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Strengthening Of RC Beams with Externally Bonded GFRPs

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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. Shear failure of RC 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. This study assimilates the experimental works of glass fiber reinforced polymer (GFRP) retrofitted RC beams under symmetrical four-point static loading system.*
Keywords: *Glass fiber, carbon fiber, epoxy, retrofitting.*

I. Introduction

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[1]. Then, the use of FRP for strengthening of existing or new reinforced concrete (RC) structures against normal and seismic loads increases at a rapid pace because of numerous advantages enlisted as follows:

1. FRP materials are not vulnerable to the swift electrochemical corrosion that occurs with steel
2. They can be rolled which makes easy to transport.
3. High fatigue resistance
4. High strength to weight ratio
5. Fiber composite materials are available in very long lengths while steel plate is generally limited to 6m. The availability of long length and the flexibility of the material simplify the installation process
6. Time required for installation is very less
7. Fiber composite strengthening materials have higher ultimate strength and lower density as compared to those of steel
8. Low energy consumption during fabrication of raw material and structure, and has the potential for real time monitoring.

II. Literature Review

When the RC beam is deficient in shear, or when its shear capacity is less than the flexural capacity after flexural strengthening, shear strengthening must be considered. It is critically important to examine the shear capacity of RC beams which are intended to be strengthened in flexure

Many existing RC members are found to be deficient in shear strength and need to be repaired. Shear failure of RC beams are catastrophic which could occur without any forewarning. Shear deficiencies in reinforced concrete beams may crop up due to factors such as inadequate shear reinforcement, reduction in steel area due to corrosion, use of outdated design codes, increased service load, poor workmanship and design faults. The application of Glass Fiber Reinforced Polymer (GFRP) composite material, as an external reinforcement is a viable technology recently found to be worth for improving the structural performance of reinforced concrete structures.[2]

Ghazi et al. (1994) 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.[5]

Varastehpour and Hamelin (1997) examined the application of composite materials in civil engineering by strengthening of a reinforced concrete beam in situ by externally-bonded fiber reinforced polymer (FRP). The study of the mechanical properties of the interface and the rheological behaviour of composite materials are very important to design.[15]

Khalifa et al. (2000) studied the shear performance and the modes of failure of reinforced concrete (RC) beams strengthened with externally bonded carbon fiber reinforced polymer (CFRP) wraps experimentally. The experimental program consisted of testing twenty-seven, full-scale, RC beams. 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 3 versus 4), CFRP amount and distribution (i.e., Continuous wrap versus strips), bonded surface (i.e., lateral sides versus U-wrap), fiber orientation (i.e., 90°/0° fiber combination versus 90° direction), and end anchor (i.e., U-wrap with and without anchor)[8]. As part of the research program, they examined the effectiveness of CFRP reinforcement in enhancing the shear capacity of RC beams in negative and positive moment regions, and for beams with rectangular and T-cross section. The experimental results indicated that the contribution of externally bonded CFRP to the shear capacity is significant and dependent upon the variable investigated. For all beams, results show that an increase in shear strength of 22 to 145% was achieved.[9]

Hadi (2003) examined the strength and load carrying capacity enhancement of reinforced concrete (RC) beams, those had been tested and failed in shear. A total of sixteen sheared beam specimens with a length of 1.2m and cross-sectional area of 100 x 150 mm were retrofitted by using various types of fiber reinforced polymer (FRP) and then retested. The retrofitted beam specimens wrapped with different amounts and types of FRP were subjected to four-point static loading. Load, deflection and strain data were collected during testing the beam specimens to failure. Results of the experimental program indicate that there were several parameters that affect the strength of the beams[6]. The results also show that the use of FRP composites for shear strengthening provides significant static capacity increase.

