REHABILITATION OF RCC FLEXURAL MEMBERS USING FRP AND FERROCEMENT OVERLAYS

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ABSTRACT. An experimental programme was carried out to conduct a comparative study on the rehabilitation potential of glass fibre reinforced polymer (GFRP), carbon fibre reinforced polymer (CFRP) and ferrocement overlays on RCC beams having different levels of distress. The levels of distresses selected in this study are 70%, 80% and 90% of the ultimate capacity of the beam. The flexural behaviour of the damaged beams rehabilitated with these different material overlays was compared in terms of strength, energy absorption and ductility. Ferrocement showed a consistent performance irrespective of the level of distress. However, both the FRPs showed a gradual reduction in performance as the distress level increases, in which the performance of GFRP decreased at a faster rate than CFRP. It was also noted that FRP and ferrocement rehabilitation are equally effective at very high levels of distress. A comparison of the shear behaviour was also done on shear deficient beams rehabilitated with the above three materials, selecting the distress level as 70% of the ultimate capacity of the beam. FRP appears as more effective when compared to ferrocement in shear strengthening.

Keywords: Rehabilitation, Carbon Fibre Reinforced Polymer, Glass Fibre Reinforced Polymer, Ferrocement, Material overlay.

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INTRODUCTION

Deterioration of reinforced cement concrete (RCC) structures generally occurs due to poor workmanship, natural calamities, ageing etc. Since demolition and recreation of such assets are not advisable considering our limited national resources, rehabilitation of structures is one of the solutions. Various rehabilitation techniques are used in the field, and out of all, providing material overlays on the concrete substrate leads to a better performance than many of the other techniques [1]. Overlays using different materials such as fibre reinforced polymer (FRP), ferrocement etc, are bonded to the surfaces of the distressed structural members to regain/increase its strength [2]. Most commonly used FRPs are glass fibre reinforced polymer (GFRP) and carbon fibre reinforced polymer (CFRP).

Ferrocement overlays are one of the commonly used rehabilitating materials these days due to the easy availability of materials, economy, durability, and their property of being cast to any shape without the need of significant formwork. FRP is comparatively a recent technology which used as an external reinforcement to deal with the strength requirements. With the introduction of this new advanced composite material, which is having high strength, durability and light weight, concrete members can now be easily and effectively strengthened. Another advantage of using externally bonded FRP composites is the ease of its use at the site without changing the structural member dimensions much.

Since FRP is a new technology, the availability of material and skilled labour are relatively low, and also incur high cost. Ferrocement is free of these disadvantages and has high tensile strength, durability and less thickness (<40mm). Review of the available literature indicates that numerous studies were conducted in the past to understand the rehabilitation capacity of FRP on various structures [3-8]. Similarly, a lot of studies were done on ferrocement rehabilitation [9, 10]. However, none of the studies were found in comparing the rehabilitation potential of these materials on the structural elements in terms of strength-stiffness/weight characteristics, ductility etc. When making a direct comparison of materials, the fibre and resin in FRP perform the same relative functions as the steel and mortar in ferrocement. It is important to find a rehabilitation strategy having optimum cost and efficiency. Hence, an attempt is made here to conduct a comparative study on the effect of rehabilitation of glass fibre reinforced polymer, carbon fibre reinforced polymer and ferrocement on the flexural and shear behaviour of RCC beams experimentally.

EXPERIMENTAL PROGRAMME

Flexural Strengthening of Beams

The experimental study consists of, (i) casting and curing of 12 numbers of RCC beams having size 100mm×150mm×1200mm, (ii) subject them to distress at various levels, and subsequently (iii) rehabilitate them with three different materials. The variables were the levels of distress and the type of materials used for rehabilitation. The distress levels selected were 70%, 80% and 90% of the ultimate capacity of the beam. The materials selected for rehabilitation were GFRP, CFRP and ferrocement.

The materials used for casting the beam specimens were Portland pozzolana cement of grade 53, Manufactured-sand (which pass through 4.75mm IS sieve; conforming to grading zone II) as fine aggregate, crushed granite stone of maximum size 12.5mm as coarse aggregate, and potable water. The mix proportion for M25 grade concrete was obtained using IS 10262:2009, and is 1:1.55:2.78 by weight, with a water-cement ratio of 0.5. The longitudinal reinforcement provided was two numbers of 10mm diameter rods at the bottom and two numbers of 8mm diameter rods at the top. The stirrups used were 8mm φ @ 220mm c/c.

The beams were tested as simply supported beams under four point bending test in a universal testing machine (UTM) of 3000kN capacity. The span of the beam kept as 1100mm. The loading points were kept at 1/3rd of the span. A dial gauge was used to measure the midspan deflection. Two linear variable differential transformers (LVDT) were placed at the mid-span portions to measure the deformations in the tensile and compression region. The schematic and actual test set up are shown in Figures 1 and 2 respectively. The load was applied at an interval of 2kN, and deflections were noted. Crack patterns were noted after the first crack load.

