

"STRENGTHENING OF CONTINUOUS RC BEAMS USING EXTERNALLY BONDED AND UNBONDED GFRP COMPOSITES"

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ABSTRACT

The use of externally bonded advanced fiber-reinforced polymer (FRP) composites for structural strengthening has gained significant popularity worldwide over the past decade. This method provides a more cost-effective and technically superior alternative to traditional strengthening techniques. It offers advantages such as enhanced strength, excellent fatigue resistance, lightweight properties, corrosion resistance, quick and easy installation, and minimal alteration to the structure's geometry. Despite the prevalence of continuous reinforced concrete (RC) beams in construction, research on FRP strengthening for such beams remains limited.

This study focuses on an experimental investigation to analyze the behavior of continuous RC beams under static loading. Strengthening techniques involve the application of externally bonded glass fiber-reinforced polymer (GFRP) sheets and unbonded GFRP secured using a steel bolt anchorage system. Various strengthening schemes have been implemented. The experiment involves six continuous (two-span) beams, each with overall dimensions of 150×250×2300 mm. All beams have identical longitudinal and transverse reinforcement. Among them, one beam remains unstrengthened and serves as the control, while the others are reinforced using different configurations of bonded GFRP sheets and unbonded GFRP with end anchorage.

The study evaluates the structural response of these beams, focusing on failure modes, load-bearing capacity improvements, and load-deflection behavior. Findings indicate that bonding GFRP sheets to the shear face significantly enhances the shear strength of RC beams. Additionally, the use of unbonded sheets with end anchorage improves crack resistance by delaying the formation of visible cracks and minimizing crack widths under higher load conditions.

1. INTRODUCTION

Concrete structures might, for a mixture of reasons, be found to perform unacceptably. This could show itself by poor execution under static loading, as cracking or excessive deflections, or there could be insufficient extreme quality or strength. A structure is designed for a specific period and depending on the nature of the structure, its design life varies. Decay in solid structures is a noteworthy test confronted by the foundation and scaffold commercial ventures around the world. The degradation could be mainly due to nature's effects, which includes gradual loss of strength with ageing, corrosion in steel, high intensity loading, freeze-thaw cycles, temperature variation, or exposure to chemicals or saline water and due to ultra-violet radiations. As complete replacement or reconstruction of the structure will be cost effective, strengthening or retrofitting is an effective way to strengthen the same.

Reinforced concrete structures regularly need to face adjustment and change of their execution amid their administration life. The primary contributing components are change in their utilization, new plan guidelines, weakening because of consumption in the steel brought about by introduction to a forceful situation and mischance occasions, for example, seismic tremors. In such circumstances there are two conceivable arrangements: substitution or retrofitting. Full structure substitution may have determinate disservices, for example, high expenses for material and work, a more grounded natural effect and drawback because of interference of the capacity of the structure, e.g. activity issues. At the point when conceivable, it is frequently better to repair or redesign the structure by retrofitting. The most mainstream systems for fortifying of RC beams have included the utilization of outer epoxy-reinforced steel plates. It has been discovered tentatively that flexural quality of a concrete beam can increment by utilizing this method. Despite the fact that steel holding system is basic, savvy and productive, it experiences a significant issue of crumbling at the steel and cement inter-phase because of consumption of steel. Other normal reinforcing method includes development of steel coats which is truly compelling from quality, firmness and flexibility contemplations. In any case, it builds general cross-sectional measurements, prompting increment in self-weight of structures and is work serious. To take out these issues, steel plate was supplanted by erosion safe and light-weight FRP Composite plates. FRPCs help to build quality and pliability without exorbitant increment in solidness. Further, such material could be intended to meet particular necessities by modifying

arrangement of strands. So solid individuals can now be effectively and viably reinforced utilizing remotely fortified FRP composites.

