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Paper Authors

Debapriya Paul[1],Rajib Majumder[2], Sayan Paul[3] , B.V.Shiva kumar[4]

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STRENGTHENING OF REINFORCED CONCRETE BEAMS USING GLASS FIBER REINFORCED POLYMER (GFRP)

Debapriya Paul[1],Rajib Majumder[2], Sayan Paul[3] , B.V.Shiva kumar[4]
[1]Department of Civil Engineering, Welfare Engineering College, Visakhapatnam, AP, India.
[2]Department of Civil Engineering, Techno International New Town, Kolkata, West Bengal, India.
[3]Department of Mechanical Engineering, RastriyaIspat Nigam Ltd., Visakhapatnam, AP, India.
[4]Department of Civil Engineering, Welfare Engineering College, Visakhapatnam, AP, India

E-Mail: deba.priya009@gmail.com[1], rajibmj@gmail.com[2],shaanpaul6@gmail.com[3]
Shivakumar.bandaru@gmail.com[4]

ABSTRACT

Retrofitting is technical interventions in structural system of a building that improve the resistance to earthquake by optimizing the strength, ductility and earthquake loads. Earthquake load is generated from the site seismicity, mass of the structures, importance of buildings, degree of seismic resistant, etc. Due to the variety of structural conditions of building, i.e. each building has different approaches depending on the structural deficiencies. Hence, engineers are needed to prepare and design the retrofitting approaches. It is also important to keep in mind that there is no such thing as an earthquake-proof structure, although seismic performance can be greatly enhanced through proper initial design or subsequent modifications. The goal is to protect human life, ensuring that the structure will not collapse upon its occupants or passers-by, and that the structure can be safely exited. Under severe seismic conditions the structure may be a total economic write-off, requiring tear-down and replacement allowing sliding connections such as passageway bridges to accommodate additional movement between seismically independent structures.

Keywords: Retrofitting, Earthquake load, Seismic resistance, Structural deficiency.

1. INTRODUCTION

Retrofitting is done to increase the local capacity of structural elements. This strategy recognizes the inherent capacity within the existing structures, and therefore adopts a more cost-effective approach to selectively upgrade local capacities like deformation, ductility, strength or stiffness of individual structural components. A high level of retrofitting, this ensures that any required repairs are only "cosmetic" - for example, minor cracks in plaster, drywall and stucco. This is the minimum acceptable level of retrofit for hospitals. It is an easy and optimistic technique, useful for any type of building.

Fig. 1: Yearns of fibre tomake products

Fibre Reinforced Polymer (FRP) composites are the new material of choice with costs less than stainless or high-Carbon alloy steel components and also they might be used in highly corrosive environments.The composite ageis revolutionizing our society and impacting our daily lives by giving us products to use that are lighter, more durable and have infinite design flexibility at a lower cost. FRP materials provide better flexibility and high tensile strength with having the property to resist corrosion. These properties make them competitive with standard bridge materials in situations where access and construction present difficulties. The FRP composites can be formed into any shape and colorants can be added to allow the structures to blend with most landscapes. The use of composites prevents large trees from being over harvested near bridge sites and thus eliminates any potential environmental impacts of treated wood or galvanized steel used in riparian environments.

2. BACKGROUND

Over 95% of the fibres used in reinforced plastics are glass fibres, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced.It is experimentally observed that the flexural strength of concrete beams is significantly increased by bonding GFRP plates to their tension flanges than Carbon Fibre Reinforced Polymer sheets. Glass FibreReinforced Polymer (GFRP) has a very high strength to weight ratio. Glass fibre is the primary reinforcement used in polymeric corrosion resistant structures due to its mechanical properties. Glass containers are used to handle corrosive chemicals and see little or no effect of the media on the container. Research shows no loss of laminated properties of GFRP even after 30 years. In load bearing, the choice of glass fibre is crucial for the long term structural performance of the composite. A number of choices of different glass fibre types are available but not all are suited for corrosive environments. Figure 2 shows thin threads of glassfibres.

Fig. 2: Threads of glass fibre

These are the glass composition and the chemicals applied to the glass to make it compatible with the chosen polymer system. There are several features of the glass fibre used to make the product suitable for the manufacture of glassfibrereinforcedpolymer (GFRP) composites. Their low density, resistance to chemicals, insulation capacity etc. are the other bonus characteristics. Glassfibres are eco-friendly in processing and have no wear of tooling and no skin problems. In the load-bearing portion of the structure, proper choice of glass fibre can make a huge difference in long term usefulness of the structure. Recent advances in polymer and materials chemistry have led to the development of materials that exhibit the ability to undergo repair. However, a poor glass choice may simply reduce the useful period of time before relining of the structure.