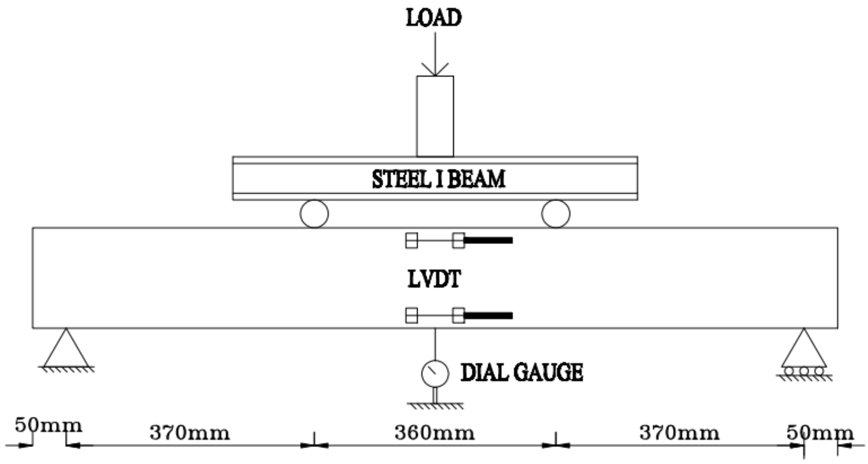


Figure 1 Schematic diagram of test setup for beam

Figure 2 Test setup showing beam specimen with LVDTs and dial gauge

Out of the 12 specimens, 3 were tested to failure to find the ultimate load and kept as control beams (CB). Other 3 beams were sorted as a group, and each group of beams were induced distress by preloading up to 70%, 80% and 90% of the ultimate load. Groups of 3 beams with different distress levels each were rehabilitated with GFRP, CFRP and ferrocement. For flexural strengthening, the laminate overlay has to be given at the beam soffit only [11], and it is better to give the overlay at the full length of the beam [12]. The method adopted here is shown in Figure 3 schematically.

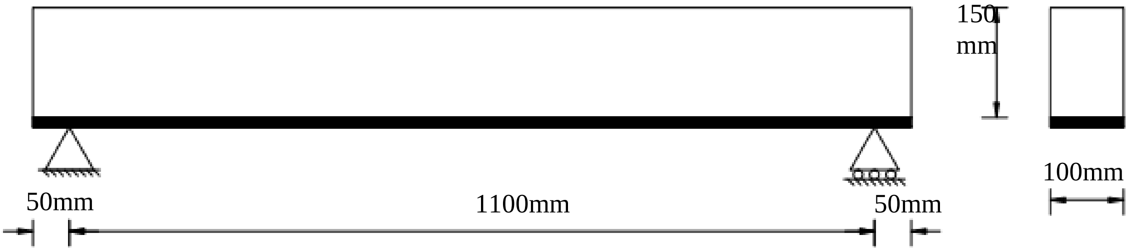


Figure 3 Beam with laminate at soffit to attain flexural strength

Shear Strengthening of Beams

For shear strengthening, RCC beams were designed as shear deficient. Four beams, having size 100mm×150mm×1200mm, were cast and cured for 28 days. One beam was tested to failure and found the ultimate load and kept as control beam (CB-S). Other three beams were subjected to distress up to 70% of the ultimate load, and rehabilitated with the above mentioned three materials. The variable was the type of materials used for rehabilitation. For shear strengthening of beams, wrapping of rehabilitating material can be done either on three sides of the beam as U-wrap or on two sides [13]. Here, the U-wrapping method was adopted which is shown in Figure 4.

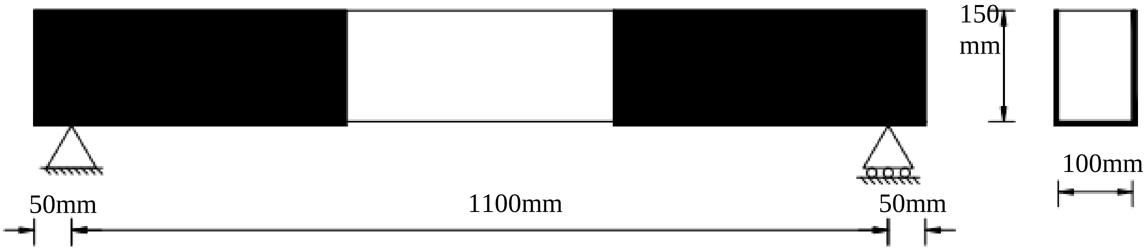
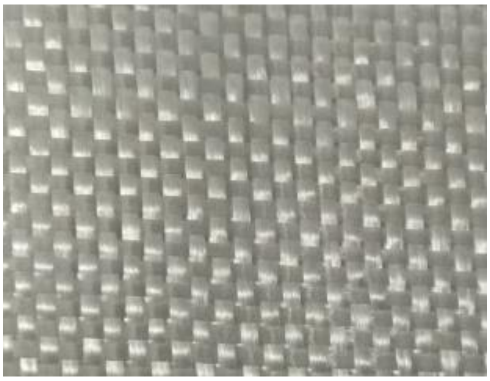


