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Retrofitting of RC Beams Using FRP

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Abstract

Retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion etc. Many of the existing reinforced concrete structures throughout the world are in urgent need of rehabilitation, repair or reconstruction because of deterioration due to various factors like corrosion, lack of detailing, failure of bonding between beam-column joints etc. Fibre Reinforced Polymer (FRP) composite has been accepted in the construction industry as a promising substitute for repairing and in incrementing the strength of RCC structures. This paper presents an experimental study on reinforced concrete beams retrofitted with various types of fibres externally. The objective of this study is to investigate the behaviour of beams after retrofitting using various natural and synthetic fibres including steel fibres, polypropylene fibres, glass fibers, coir fibers, carbon fibres etc.

1. Introduction

Structures deteriorate due to problems associated with reinforced concrete. Natural disasters like earthquakes have repeatedly demonstrated the susceptibility of existing structures to seismic effect and hence implements like retrofitting and rehabilitation of deteriorated structures are important in high seismic regions. Thus retrofitting and strengthening of existing reinforced concrete structures has become one of the most important challenges in Civil engineering. Engineers often face problems associated with retrofitting and strength enhancement of existing structures. Commonly encountered engineering challenges such as increase in service loads, changes in use of the structure, design and/or construction errors, degradation problems, changes in design code regulations, and seismic retrofits are some of the causes that lead to the need for rehabilitation & retrofitting of existing structures. Complete replacement of an existing structure may not be a cost-effective solution and it is likely to become an increased financial burden if upgrading is a viable alternative. In such occasions, repair and rehabilitation are most commonly used solutions.

Reinforcement corrosion and structural deterioration in reinforced concrete (RC) structures are common and prompted many researchers to seek alternative materials and rehabilitation techniques. While many solutions have been investigated over the past decades, there is always a demand to search for use of new technologies and materials to upgrade the deficient structures. In this context, strengthening with Fibre Reinforced Polymers (FRP) composite materials in the form of external reinforcement is of great interest to the Civil engineering community. The conventional strengthening methods of reinforced concrete structures attempt to compensate the lost strength by adding more material around the existing sections. Thus retrofitting and rehabilitation of structures can be concluded to be the best alternative.

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. With better understanding of seismic demand on structures and with our recent experiences with large earthquakes near urban centers, the need of seismic retrofitting is well acknowledged.

The main purpose of the retrofitting (strengthening) is to upgrade the resistance of a damaged building while repairing so that it becomes safer under future earthquake occurrences. This work may involve some of the following actions:

a) Increasing the lateral strength in one or both directions by increasing column and wall areas or the number of walls and columns.

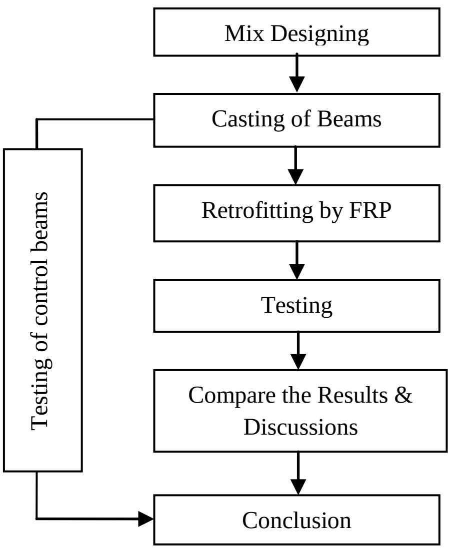
b) Giving unity to the structure, by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them.

c) Eliminating features that are sources of weakness or that produce concentration of stresses in some members.

d) Avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members.

Externally bonded, FRP sheets are currently being studied and applied around the world for the repair and strengthening of structural concrete members. FRP composite materials are of great interest because of their superior properties such as high stiffness and strength as well as ease of installation when compared to other repair materials. Also, the non-corrosive and non-magnetic nature of the materials along with its resistance to chemicals makes FRP an excellent option for external reinforcement. The addition of externally bonded FRP sheets to improve the flexural and shear performance of RC beams has been actively pursued during the recent years. Research reveals that strengthening using FRP provides a substantial increase in post-cracking stiffness and ultimate load carrying capacity of the members subjected to flexure and shear.