Teng et al. (2004) have studied the shear strengthening of reinforced concrete (RC) beams with FRP composites. A recent technique for the shear strengthening of RC beams is to provide additional FRP web reinforcement, commonly in the form of bonded external FRP strips/sheets. Over the last few years, a large amount of research has been conducted on this new strengthening technique, which has established its effectiveness and has led to a good understanding of the behaviour and strength of such shear-strengthened beams. Here, the methods of strengthening were described first, followed by a summary of experimental observations of failure processes and modes. The accuracy of existing design provisions was examined next through comparisons with test results. Limitations of existing experimental and theoretical studies were also highlighted.[14]

Islam et al. (2005) investigated shear strengthening of RC deep beams using externally bonded FRP systems. In this study, six identical beams were fabricated and tested to failure for this purpose. One of these beams was tested in its virgin condition to serve as reference, while the remaining five beams were tested after being strengthened using carbon fiber wrap, strip or grids. The test results have shown that the use of a bonded FRP system leads to a much slower growth of the critical diagonal cracks and enhances the load-carrying capacity of the beam to a level quite sufficient to meet most of the practical upgrading requirements[7]. Although FRP grids placed in normal orientation demonstrated to be the most effective system as far as the amount of material used in strengthening is concerned, other systems were found to be almost equally effective. An enhancement of shear strength in the order of about 40%, was achieved in this study. Saafan (2006) studied the shear strengthening of reinforced concrete (RC) beams using GFRP wraps. The objective of the experimental work was to investigate the efficiency of GFRP composites in strengthening simply supported reinforced concrete beams designed with insufficient shear capacity. Using the hand lay-up technique, successive layers of a woven fiber glass fabric were bonded along the shear span to increase the shear capacity and to avoid catastrophic premature failure modes. The strengthened beams were fabricated with no web reinforcement to explore the efficiency of the proposed strengthening technique using the results of control beams with closed stirrups as web reinforcement. The test results of 18 number of beams were reported, addressing the influence of different shear strengthening schemes and variable longitudinal reinforcement ratios on the structural behaviour. The results indicated that significant increase in the shear strength and improvements in the overall structural behaviour of beams with insufficient shear capacity could be achieved by proper application of GFRP wraps. It was observed that the layers can easily slip down under self weight[13].

Mosallam and Banerjee (2007) studied experimentally on shear strength enhancement of reinforced concrete beams externally reinforced with fiber-reinforced polymer (FRP) composites. A total of nine full-scale beam specimens of three different classes, as-built (unstrengthened), repaired and retrofitted were tested. Three composite systems namely carbon/epoxy wet layup, E-glass/epoxy wet layup and carbon/epoxy procured strips were used for retrofit and repair evaluation. Experimental results indicated that the composite systems provided substantial increase in ultimate strength of repaired and strengthened beams as compared to the pre-cracked and as-built beam specimens.[11]

Kim et al. (2008) studied the shear strength of RC beams strengthened by fiber material. It consists of a plasticity model for web crushing, a truss model for diagonal tension, and a simple flexural theory based on the ultimate strength method. To analyze the shear strengthening effect of the fiber, the model considers the interfacial shear-bonding stress between base concrete and the fiber. This reflects that the primary cause of shear failure in strengthened RC beams is rapid loss of load capacity due to separation of the strengthening fibers from the base material. The predictive model can estimate load capacities of each failure mode, and is compared to tested specimen data including extreme load failure. The analysis matches well with the experiments concerning load capacity and failure mode. Also, the experimental results of other published data are compared to the predictive model to evaluate its application. The results show that the predictive model has good adaptability and high accuracy.[10]

Balamuralikrishnan (2009) has studied the flexural behaviour of RC beams strengthened with carbon fiber reinforced polymer (CFRP) fabrics. For flexural strengthening of RC beams, total ten number of beams were cast and tested over an effective span of 3000 mm up to failure under monotonic and cyclic loads. The beams were designed as under-reinforced concrete beams. Eight number of beams were strengthened with bonded CFRP fabric in single layer and two layers which are parallel to beam axis at the bottom under virgin condition and tested until failure; the remaining two beams were used as control specimens. Static and cyclic responses of all the beams were evaluated in terms of strength, stiffness, ductility ratio, energy absorption capacity factor, compositeness between CFRP fabric and concrete, and the associated failure modes. The theoretical moment-curvature relationship and the load-displacement response of the strengthened beams and control beams were predicted by using software ANSYS. Comparison has been made between the numerical (ANSYS) and the experimental results. The results show that the strengthened beams exhibit increased flexural strength, enhanced flexural stiffness, and composite action until failure.[3] Ceroni (2010) experimentally studied on RC beams externally strengthened with carbon fiber reinforced plastic (FRP) laminates and Near Surface Mounted (NSM) bars under monotonic and cyclic loads, the latter ones characterized by a low number of cycles in the elastic and post-elastic range. Comparisons between experimental and theoretical failure loads were discussed in detail.[4]

