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. Fiber-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. A few studies on shear strengthening of RC T-beams using externally bonded FRP sheets have been carried out but still the shear performance of FRP strengthened beams has not been fully understood. The present study therefore explores the prospect of strengthening structurally deficient T-beams by using an externally bonded fiber reinforced polymer (FRP). This study assimilates the experimental works of glass fiber reinforced polymer (GFRP) retrofitted RC T-beams under symmetrical four-point static loading system. The thirteen number of beams were of the following configurations, (i) one number of beam was considered as the control beam, (ii) seven number of the beams were strengthened with different configurations and orientations of GFRP sheets, (iii) three number of the beams strengthened by GFRP with steel bolt-plate, and (iv) two number of beams with web openings strengthened by U-wrap in the shear zone of the beams. The first beam, designated as control beam failed in shear. 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 has been used to prevent these premature failures, which as a result ensure full utilization of the strength of FRP. A theoretical study has also been carried out to support few of the experimental findings.**

1. 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 up gradation. 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. With increase in research and introduction of new materials and technology there are new ways of retrofitting the structure with many added advantages. Introduction of Fiber Reinforced Polymer (FRP) Composite is one of them. FRP composites comprise fibers of high tensile strength embedded within a thermosetting matrix such as epoxy, polymer or vinyl ester. The most widely used matrix is epoxy. FRP was originally developed for aircraft, helicopters, space-craft, satellites, ships, submarines, high speed trains because of its light weight. The application of FRP in the civil engineering structures has started in 1980s. The first application of FRP strengthening was made to reinforce the concrete beams. The beams are load bearing structural elements that are designed to carry both vertical gravity loads and horizontal loads due to seismic or wind. The structurally deficient beams fail during such events. There are mainly two types of failure of beams i.e., flexural and shear. Hence, the strengthening of such beams is needed in flexure or shear or both zones and the use of external FRP strengthening to beams may be classified as:

i) Flexural strengthening ii) Shear strengthening.

II. Objective of the Present Work

In the light of the literature survey presented above, the following objectives of are identified for the present work:

1) To study the structural behaviour of reinforced concrete (RC) T-beams under static loading condition.
2) To study the contribution of externally bonded (EB) Fiber Reinforced Polymer (FRP) sheets on the shear behaviour of RC T-beams.
3) To investigate the effect of a new anchorage scheme on the shear capacity of the beam.

III. Design of Material Properties

The material properties reported by the manufacturers, such as the ultimate tensile strength, typically do not consider long-term exposure to environmental conditions and should be considered as initial properties. Because long-term exposure to various types of environments can reduce the tensile properties and creep-rupture and fatigue endurance of FRP laminates, the material properties used in design equations should be reduced based on the environmental exposure condition. Eq.s (1) through (3) gives the tensile properties that should be used in all design equations. The design ultimate tensile strength should be determined using the environmental reduction factor given in ACI 440.2R-02 document for the appropriate fiber type and exposure condition:

Design ultimate tensile strength = ffu = CE f*fu (1)

Where, ffu = design ultimate tensile strength of FRP, (MPa)

CE = environmental reduction factor

f*fu = ultimate tensile strength of the FRP materials as reported by the manufacturer, (MPa)

Similarly, the design rupture strain should also be reduced for environmental-exposure conditions:

Design rupture strain = εfu = CE ε*fu (2) Where, εfu = design rupture strain of FRP reinforcement, (mm/mm)

ε*fu = ultimate rupture strain of the FRP reinforcement, (mm/mm) Because FRP materials are linearly elastic until failure, the design modulus of elasticity can then be determined from

Hook's law. The expression for the modulus of elasticity, given in Eq. (3), recognizes that the modulus is typically unaffected by environmental conditions. The modulus given in this equation will be the same as the initial value reported by the manufacturer.

Efu = ffu / εfu (3)

The material used for this present work is glass fiber and epoxy resin, and the exposure condition is internal exposure. For present calculation the environmental reduction factor (CE) is used as 0.75.