2. Methodology



3. Materials

Ordinary Portland Cement of Grade 53 satisfying the requirements of IS 12269-1987 was used for the investigation. The initial setting time of cement was 30 minutes with a specific gravity of 3.15. It was tested for its physical properties as per Indian Standard specifications. The fine aggregate used in this investigation was clear river sand passing through 4.75 mm sieve with a specific gravity of 2.604. The grading zone of aggregate was Zone II as per Indian Standard specifications. Machine crushed broken stone in angular shape was used as coarse aggregate. The maximum size of coarse aggregate was 20 mm and its specific gravity was 2.6. Ordinary clean potable water free from suspended particles and chemical substances was used for both mixing and curing of concrete.

Design concrete mix of 1:1.77:2.89 by weight is used to achieve the strength of 20 N/mm^2. The water cement ratio of 0.5 was used. Three cube specimens were cast and tested (at the age of 28 days) to determine the compressive strength. The average compressive strength of the concrete was 26.87 N/mm^2. Mild steel bars of 8 mm diameter were used as longitudinal reinforcement and 6 mm diameter bars were used for shear reinforcement. The fiber sheets used for this study were Carbon, Glass, Steel, Polypropylene and Coir.

4. Casting of Beams

The moulds were prepared using plywood. The dimensions of all the specimens were identical. The length of beams was 1000mm and the cross sectional dimensions were 150 mm x 150 mm. The design mix ratio was adopted for designing the beam. Thirty under reinforced beams were cast, five as control specimens and twenty five beams for retrofitting. Three bars of 8 mm diameter were provided as tension reinforcement at the soffit of the beam and bars of 6 mm diameter were provided as shear reinforcement.

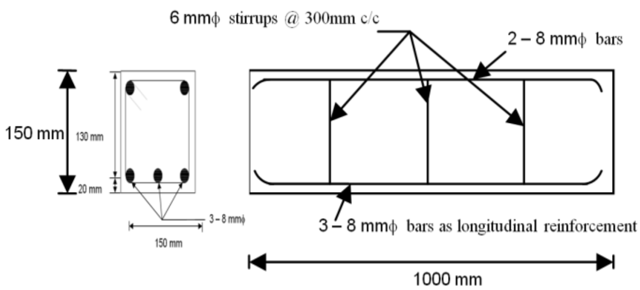


Fig 1 Reinforcement detailing of the beam

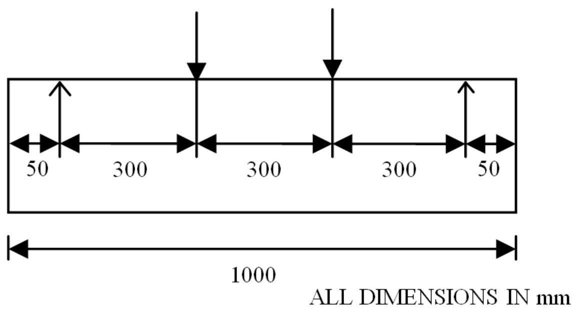


Fig 2 Loading Diagram

5. Retrofitting of Beams

The full wrapping technique around all the four sides of the beam is used as the method of retrofitting. At the time of bonding of fiber, the concrete surface is made rough using a wire brush and then cleaned with water to remove all dirt and debris. The beams are allowed to dry for 24 hours. The fibre sheets are cut according to their size. After that, the epoxy resin primer is mixed in accordance with manufacturer’s instructions. The mixing is carried out in a plastic container (Base: Hardener = 4Kg : 2 Kg). After uniform mixing, the epoxy resin primer is applied to the concrete surface. The beams are allowed to cure for 8 hours. The epoxy matrix is mixed in a plastic container in accordance with the manufacturer’s instructions to produce a uniform mix of base and hardener (Base : Hardener = 3.7 : 1.3). The coating is applied on the beams and fibre sheets for effective bonding of the sheets with the concrete surface. Then the fibre sheet is placed on top of epoxy resin coating and the resin is squeezed through the roving of the fabric. Air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface are eliminated.

During hardening of the epoxy, a pressure is applied on the composite fabric surface in order to extrude the excess epoxy resin and to ensure good contact between the epoxy, the concrete and the fabric. This operation is carried out at room temperature. Concrete beams strengthened with fiber sheets are cured for 3 days at room temperature before testing.

Fig 3 Retrofitting of beams

6.Testing of Beams

The control beams and the retrofitted beams were tested for the flexural strength. The testing procedure for the all the specimens was same. The beams were cured for a period of 28 days. The surface of control beams is cleaned and washed for clear visibility of cracks. The surface of the retrofitted beams is cleaned with cotton. The two-point loading arrangement is used for testing of beams. This has the advantage of a substantial region of nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed. The load is transmitted through a load cell.