By wrapping FRP sheets, retrofitting of solid structures give a more temperate and in fact better option than the conventional systems by and large on the grounds that it offers high quality, low weight, consumption resistance, high exhaustion resistance, simple and quick establishment and insignificant change in basic geometry. FRP frameworks can likewise be utilized as a part of zones with restricted access where customary strategies would be unrealistic. Then again, because of absence of the best possible information on auxiliary conduct of solid structures, the utilization of these materials for retrofitting the current solid structures can't reach up to the desire. Fruitful retrofitting of solid structures with FRP needs a careful learning on the subject and accessible easy to understand rules in advanced technologies.

Beams are the critical structural members subjected to bending, torsion and shear in all type of structures. Similarly, columns are also used as various important elements subjected to axial load combined with/without bending and are used in all type of structures. Therefore, extensive research works are being carried out throughout world on retrofitting of concrete columns and beams with externally bonded FRP composites. Several investigators took up concrete columns and beams strengthened with GFRP(glass-fibre reinforced polymer) or CFRP (carbon-fibre reinforced polymer) composites in order to investigate the increase in strength and durability, ductility, preparation of design guidelines and the effect of confinement.

STRENGTHENING OF BEAMS

For flexural strengthening, there are numerous techniques, for example, steel plate holding, segment expansion, outer post tensioning system, near or close surface mounted (NSM) framework and EB or externally bonded framework. While numerous routines for fortifying structures are accessible, reinforcing structures by means of outside holding of cutting edge fiber-strengthened polymer composite (FRP) has turn out to be extremely prominent around the world. Amid the previous decade, their application in this field has been ascending because of the surely understood focal points of FRP composites over different materials. Thus, an awesome amount of exploration, both test and hypothetical, has been led on the conduct of FRP-reinforced strengthened cement (RC) structures. In such manner, the advancing innovation of utilizing carbon-fortified fiber-strengthened polymers (CFRP) for fortifying of RC pillars has pulled in much consideration as of late.

ADVANTAGES OF FRP

Some of the basic advantages of FRP are listed below:

Low weight: FRP is considerably less thick and in this manner lighter than the proportional volume of steel. The lower weight of FRP makes establishment and taking care of altogether less demanding than steel. These properties are especially imperative when establishment is done in cramped areas. Different works like deals with soffits of extensions and building floor chunks are done from man-access stages as opposed to from full framework. The utilization of fiber composites does not altogether build the heaviness of the structure or the measurements of the part. Furthermore, on account of their light weight, the vehicle of FRP materials has negligible ecological effect.

Mechanical strength: FRP can give a most extreme material stiffness-density proportion of 3.5 to 5 times that of aluminum or steel. FRP is so solid and hardened for its weight, it can out-perform alternate materials.

Formability: The material can take up anomalies fit as a fiddle of the solid surface. It can be formed to any wanted shape. We can make or duplicate most shapes without hardly lifting a finger.

Chemical resistance: It is insignificantly receptive, making it perfect as a defensive covering for surfaces where there is chemical attack.

Joints : Joints and laps are not needed.

Corrosion resistance: FRP can be used to make durable structures as it does not rust away.

Low Up keep: Once FRP is introduced, it requires insignificant support. The materials strands and tars are strong if effectively indicated, and oblige little support. In the event that they are harmed in administration, it is generally easy to repair them, by including an extra layer.

Long life: It has high imperviousness to weariness and has demonstrated incredible toughness throughout many years.

Simple to apply: The utilization of FRP plate or sheet material is similar to applying wallpaper; once it has been moved on precisely to uproot entangled air and abundance cement it might be left unsupported. Fiber composite materials are accessible in long lengths while steel plate is by large restricted to 6 m.

Simply Supported Beam

Grace et al. (1999) explored the conduct of strengthened RC beams with GFRP and CFRP sheets and covers or

laminates. They considered the impact of the quantity of layers, epoxy sorts, and pattern of strengthening on response of the RC beams. They discovered that all the beams experienced brittle failure, with obvious upgrade in strength, and thus requiring a higher design factor of safety.