3. LITERATURE REVIEW

Hamid SaadatManesh and Mohammed R. Ehsani [XX] (1991) carried out investigation on the static strength of concrete beams after gluing their tension flanges of concrete beams by gluing GFRP plates. T-beams were generally adopted in this case. The results showed that the flexural strength of RC beams increases by a significant amount after gluing GFRP plates to their flanges.

M. Zako and N. Takano [XX] (1999) carried out extensive study to provide an intelligent material system that can perform a self-repairing operation against initial damage occurring in GFRP laminates. After checking the basic characteristics of materials used it is ascertained whether these particles can repair when damaged due to intense heat or cracking. The embedded particles can perform repair if melted down by heat.

Chris Gentile et al [XX] (2001) investigated the use of near-surface GFRP bars to overcome the effect of local defects in the timber and to enhance the bending strength of the members. Due to material deterioration and limited capacity to accommodate current load levels, repair and rehabilitation ofinfrastructure is becoming increasingly important for bridges. Twenty-two half-scale and four full-scale timber beams strengthened with GFRP were tested to failure. Reinforcement ratios were between 0.27 and 0.82%. As control specimens unreinforced timber beams were used. It was observed that using the proposed experimental technique changed the failure mode from tension to compression failure and flexural strength increased by 18 to 46%.

It is experimentally observed that the flexural strength of concrete beams is significantly increased by gluing GFRP plates to their tension flanges. So, it has been clearly established through various experiments that the flexural strength of plain concrete or reinforced concrete is significantly increased by gluing GFRP sheets to tension flanges.

4. EXPERIMENTATION

Normally, for most structural work the concrete is designed to give compressive strengths of 15 to 35 MPa. All the parameters of Cement, Fine Aggregate, Coarse Aggregate and Water which arerequired for the design mix of M20, done carefully. The mixing is done thoroughly and proportionately with the help of machine mixer so that a uniform quality of concrete of grade M20 is obtained. Then compaction is done by tamping manually. Curing is done to prevent the loss of water which is essential for the process of hydration and hence for hardening. Here curing of each beam is done for a period of 28 days in curing tank. After 28 days, the first layer of epoxy is applied. Then the sheets of the materials used for retrofitting are placed over the layer of epoxy immediately, before allowing

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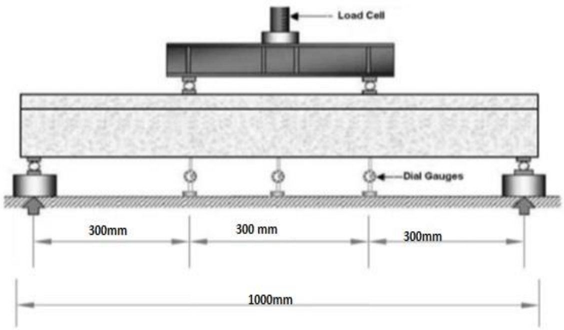
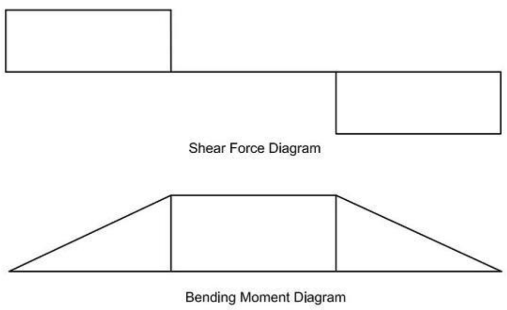
the epoxy to harden. Then the second layer of epoxy is placed after aligning the sheets into proper positions. As adhesive, we used epoxy resin in this experiment. The success of the strengthening technique primarily depends on the performance of the epoxy resin used for bonding of FRP to concrete surface.



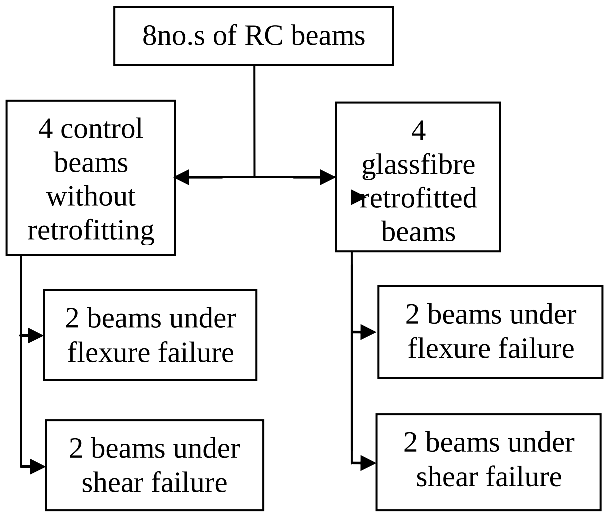
The experimental study consists of casting of eight reinforced concrete beams. Among these, all the eight beams are cast, out of which four are taken as controlled beams and rest four beams are strengthened using continuous glass fiber reinforced polymer (GFRP) sheets. Experimental data on load, deflection and failure modes of each of the beams