More recently, Obaidat et al. (2011) investigated experimentally, the behaviour of the structurally damaged full-scale reinforced concrete beams retrofitted with CFRP laminates in shear or in flexure. The main variables considered were the internal reinforcement ratio, position of retrofitting and the length of CFRP. The experimental results, generally, indicate that beams retrofitted in shear and flexure by using CFRP laminates are structurally efficient and are restored to stiffness and strength values nearly equal to or greater than those of the control beams. Employing externally bonded CFRP plates resulted in an increase in maximum load. The increase in maximum load of the retrofitted specimens reached values of about 23% for retrofitting in shear and between 7% and 33% for retrofitting in flexure. Moreover, retrofitting shifts the mode of failure to be brittle. It was found that the efficiency of the strengthening technique by CFRP in flexure varied depending on the length. The main failure mode in the experimental work was plate debonding which reduces the efficiency of retrofitting. Based on the conclusion deeper studies should be performed to investigate the behaviour of the interface layer between the CFRP and concrete. Also numerical work should be done to predict the behaviour of retrofitted beams and to evaluate the influence of different parameters on the overall behaviour of the beams.[12]

Mix Design:

The mix design strength of concrete is 25 Mpa in 28 days. The specific gravity of Coarse and Fine Aggregates are 2.88 and 2.64. The standard deviation is taken as 4Mpa. Portland slag cement is being used of specific gravity 2.96.

Table 1: Mix Proportions

Water	Cement	Fine Aggregates	Coarse Aggregates
0.45	1	1.49	2.89

Table 2: Quantity of materials for casting

Materials	One Mould (in Kg)	Three Mould (in Kg)
Cement	2.816	8.448
Fine Aggregate	5.376	17.208
Coarse Aggregate	7.460	22.380
Fly Ash	0.256	0.768
Water	1.3	3.9

Table 3: Curing Specimens

Cured	Plain concrete beam	U Wrapped beam	Two side Wrapped beam
7 Days	3 nos	3 nos	3 nos
28 Days	3 nos	3 nos	3 nos

Experimental Study:

Analysis of beam for 7 days:

The beams B1, B2 and B3 cured for 7 days and 28 days were tested on Flexural Testing Machine. One sided GFRP Wrapped concrete beams, Two sided GFRP Wrapped concrete beams , Details are illustrated in the table below:

Table 4: Load in KN for 7 Dyas & 28 Days

Beam	Plain cement concrete		U GFRP wrapped		Two sided GFRP wrapped	
	Load in KN		Load in KN		Load in KN	
	7 days	28days	7 days	28 days	7 days	28 days
B 1	26	31	31	40	28	33
B 2	25	30	32	39	30	32
B 3	26.5	31	33	42	31	39
Avg Load (KN)	25.84	30.67	32	40.34	20.34	34.67

III. Results

Conclusion drawn from above results

Sr No	Beam	Increase in strength compared to PCC in %
1	GFRP Wrapped U	32
2	GFRP Wrapped Two sides	11

The strength of beam wrapped by GFRP on beam in U shape is 32% more than that of Plain cement concrete and the strength of beam wrapped on two parallel sides is comparatively more than the strength of Plain cement concrete but lesser than the wrapped in one side.

IV. Conclusion

From theabove research and results we can conclude that GFRP wrapped in U shape gives better strength as compared to GFRP wrapped on two parallel sides. The strengthening of beam in U shape is more effective than in sides of beam. And finally we can conclude that the GFRP can increase the shear capacity of beams. The use of GFRP sheets as an external reinforcement is recommended to enhance the shear capacity of RC Beams with anchorage system.

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