"Comparative Evaluation of Externally Bonded and Unbonded GFRP Composites for Strengthening Continuous RC Beams"

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ABSTRACT: The application of externally bonded Fiber-Reinforced Polymer (FRP) composites has become a widely accepted technique for strengthening and rehabilitating structural elements in recent years. Compared with conventional strengthening methods, FRP systems offer a cost-efficient and technically effective solution due to their high strength-to-weight ratio, excellent durability, resistance to corrosion, superior fatigue performance, and ease of installation. Furthermore, these systems require minimal modifications to the existing structural geometry.
Although continuous reinforced concrete (RC) beams are extensively used in engineering structures, limited research has been conducted on their strengthening using FRP composites. Therefore, this study presents an experimental investigation of the structural behavior of continuous RC beams subjected to static loading conditions.
The strengthening methods examined include externally bonded Glass Fiber-Reinforced Polymer (GFRP) sheets and unbonded GFRP sheets anchored with a steel-bolt end anchorage system. Six two-span continuous RC beams with dimensions of 150 mm × 250 mm × 2300 mm were tested. All specimens were designed with identical longitudinal and transverse reinforcement details. One beam was left unstrengthened as a control specimen, while the remaining beams were strengthened using different arrangements of bonded GFRP sheets and unbonded GFRP sheets with mechanical anchorage.
The experimental program focused on evaluating the structural performance of the strengthened beams in terms of failure characteristics, load-carrying capacity, and load-deflection response. The results demonstrated that externally bonded GFRP sheets applied to the shear zones significantly improved the shear resistance of the RC beams. In addition, unbonded GFRP sheets with end anchorage enhanced crack control performance by postponing the initiation of visible cracks and reducing crack widths under increased loading levels.

Keywords: Fiber-Reinforced Polymer (FRP), Glass Fiber-Reinforced Polymer (GFRP), Structural Strengthening, Load-Deflection Behavior, Shear Strength, Crack Control, Corrosion Resistance.

INTODUCTION: Concrete structures might be found to perform unacceptably for a variety of reasons. According to poor performance under static loading, it could show cracking or excessive deflections or there may be insufficient extreme quality or strength. Different types of structures have different design lives depending on the purpose for which it is constructed. The deterioration of solid structures is a significant problem faced globally by the construction and bridge industries. The deterioration could mainly be because of nature's effects; gradual loss of strength with ageing, corrosion in steel, high intensity loading, freeze-thaw cycles, temperature variations, or due to chemical or saline water exposure and ultra-violet radiations. Repairing strengthening or retrofitting of the structure is an effective way to strengthen the same as it will prove cost effective for complete replacement or reconstruction.

Adjustments and modifications are regularly required for reinforced concrete structures during their service life. The leading contributing factors are changes in their application, new design specifications, deterioration due to corrosion in the steel caused by exposure to an aggressive environment, and accident events such as earthquakes. In such a scenario, substitution is an option along with retrofitting. The complete replacement of a building may have specific disadvantages, such as high costs of material and labor, a stronger environmental impact and inconvenience due to the disruption in the operation of the building, for example, traffic problems. Whenever possible, it's usually more advantageous to repair or upgrade the structure through retrofitting. The most common systems for strengthening of RC beams have included the use of external epoxy-bonded steel plates. A method that uses a hollow cylindrical to enhance the flexural quality compares the strength enhancement with normal concrete. Even though the steel holding framework is straightforward, economical and effective, it has a major problem of disintegration at the steel and cement inter-phase due to erosion of steel. Another conventional reinforcement method includes the development of steel coatings that is very effective from strength, durability and flexibility considerations. The overall section measurement through lead design in increasing self weight of structure and is labour intensive. In order to resolve these issues, the steel plate has been replaced with corrosion resistant and lightweight FRP Composite plates. FRPCs assist in creating quality and flexibility without a huge increase in hardness. This approach may assist in modifying materials for specific requirements.