Trial examinations, theoretical-based calculations and a number of simulations demonstrated that fortifying the strengthened concrete beams with externally-bonded CFRP sheets in the tension zone extensively expanded the strength at flexure, diminished deflections and also crack widths (Ross et al., 1999; Sebastian, 2001; Smith & Teng, 2002; Yang et al., 2003; Aiello & Ombres, 2004). It likewise changed the conduct of these beams under load type and failure pattern. Regularly the strengthened beams fizzled in a brittle manner, for the most part because of the loss of association between the concrete or cement and the composite material. They inferred that the surface preparation alongside soundness of cement could impact a definitive bond quality. From there on, Study on de-holding issues in beams remotely reinforced with FRP composites are done by numerous analysts.

Numerous agents utilized externally bonded FRP composites to enhance the flexural quality of RC concrete. To assess the flexural execution of the reinforced individuals, it is important to study flexural firmness of FRP fortified individuals at distinctive stages, for example, pre-cracking, post-breaking and post-yielding. Notwithstanding, just few mulled over are centered around the strengthened solid individuals reinforced under preloading or pre-cracking (Arduni&Nanni, 1997).

F. Ceroni (2010) explored the experimental program on RC beams remotely bonded with carbon Fiber Reinforced Plastic (FRP) overlays and Near Surface Mounted (NSM) bars under monotonic and cyclic burdens, the last ones described by a low number of cycles in the versatile and post-flexible extent. Comparisons on theoretical and experimental failure loads are examined in point of interest.

Obaidat et al. (2010) concentrated on the Retrofitting of reinforced concrete beams composite laminates while the main variables considered were steel reinforcement, the length and position of CFRP. The trial tests were performed to research the conduct of beams composed in such a route, to the point that either shear or flexural failure will occur. The beams were loaded in four-point bending until there was cracks. The beams were then emptied and retrofitted with CFRP. At last the bars were loaded until failure. The ABAQUS system was utilized to create FEMs to study the conduct of beams. From the analyses the load-deflection relationships until failure, failure modes and crack patterns were obtained and compared to the experimental results. The FEM results concurred well with the analyses when utilizing the binding model in regards to failure mode and load carrying capacity

In another examination, Kim (2011) carried on test investigations of 14 strengthened RC beams retrofitted with new hybrid FRP(fiber reinforced polymer) framework comprising carbon FRP (CFRP) and glass FRP (GFRP). The target of this study was to inspect impact of hybrid FRPs on structural conduct of retrofitted RC beams and to research if different groupings of CFRP and GFRP sheets of the hybrid FRPs have impacts on strengths of reinforced RC beams. The beams are loaded with different values before retrofitting to study the factor of initial loading on the flexural behavior of the retrofitted beam. Under loaded condition, beams are retrofitted with a few layers of hybrid FRPs, then the load increases until the beams achieve failure. Test outcomes presume that impacts of hybrid FRPs on stiffness and ductility of RC beams rely on number of FRP layers.

Continuous Beam

Grace et al. (2001) explored the test execution of CFRP strips utilized for flexural reinforcing as a part of the negative moment area of a full-scale reinforced concrete beam. They considered two classes of beams (I and II) for flexural fortifying. Class I beams were intended to fail in shear where as Class II beams were intended to come up short in flexure. A total of five full scale beams of each class were tried. It was observed that beams of Class I failed due to diagonal cracking along with local debonding at the top. Meanwhile, beams of Class II failed by delamination at the interface of the concrete surface and the CFRP strips. The ductile failures of all the beams were observed as the strips of were not stressed to their maximum capacity. The greatest increment of load carrying limit because of fortifying was seen to be 29% for Class I beams, and 40% for Class II beams. Then again, Grace et al. (2005) performed another exploration work where three continuous beams were tried. And one of them was considered as a control beam and a ductile flexural failure happened. They strengthened the other two bars along their negative and positive moment areas around the top and base faces on both sides as a U-wrap. It was reasoned that the fortified beams with the tri-axial fabric demonstrated more noteworthy ductility than the beams strengthened with CFRP sheets.

In another exploration, El-Refaie et al., (2003) inspected 11 RC beams(two-span) fortified in flexure with outer reinforced CFRP sheets. The beams were classified into two groups according to the arrangement of their internal steel reinforcement. Each group had one control beam. It was noted that, all strengthened beams showed less ductility compared with that of control beams. A limit to the number of CFRP layers was found after which there was no

further increase in the capacity of the beam. It was also seen that increasing the CFRP sheet length to cover the entire hogging or sagging zones did not prevent the failure of the CFRP sheets, which was the dominant mode of failure.