are obtained. The change in load carrying capacity and failure mode of the beams are investigated. The sheets are externally bonded to the surface of the beams in both shear and in flexure. For shear failure, the shear zones are marked with the help of the shear force diagram and the bending moment diagram gives an idea about the flexure zone which is required to adhere the sheets to.

All the eight beams are tested one by one. The dial gauge reading showed the deformation. The load at which the first visible crack is developed is recorded as cracking load. Then the load is applied till the ultimate failure of the beam. The deflections are measured at a distance L/2 from either support and the values are furnished in the table.

The experimental study consists of casting of twenty reinforced concrete beams:



5. RESULTS AND DISCUSSIONS

A number of failure modes have been observed in the experiments of RC beams in flexure and shear by the fibres. Yielding of the steel in tension is occurred followed by rupture of the fibre laminate and concrete crushing. De-bonding of the FRP from the concrete substrate took place. The

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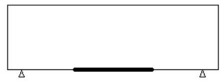
failure modes of the RC beams strengthened using glass fibre, include shear failure, shear failure due to fibre rupture, splitting of laminate at the shear zones and the segregation of concrete. Rupture of the FRP laminate is assumed to occur if the strain in the FRP reaches its design rupture strain before the concrete reachesits maximum usable strain.

The behavior of the 8 no.s00 of reinforced concrete beams throughout the test is described using recorded data on deflection behavior and the ultimate load carrying capacity in table 1. The crack patterns and failure of each beam are also noted. All the beams are tested for their ultimate strengths. The average deflection in mm, the average ultimate load in kN and the strengthening effect in % is also has been reported in table 1. It is observed that the control beams had less load carrying capacity and high deflection values compared to that of the externally strengthened beams using the GFRP sheets both in flexure and shear.

Table-1: Summary of experimental results

Wrapping configuration	**Deflection at mid span (mm)**	**Avg. deflection (mm)**	**Avg.ultimate load (kN)**	**Strengthening effect (%)**
Control beam without using FRP under flexure failure (con1 & con2)	8	7.5	30	-
	7			
Control beam without using FRP under shear failure (con3 & con4)	2.17	2.14	31	-
	2.1			
Beam strengthened with Glass FRP in flexure zone (GF1 & GF2) 	4.26	4.26	46	54
	4.26			
Beam strengthened with Glass FRP in shear zone (GF3 & GF4) 	1.9	1.95	40.6	31.2
	2			

Control beam 1 (con1) and control beam 2 (con2) are weak in flexure and no strengthening is done. Two point static loading is applied on the beams and at the each increment of the load; deflection at L/2 is taken with the help of a digital dial gauge. Using this load and deflection data, load - deflection has been understood. At the load of 15 kN initial hairline cracks appeared which is noted as first crack. Later with the increase in loading values the crack propagated further. The next crack was observed at a load of 20kN. On further increase of the load to 25 kN, the final cracks were observed. The Beam1 failed completely in flexure. Table 2 contains the results observed during the experiment of the two control beams i.e. con1 & con2 under flexural failure.

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Table-2: Deflection values of con1 & con2

Load in kN	Deflec-tion at L/2 for con 1	Re-marks	Deflec-tion at L/2 for con 2	Re-marks
0	0		0	
5	0.37		0.5	
10	1.2		1.8	
15	3.9	1st Crack	3.4	Crack started
20	5.2		4.9	2nd crack
25	6.4	2nd crack	6.8	3rd crack
30	7	Failure	8	Failure

The same experiment is done for the beams retrofitted with glass fibre reinforced polymer and the results are been tabulated in table 3. For GFRP retrofitted beams (GF1 & GF2), when two point static loading is applied on flexure, at the each increment of the load; deflection at L/2 is taken with the help of a digital dial gauge and thus the load and deflection values are noted.