IV. Nominal shear strength

The nominal shear strength of a RC beam may be computed by basic design equation presented in ACI 318-95 and given as in Eq. (4)

Vn = Vc + Vs (4)

In this equation the nominal shear strength is the sum of the shear strength of the concrete (which for a cracked section is attributable to aggregate interlock, dowel action of longitudinal reinforcement, and the diagonal tensile strength of the un-cracked portion of the concrete) and the strength of the steel shear reinforcement. In the case of beams strengthened with externally bonded FRP sheets, the nominal shear strength may be computed by the addition of a third term to account for the contribution of FRP sheet to the shear strength. This is expressed in Eq. (5)

Vn = Vc + Vs + Vf (5)

V. FRP system contribution of shear strength

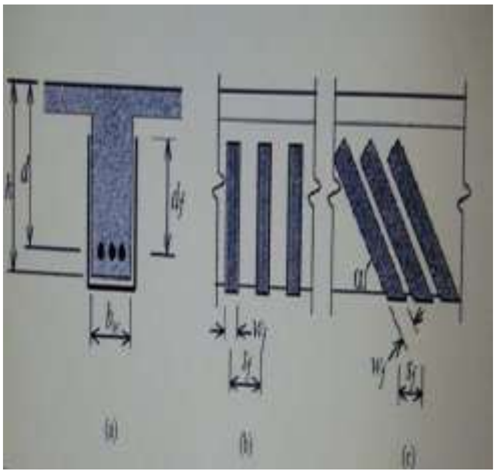

Figure 1: Illustration of the dimensional variables used in shear-strengthening calculations for repair, retrofit, or strengthening using FRP laminates.

(a) Cross-section, (b) Vertical FRP strips, (c) Inclined FRP strips

Figure 1 illustrates the dimensional variables used in shearstrengthening calculations for FRP laminates. The contribution of the FRP system to shear strength of a member is based on the fiber orientation and an assumed crack pattern [Khalifa et al. 1998]. The shear strength provided by the FRP reinforcement can be determined by calculating the force resulting from the tensile stress in the FRP across the assumed crack.

VI. Conclusion

In this experimental investigation the shear behavior 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 composites 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, number of layers and anchorage scheme. Based on the experimental and theoretical results, the following conclusions are drawn:

1) Externally bonded GFRP reinforcement can be used to enhance the shear capacity of RC T-beams.

2) The test results confirm that the strengthening technique of FRP system can increase the shear capacity of RC Tbeams.

3) The initial cracks in the strengthened beams are formed at a higher load compared to the ones in the control beam.

4) Strengthening of T-beam on the webs with GFRP is most vulnerable to debonding with premature failure.

5) The beam strengthened with a U-wrap configuration is more effective than the side-wrap configuration.

6) Among all the GFRP strip configurations (i.e. vertical strips, strips inclined at 45° and strips inclined at +45° in one direction and +135° in another direction making an "X-shape"), the X-shape is more effective than the

others.
7) Applying GFRP to the beam with end anchorage is better than strengthening without end anchorage.
8) The use of anchorage system eliminates the debonding of the GFRP sheet, and consequently results in a better utilization of the full capacity of the GFRP sheet.
9) The test results indicated that the most effective configuration was the U-wrap with end anchorage among all the configurations.
10) The load-deflection behaviour was better for beams retrofitted with GFRP inclined strips than the beams retrofitted with GFRP strips on the sides alone. Finally, the use of GFRP sheets as an external reinforcement is recommended to enhance the shear capacity of RC Tbeams with anchorage system.

VII. Future scope

Based on the finding and conclusions of the current study the following recommendations are made for future research in FRP shear strengthening:
1) Study of bond mechanism between CFRP, AFRP and BFRP and concrete substrate.
2) FRP strengthening of RC T-beams with different types of fibers such as carbon, aramid & basalt.
3) Strengthening of RC L-beams with FRP composite.
4) Strengthening of RC L-section beams with web opening.
5) Effects of web openings of different shape and size on the shear behaviour of T & L-beams.
6) Effects of shear span to depth ratio on shear strengthening of beams.
7) Numerical modelling of RC T & L-beams strengthened with FRP sheets anchored at the end.

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