Ashour et al., (2004) tried 16 strengthened cement (RC) continuous beams with various reinforcements of inner steel bars and outside CFRP covers. Every single test example had the same geometrical measurements and were ordered into three gatherings as per the measure of interior steel support. Every gathering incorporated one non-reinforced control beam intended to fizzle in flexure. Three types of failure modes were watched, to be peeling failure of the concrete cover, laminate rupture and cover detachment. The ductility of every single reinforced beam was diminished in examination with their particular reference beam. Moreover, rearranged routines for assessing the flexural load capacity and the interface shear stresses between the concrete and the adhesive material were displayed. As in past studies, they watched that expanding the CFRP sheet length did not counteract peeling failure of the CFRP laminates.

Aiello et al., (2007) thought about the conduct between continuous RC beams reinforced with CFRP sheets at negative or positive moment areas and RC beams fortified at both negative and positive moments. All the bars were fortified with one CFRP sheet layer and with the comment that the beams were not loaded at the mid-span. The control beams experienced a typical bending and failure of the reinforced beams happened by debonding of the CFRP sheets, along with crushing of the concrete. It was figured out that when the reinforcing was connected to both sagging and hogging areas the ultimate capacity was greatest.

As of late, Maghsoudi et al., (2009) inspected the flexural conduct and moment redistribution of RHSC (Reinforced High-Strength Concrete) continuous beams reinforced with carbon fiber. They watched that by expanding the quantity of CFRP layers, a ultimate capacity expands, and in the mean time ductility, moment redistribution, and ultimate strain of CFRP sheet diminish. Test outcomes likewise demonstrated that by expanding the quantity of CFRP sheet layers, there was an adjustment in the failure mode from ductile break to IC debonding.

Materials for Casting

1. Cement

Portland Slag Cement (PSC) of Ultratech brand is used for the experiment. It is tested for It's physical properties in accordance with Indian Standard specifications. Tests were conducted on Cement and the results are as below:

- Normal Consistency: 33%
- Setting Times: Initial Setting Time: 85 minutes
- Final Setting Time: 485 minutes
- 28-day Compressive Strength: 47.33 MPa
- Fineness: 1 gm retained in 90 micron sieve

2. Fine Aggregate

The fine aggregate passing through 4.75 mm sieve are used. The grading zone of fine aggregate is zone III as per Indian Standard specifications.

3. Water

Ordinary tap water is used for concrete mixing in all the mix.

4. Coarse Aggregate

Two grades of coarse aggregates are used one retained on 10 mm size sieve and the other grade contained aggregates retained on 20 mm sieve. Both the grades of coarse aggregates had equal weightage.

5. Reinforcing Steel

All the beams had same longitudinal and transverse steel reinforcement ratios and were casted and tested to failure. The beams were reinforced with two 12 mm diameter at the bottom, two 10 mm diameter bars as top reinforcement throughout the length to strengthen the beam in flexure. Stirrups of 8 mm diameter high-yield Strength Deformed (HYSD) bars were provided throughout the beam at 150 mm center-to-center distance to make the beam weak in shear. And, finally 6 mm bars are used as hanger bars for lifting of the beam.



Fig. 1. Steel Reinforcement for the beam

STRENGTHENING OF BEAMS

At the time of bonding of glass fiber, the concrete surface was made rough using a coarse sand paper texture and then the surface was cleaned with an air blower to remove all dirt and debris. The fabrics were cut according to the size and then the epoxy resin was mixed according to the instructions of the manufacturer. The mixing was carried out in a plastic mug with 10 parts by weight of Hardener HY 951 to 100 parts by weight of Araldite LY 556. After mixing it uniformly, the epoxy resin was applied to the surface where the GFRP is to be applied. Then the GFRP sheet was placed on top of the coating and the resin was squeezed with the help of the roller. The entrapped air bubbles in the inter-phase were eliminated. The above process took place at room temperature. Concrete beams strengthened with GFRP were cured for at least 7 days before testing each of them.