STRENGTHENING OF BEAMS There are several techniques for flexural strengthening, such as steel plate bonding, section enlargement, external post-tensioning system, near-surface mounted (NSM) system, and externally bonded (EB) system. The introduction of advanced fiber-reinforced polymer composite (FRP) retrofitting solutions has spread like wildfire globally. While many techniques are available to strengthen structures, the outside holding (or near-surface mounted method) has proven to be extremely popular. Over the past decade, their utilization in this industry has been growing due to the well-known advantages of FRP composites over other materials. As a result, a great deal of experimental and theoretical research has been done on the behaviour of FRP-strengthened reinforced concrete (RC) structures. The modern technology of using CFRP properties in strengthening of RC columns has received quite wide attention lately.

ADVANTAGES OF FRP Some of the basic advantages of FRP are listed below:

Low mass: FRP is considerably less heavy and thereby lighter than the same mass of steel. The lightweight nature of FRP makes its setting up and maintenance much easier compared to steel. Affordable housing fulfillment is more imperative when site is planned in compact zones. Tasks such as soffits of extensions and building floor chunks are completed from man-access stages instead of from full framework. The use of fiber composites does not significantly increase the weight of the structure or the size of the part. Moreover, due to their low weight, the vehicle made of FRP materials has little environmental impact. FRP can provide a maximum material stiffness-density ratio of 3.5 to 5 times that of aluminium or steel. FRP is so light and hard that its performance beats materials of similar weight. The material can bend without damage and assumes the shape of the solid surface. It can be shaped into any desired form. Most shapes can be created, or mimicked, by us with little effort. It has negligible reactivity with chemicals which makes it ideal to be used as a protective coating on surfaces that face chemical attack. Joints and laps are not required. Corrosion resistance: FRP does not rust away thus it can be used to make durable structures. Once FRP is installed, it requires very little maintenance. The materials strands and tars are powerful if suitably suggested, and necessitate little support. If they get damaged in service, they are typically easy to repair, by adding an extra layer. Something that endures: It has high resistance to weariness and has proven remarkably resilient over the years. Utilizing the FRP plate or sheet material is like wallpapering, as soon as it has been moved on correctly to take away entangled air and excess cement it can be left unsupported. Fiber composite materials are available in long lengths whereas steel plate is mostly restricted to 6 m.

OBJECTIVE AND SCOPE OF THE PRESENT WORK The objective of the present work is to study the behavior of continuous beams strengthened with bonded and unbonded GFRP sheets under static loading condition.In the present work, behavior of RC continuous rectangular beams strengthened with externally bonded or unbonded GFRP is experimentally studied. The beams have samelongitudinal and transverse steel reinforcement ratios. All beams have the same geometrical dimensions. These beams are tested up to failure by applying two points loading to evaluate the enhancement of its strength due to strengthening

LITERATURE REVIEW:

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 asper 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 there in forcing 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 Obaid at and others focused on composite laminates' retrofitting of reinforced concrete beams while the main variables concern steel reinforcement, the length and position of CFRP. Shear or flexural failure will occur, and an investigation was carried out with trial tests for the functioning of beams constructed in such a manner. The beams were loaded in a four-point bending till there was failure. After the beams were emptied, they were retrofitted with CFRP. The bars were at last loaded to failure The ABAQUS system was used to develop FEMs for investigating the behavior of beams. By analysing the load-deflection relationships until failure, failure modes and crack patterns were obtained and compared with the experimental one. The FEM results are consistent with the analyses when applying the binding model regarding failure mode and load carrying capacity.

Kim (2011) performed experimental investigations on 14 strengthened RC beams retrofitted with new hybrid FRP (fiber reinforced polymer) system consisting of carbon FRP (CFRP) and glass FRP (GFRP). This research aims to examine the impact of hybrid FRPs on the structural behaviour of retrofitted RC beams, along with studying whether different combinations of CFRP and GFRP sheets of hybrid FRPs have effects on strengths of reinforced RC beams. The consultative research group is dynamic, comprising groups created on a rolling basis, federative members by agreement and various other collaborations. Under a loaded condition, beams are retrofitted with a few layers of hybrid FRPs with load is increased until beams achieve failure. The test results indicate that the effects of hybrid fiber reinforced polymers on the stiffness and ductility of reinforced concrete beams depend on the number of fiber reinforced polymer layers.

