U strip specimens.

TABLE 2 PERCENTAGE INCREASE IN SHEAR CAPPACITY

Beam designation	Number of layers of frp	Percentage increase in shear capacity compared to CB
SB1	Single	42.22%
SB2	Single	28.8%
SB3	Single	33.33%
SB4	Single	35.55%
SB5	Double	46.67%
SB6	Double	33.33%
SB7	Double	35.55%
SB8	Double	40%

Using the data obtained from the experiment, the load deflection plots were drawn. All the plots show linear behavior upto the formation of the first crack. This could be termed as the precracking stage. Beyond this point the slope of the curve decreases. This indicates the formation of multiple cracks. In this stage deflection increased non linearly with the load. The FRP wrapped specimens showed improvement in the load deflection behaviour.

From the load deflection behavior of the tested beams it can be seen that the ultimate load increased for the Glass fiber reinforced polymer strip wrapped specimens when compared to the control beam. The improvement in ultimate load was upto 42.2% for U wrapped specimen of single layer and upto 46.67% for double layer. In the case of side wrap specimen the ultimate load increase 28.8% for single layer and 33.33% for double layer. The improvement in ultimate load was upto 33.33% for U strip specimen of single layer and upto 35.55% for double layer. The improvement in ultimate load was upto 35.55% for angle strip specimen of single layer and upto 40% for double layer. So as the number of layers of GRFP increased there was improvement in the load carrying capacity of the beams.

In case of wrapped specimens, at the failure there was rupture and debonding of the glass fibre strips from the beam. The glass fibre reinforced polymer strips inhibited the crack propagation, thereby improving the load carrying capacity of the specimens. Although the ultimate failure of the specimen was by shear, the wrapped specimens developed flexure cracks before failure thus exhibiting an improvement in ductility of the wrapped specimens. Hence it can be concluded that wrapping helps to improve the ductility of the specimens.

The comparison of the ultimate loads for the wrapped specimens for single layer and double layer are shown in the form of Bar chart in Fig 5

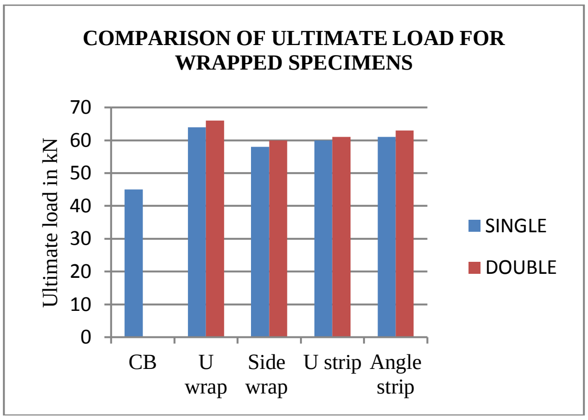

Fig 5 Comparison of ultimate loads

The crack patterns of the beams were observed with the progress of the load. The load at initial crack of the beams was recorded and presented in Fig 6. It is observed that the initial cracks in the strengthen RC beams are developed at a higher load than the control beam. From Fig 6, the load at first crack of SB8 is 38.88% higher than the control beam and is the highest among the strengthen beams.

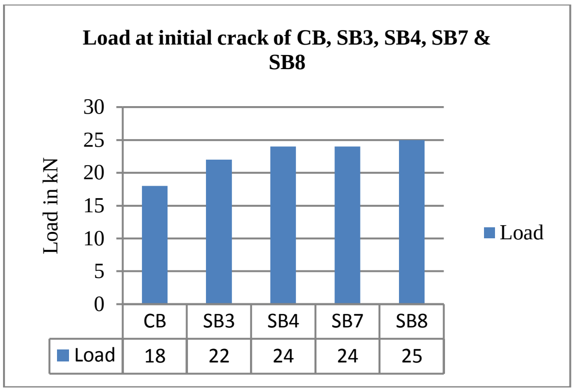

Fig 6 Load at initial crack

Fig 7 Shear failure of control beam

Fig 8 Testing of U-strip specimen

Fig 9 Debonding of GFRP strip followed by shear failure

Fig 10 Shear failure in SB4

IV. CONCLUSION

In this experimental investigation the shear behaviour of RC T-beams strengthened by GFRP sheets are studied. The test results illustrated in the present study showed that the external strengthening with GFRP sheets can be used to increase the shear capacity of RC T-beams, but the efficiency varies depending on the test variables such as fiber orientations, wrapping schemes and number of layers.

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

- Externally bonded GFRP sheets can be used to enhance the shear capacity of RC T-beams.
- The test results confirm that the strengthening technique of FRP system can increase the shear capacity of RC T-beams. Increasing the number of layers of FRP sheets, the shear capacity also increases.
- The initial cracks in the strengthened beams are formed at a higher load compared to the ones in the control beam. When compared with the control beam, the improvement in initial crack load was upto 39% for strengthened beams. The maximum improvement in initial crack load was with inclined wrap with double layer.
- The beam strengthened with a U-wrap configuration is more effective than the side-wrap configuration. The improvement in shear capacity was upto 46% for U wrapped specimens and 33% for side wrapped specimen, compared with the control beam.
- The load-deflection behaviour was better for beams retrofitted with GFRP inclined strips than the beams retrofitted with GFRP U strips.
- The ultimate load carrying capacity of the strengthen beams were found to be greater than that of the control beams. The improvement in ultimate load carrying capacity was upto 46% for strengthened beams, compared with the control beam.

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