Two beams were strengthened with unbonded glass fibre-reinforced polymer sheets with end anchorage using steel bolt system. The holes were made during casting and glass FRP sheets were applied externally on the surface without applying epoxy resin. And, steel bolts were inserted into the holes and using steel plates at both the ends the glass FRP sheets were applied. Finally, the beams were tested under two point loading.

2. RESULTS AND DISCUSSION

The loadings on the beams were a concentrated load at each mid-span and the experimental results thus obtained are discussed in terms of the failure mode observed and the load vs deflection curve. The crack patterns and the mode of failure of each beam are also described in this chapter. All the beams are tested for their ultimate strengths and it is observed that the control beam had less load carrying capacity than the strengthened beam. One beam from the series was tested as un-strengthened control beam and rest beams were strengthened with various patterns of FRP sheets. The different failure modes of the beams were observed for different beams.

3. EXPERIMENTAL RESULTS

Failure Modes

Control Beam

The control beam failed completely in shear. The failure started first at the center span areas and then propagated towards the central support and finally failed in shear.

Strengthened Beam

Generally, the rupture of FRP sheet was very quick and sudden, and a loud noise was audible indicating a sudden energy release and thus loss in load-carrying capacity. For all the strengthened beams, the failure modes are described as below.

The following failure modes were examined for all the tested beams:

- Shear failure
- Debonding failure (with or without concrete cover)
- Debonding along with shear cracks at the span

Table 1 Experimental Results of the Tested Beams

Designation of Beams	Failure Mode	Pu(KN)	$\lambda = \frac{\text{Pu(strengthened beam)}}{\text{Pu(Control beam)}}$
CB1	Shear failure	240	1
SB1	Debonding failure along with shear cracks	288	1.2
SB2	Debonding failure	310	1.29
SB3	Debonding failure	340	1.42
SB4	Shear failure	270	1.125
SB5	Shear cracks along with cracks at vertical support	318	1.325

The ultimate failure load for all the tested beams are summarized in the above table. The ratio of load enhancement (λ), which is the ratio of the ultimate load of the strengthened beam to that of the control beam, is also presented in the table. From the table it is found that, addition of GFRP layers increased the load-carrying capacity and by introducing the anchoring system, the enhancement of load capacity can be done.

LOAD DEFLECTION AND LOAD CARRYING CAPACITY

The GFRP strengthened beams and the control beams are tested to find out their ultimate load carrying capacity. The deflection of each beam under the load point i.e. at the midpoint of each span position is analyzed. Mid-span

deflections of each strengthened beam are compared with the control beam. It is noted that the behavior of the beams when unbonded or bonded with GFRP sheets are better than the control beams. The mid-span deflections of the beams are lower when bonded externally with GFRP sheets. The strengthened beams were found to have higher stiffness than the control beams. Increasing the numbers of GFRP layers generally reduced the deflection at mid span and increased the beam stiffness for the same value of load. The use of GFRP sheet had effect in slowing the growth of cracks.

4. CONCLUSIONS

The present experimental study is carried out on the behavior of reinforced concrete rectangular beams strengthened by GFRP sheets. Six reinforced concrete (RC) beams weak in shear are casted and tested. All the beams had same longitudinal and transverse steel reinforcement ratios. The conclusions drawn from the experimental results are as follows:

1. The strengthened beams had higher load-carrying capacity as compared to the control beam.
2. The initial cracks in the strengthened beams appeared at higher loads compared to the control beam.
3. The test results show that on strengthening the beams using FRP technique, the shear capacity can be increased.
4. Strengthened beam SB3, which was strengthened by four layers of FRP showed the highest ultimate load value of 340 KN and the percentage increase in the load capacity of SB3 was 41.67 %.
5. On increasing the number of layers of glass FRP, the load carrying capacity of the beams also increases.
6. Unbonded FRP system with end anchorage using steel bolts and plates is a very new, time and cost-effective technique.

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