MATERIALS FOR CASTING

Cement

The experiment makes use of Konark brand Portland Slag Cement (PSC). It is examined for its physical properties as per IS specifications. The tests on the Cement were done and the results are.:

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

Fine Aggregate

Fine aggregate passing through 4.75 mm sieve are used. According to the Indian Standard Specifications, zone III is the grading region of sand.

Water

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

Coarse Aggregate

Two types of coarse aggregates are used one involving sieving of aggregates through 10 mm size and the other grade through 20 mm size. The weights of both the coarse aggregate grades were equal.

Reinforcing Steel

The casting and testing to failure of all the beams had the same longitudinal and transverse steel reinforcement ratios. The beams were provided with two 12 mm diameter in the bottom, two 10 mm diameter bars as top reinforcement at full length to increase the flexure strength of the beam. The beam was made shear-deficient by a providing 8 mm diameter high-yield Strength Deformed (HYSD) bars stirrups 150 mm c/c through the beam. Finally, to support your beams using masons, we provide 6 mm bars as aircraft bars.

Fig. Steel Reinforcement for the beam

STRENGTHENING OF BEAMS

When bonding the glass fibre, the concrete surface was rubbed with coarse sand paper texture to make it rough and the surface was cleaned with air blower to remove all dirt and debris. The manufacturer's instructions of the epoxy resin were followed to mix and cut the fabrics as per the requirement of size. Mixing tooke place in a plastic mug by taking 10 parts by weight of hardener hy 951 to 100 parts by weight of araldite ly 556. After uniform mixing epoxy resin was applied to the surface where gfrp is to be applied.

Bearing capacity of soil is increasing with fibre reinforcement. After that, the GFRP sheet was placed on the top of the coating and resin was squeezed with the help of roller. The air bubbles trapped in the inter-phase were removed. The aforementioned process occurred at room temperature. Concrete beams strengthened with GFRP were cured before testing each of them for a minimum of 7 days. Two beams were strengthened using unbonded glass fibre-reinforced polymer sheets with end anchorage using steel bolt system. The holes were made during casting and epoxy resin not provided while applying glass FRP sheets externally on the surface. Steel bolts were inserted into the holes, and the glass FRP sheets were applied using steel plates at both ends. Finally, the beams were subjected to two-point loading.

RESULT AND DESCUSSION

Failure Modes

Control Beam The beam that is the control has failed entirely in shear. Initially, the central span region experienced a failure, which subsequently progressed towards the central support before ultimately culminating in shear failure.

Strengthened Beam In general, the failure of the FRP sheet occurred very rapidly and suddenly with a loud noise which indicates a sudden release of energy causing loss in the load-carrying capacity. The modes of failure are described below for all the strengthened beams.

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 Experimental Results of the Tested Beams

Designation of Beams	**Failure Mode**	***Pu*(KN)**	**λ=Pu(strengthened beam) / 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

LOAD DEFLECTION AND LOAD CARRYING CAPACITY The beams with GFRP strengthening and the control beams are tested to find out their ultimate load carrying capacity. The deflection of each beam due to the load point which is at the midpoint of each span position. The mid-span deflections of all strengthened beams were compared with control beam. The unbonded or bonded GEFRP bonded behavior of beams is noted to be superior to that of the control beams. Bonding the beams externally with GFRP sheets reduces their mid-span deflections. The beams that were strengthened were presented with more stiffness as compared to the control beams. With the same value of load, an increase in the number of GFRP layers reduces the mid span deflection and also increases the stiffness of the beam. The effect of GFRP sheet had a considerable impact on the growth of cracks.

CONCLUSION

The present experimental study is focused on reinforced concrete rectangular beams integrating GFRP sheets. Six beams of reinforced concrete weak in shear were cast and tested. All beams were designed with consistent longitudinal and transverse steel ratios. Based on the experimental results, we draw the following conclusion.

1. The strengthened beams could bear more load than that of the control beam.
2. The first cracks in the strengthened beams occurred at a load greater than that in control beam.

3. The tests have been conducted to check the feasibility of increasing the shear capacity by strengthening beams using FRP technique.
4. Beam SB3 that 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. Increasing the number of glass FRP layers will also increase the load-carrying capacity of the beams.
6. The recently developed unbonded fibre-reinforced polymer system with end anchorage via steel bolts and plates is more cost-effective.

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