Fig 4 Experimental test set up

The test beam was supported on roller bearings acting as supports. The specimen was placed over the two steel rollers bearing leaving 50 mm from the ends of the beam. The remaining 900 mm was divided into three equal parts of 300 mm as shown in the fig 2. Two point loading arrangement was done as shown in the figure. Loading was done by hydraulic jack. Dial gauge was used for recording the deflection of the beams. The deflections of the beams were noted till the appearance of the first crack using dial gauge. The dial gauge was removed after the appearance of the crack and the load was further applied till fracture load. The ultimate load or fracture load was taken as the load at which the needle of load dial on the UTM returned back. The average of the five trials was taken and the load – deflection graph was plotted.

Fig 5 Testing of retrofitted beams

Six sets of beams were tested for their ultimate strengths. It is found that all the beams were failed in flexure. It is observed that the control beam had less load carrying capacity and high deflection values compared to that of the externally strengthened beams using FRP sheets.

Fig 6 Cracks on control specimen

Fig 7 Failure of Retrofitted beam

The deflection of each beam for two point loading is analyzed. The deflections of each type of retrofitted beams are compared with the control beam. Also the load deflection behavior is compared between beams retrofitted with different FRP sheets having the same reinforcement. It is noted that the behavior of the beams when bonded with FRP sheets are better than the control beams. The deflections are lower when bonded externally with FRP sheets. The use of FRP sheet had effect in delaying the growth of crack formation.

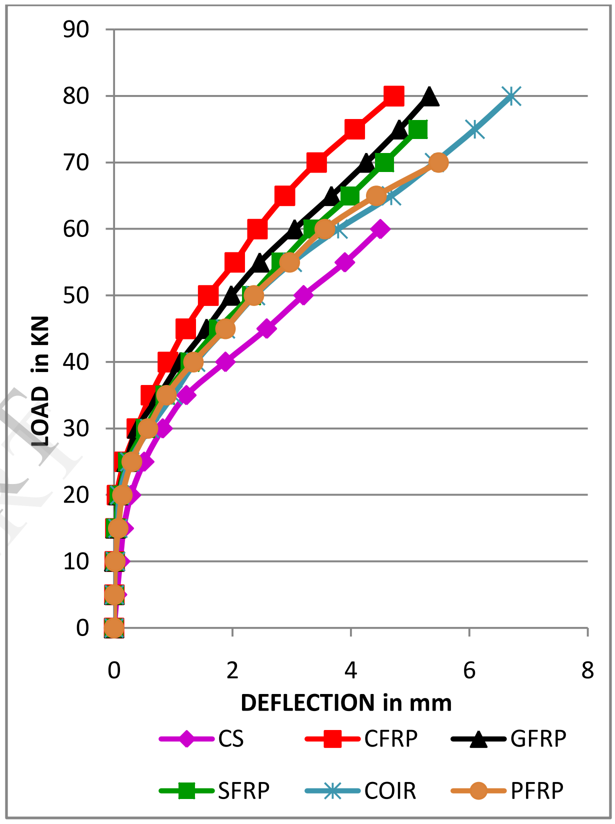


Fig 8 Load Vs Deflection Graph

When all the retrofitted beams are considered it is found that the beams with CFRP sheet wrapping had a better load deflection behavior compared to the other strengthened beams. It is found to be more effective in improving the flexural strength of the beam. At the load of 95 KN the first crack appeared on the beam.

The external strengthening of beams using GFRP also reduced the deflections of the beams to an extent. But it had a less load deflection performance when compared with that of CFRP strengthened beams. The strengthening of beams using steel, coir and polypropylene fibre sheets also enhanced the resistance to deflection under applied load. SFRP retrofitted beams had a better load deflection behavior than the coir fibre and PFRP retrofitted beams.

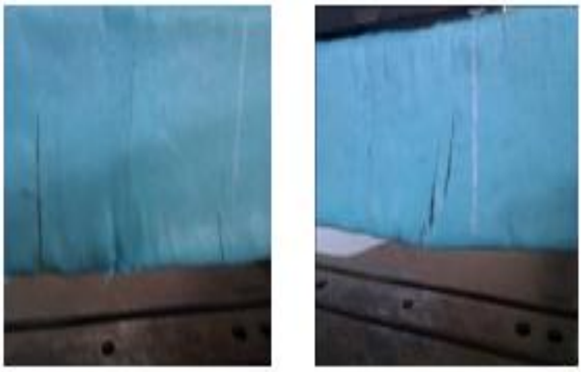


Fig 9 Cracks on retrofitted beams

Since the full wrapping technique is used for retrofitting, initial cracks are not visible. Further with increase in loading, propagation of the cracks took place but it had poor visibility of cracks due to the covering of the FRP sheets. The beams retrofitted with PFRP had the maximum deflections and lower ultimate load carrying capacity.