Table-3: Deflection values of GF1&GF2

Load in kN	Deflec-tion at L/2 for GF 1	Re-marks	Deflec-tion at L/2 for GF 2	Re-marks
0	0		0	
5	0.2		0.3	
10	0.35		0.4	
15	0.5		0.7	
20	0.66		0.9	1stcrac k
21	0.78	Crack started	1.1	
25	1		1.4	
28	1.4	2nd crack	1.6	
30	1.5		1.9	2nd crack
32	1.6	3rd crack	2.2	
35	1.8		2.5	3rd crack
38	2.1	4th crack	2.9	
40	3.2		3	4th crack
45	4		4	
46	4.26	Failure	4.26	Failure

At the load of 21 kN initial hairline cracks appeared. Later with the increase in loading values the crack propagated further. The next crack was observed at a load of 28 kN. On further increase of the load to 38 kN, the final cracks were observed. The Beams failed completely in flexure. The failure load for both GF1 & GF2 is 46 kN. And the maximum deflection value of 4.26 mm was noted for both of the beams under flexure.

Table-4: Deflection values of con3 & con4

Load in kN	Deflec-tion at L/2 for con 3	Re-marks	Deflec-tion at L/2 for con 4	Re-marks
0	0		0	
5	0.25		0.25	
10	0.5		1	
15	1		1.6	
20	1.3		1.9	
20.5	1.8	1st crack	2	1st crack
25	2	2nd crack	2	
30	2.1		2.1	2nd crack
31	2.17	Failure	2.1	Failure

Under shear failure, when two point static loading is applied on con3 & con4, at each increment of the load; deflection at L/2 is taken with the help of a digital dial gauge upto maximum deflection occurred at the point of failure. At the load of 20.2 kN initial hairline cracks appeared on the beam and is marked as first crack. Later with the increase in loading values the crack propagated further. The next crack was observed at a load of 29 kN. On further increase of the load to 30 kN, the final cracks were observed. The Beams failed completely in flexure at load 31 kN. Table 4 contains the results observed during the experiment of the two glass fibre reinforced polymer retrofitted beams i.e. GF1 & GF2 under shear and the loads at which first crack occurred is also has been tabulated along with the load at failure.

Table-5: Deflection values of GF3 & GF4

Load in kN	Deflec-tion at L/2 for GF 3	Re-marks	Deflec-tion at L/2 for GF 4	Re-marks
0	0		0	
5	0.2		0.2	
15	0.6		0.9	
20	0.7	1st crack	1	
30	1.5	2nd crack	1.8	1st crack
34	1.7		1.9	2nd crack
40.6	1.9	Failure	2	Failure

For the GFRP retrofitted beams (GF3 &GF4) under shear failure, when two point static loading is applied, at the each increment of the load; deflection at L/2 is taken with the help of a digital dial gauge and the thus maximum load and maximum deflection values are obtained. At the load of 20 kN initial hairline cracks appeared. Later with the increase in loading values the crack propagated further. The next crack was observed at a load of 30 kN. On further increase of the load to 34 kN, the final cracks were observed after which the beam continued to rupture point. Both the beams GF3 &

GF4 failed completely in flexure. In table 5, the deflection values of GF3 & GF4 is noted along with the maximum load values at first crack, second crack and even at failure. At almost 41 kN load, both the beams GF3 & GF4 failed showing maximum deflection value of 1.9 mm and 2.0 mm respectively under shear failure.

6 CONCLUSION

The present experimental studies are done on the flexural and shear behavior of reinforced concretebeams strengthened by GFRP sheets. From the test results and calculated strength, and deflection values, the following conclusions are drawn.

- There was a significant enhancement of ultimate flexural strength of GFRP retrofitted beams over the controlled RC beams. They failed at 46 kN. FRP retrofitting techniques successfully lead to the enhancement of the ultimate flexural load carrying capacities of the beams.
- In the flexural load carrying capacity, glass FRP retrofitted beams underwent 54%.
- Under flexural retrofitting, glass fibre reinforced polymer retrofitted reinforced concrete beams displayed deflection of 4.26mm. So, it can be said that the deflection ductility of retrofitted beams is higher than control beams.
- Under flexural studies, first crack load displayed by the controlled beams was 15 kN but glass FRP retrofitted beams displayed the first crack load at 21 kN. Hence, the retrofitted beams, displayed higher value of first crack load over the controlled beams.
- There was a significant enhancement of ultimate shear strength of FRP retrofitted beams over the controlled RC beams. Glass FRP retrofitted beams failed at 40.6 kN.
- Under shear studies, the first crack load displayed by the controlled beams was 20.2 kN, glass FRP retrofitted beams displayed the first crack load at 25 kN.
- Glass FRP retrofitted beams underwent 31.2%, in the shear load.
- Under shear retrofitting,Glass FRP retrofitted beams displayed a maximum deflection of 1.95mm.

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