From the graph it is clear that all the FRP retrofitted beams have better load deflection characteristics than the control specimen.

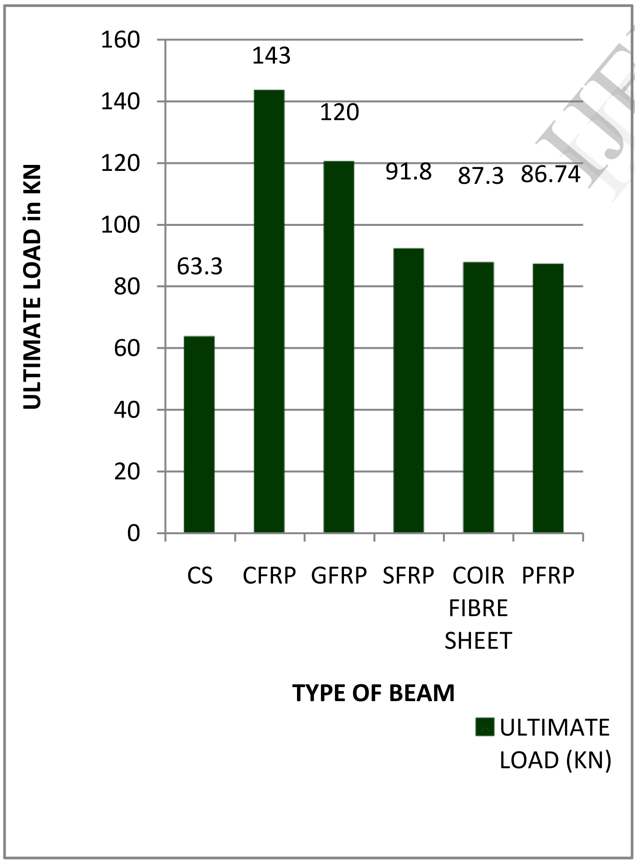


Fig 10 Comparison of ultimate load capacity

Retrofitting of beams enhances the ultimate load capacity of the beams. The control specimen had an ultimate load of 63.3 KN, whereas all the retrofitted beams had an ultimate load greater than 80 KN. The ultimate load capacity of the CFRP retrofitted beams increased by 125% than the control specimen and had the highest ultimate load capacity than all other retrofitted beams.

GFRP retrofitted beams had an ultimate load of 120 KN, which 89.6% greater than that of control specimen. Among the five sets of retrofitted beams, the beams retrofitted with PFRP had the least ultimate load carrying capacity and the value is 86.74 KN, which is 37.03% greater than the ultimate load capacity of control specimen.

Conclusion

In this experimental investigation the flexural behaviour of reinforced concrete beams externally strengthened by carbon, glass, steel, coir and polypropylene sheets are studied. From the test results and calculated strength values, the following conclusions are drawn:

- The deflections of the beams are minimized due to full wrapping technique around all the four sides of the beam.
- The initial cracks in the strengthened beams appear at a higher load compared to the un-strengthened control beam.
- The flexural strength and ultimate load capacity of the beams improved due to external strengthening of beams.
- The strengthening of beams using carbon fibre sheets is found to be more effective in improving the flexural strength and ultimate load capacity of beams.
- The ultimate load capacity of the beams strengthened using carbon fibre sheets is increased by 125% when compared to that of control beam.
- The ultimate load capacity of GFRP, SFRP and coir fibre sheet strengthened beams increased by 89.6%, 45.02% and 37.9% respectively.
- The increase in ultimate load capacity is least for the beams retrofitted with Polypropylene fibre sheets and is increased by only 37.03%.
- Even though the beams retrofitted with CFRP sheets have the maximum ultimate load capacity, the cost of the material is high.
- Retrofitting using GFRP sheets prove to be economical since its cost is only Rs. 300/m^2 and showed 89.6% increase in ultimate load capacity.
- Retrofitting using PFRP sheets is least recommended since its cost is high and increase in ultimate load capacity is less.
- The bonding between the FRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to FRP sheets.

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