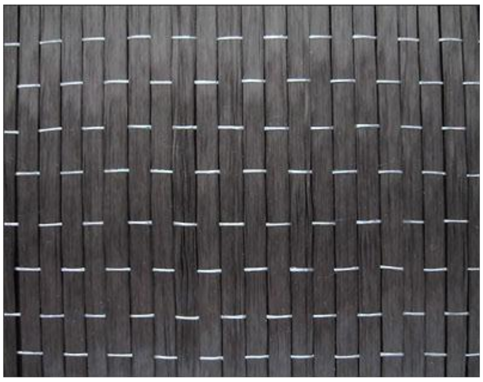
Figure 4 U-wrapping by the rehabilitation material to attain shear strength

FRP Rehabilitation Procedure

FRP rehabilitation was done thorough wet lay-up procedure. Laminates of GFRP were prepared by impregnating two layers of bi-directional plain woven glass fibre mats (Figure 5a) in a matrix. Similarly, for CFRP, two layers of unidirectional carbon fibre woven mats (Figure 5b) were used with the same matrix material. The number of layers of fibre mat was selected as two because of the fact that it gives optimum performance in terms of strength and ductility [14]. The matrix material used was a two-part system of epoxy resin (CERA EPS). Its base and hardener combined in a mix ratio of 5:3 by weight. For preparing the FRP composite, the fibre and the resin were taken in a ratio 1:1 by weight. Before the application of the resin, an inorganic epoxy primer was also applied to the surface for better penetration and adhesion of matrix. The primer used was CERA EP18, which was also a two-part system of base and hardener, mixed in a proportion of 2:1 by weight. These resins were easy to use and had excellent bonding properties with the concrete surface.



(a) Woven glass fibre mat



(b) Woven carbon fibre mat

Figure 5 Fibre mats used for FRP

The procedure for wet lay-up includes the following steps:

- Initially, the distressed surface of the beam was prepared using a sand paper to obtain a smooth concrete characteristic for proper bonding of FRP. Air blower was used to remove the sand particles sticking on the surface.
- Mixed the base and hardener of the primer (EP18) in a proportion 2:1 by weight and applied uniformly over the prepared surface, to fill its small pores and cracks. Cure the specimen at ambient temperature for 24 hours which results in an even and smooth surface for the proper bonding of the composite.
- Cut the fibre mat into strips of size 100mm×1000mm, which was the beam soffit dimension, from the whole mat for attaching to the soffit of the distressed beam in flexural strengthening. For shear strengthening, FRP wraps were done on the shear span area as a U-wrap, cut appropriate size of the mat to cover that portion. Each distressed beam was rehabilitated with two strips in both strengthening methods.
- Applied a thin layer of the matrix over the primed surface by using a paint brush. The fibre mat strips were put in the prepared resin and get it saturated, and immediately placed over the concrete surface. Pressed it with the paint roller to bond it firmly to the surface. Placed both layers one after the other leaving a small time gap between placing for partially curing the first layer. Removed the excess resin using a flat scraping blade.
- Cured the strengthened specimen at ambient temperature for few days so that it was completely hardened before testing.

Ferrocement Rehabilitation Procedure

Ferrocement is a thin composite laminate of cement-sand mortar reinforced with small diameter steel wire meshes. Ferrocement and beam specimens were made of the same cement and sand. Two layers of a hexagonal chicken mesh of 24 gauge (0.56 mm diameter) wire were used as reinforcement in the ferrocement.

Initially, the surfaces, to be covered by the laminates, of the distressed beams were roughened by using a hacker. A thick cement paste was applied as a bonding agent before the application of mortar in order to get a good bond. Then two layers of wire meshes, which cut to the required sizes, were placed and fastened to the beam surface using binding wires. Cement-sand mortar, having a proportion 1:3 by weight, was made with a water-cement ratio of 0.4. Then this mortar was placed over the beam surface to make the ferrocement layer. The thickness of the ferrocement layer was kept as 20mm. The rehabilitated specimens were water cured for 28 days before further testing.

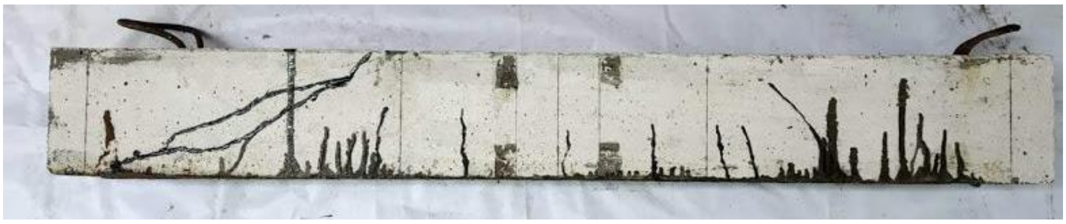
TEST RESULTS AND DISCUSSIONS

Behaviour in Flexural Strengthening

The completely cured strengthened specimens were again tested to failure to find the ultimate load carrying capacity, by the four point bending tests in UTM. The cracking patterns were noted for the beams during the tests before and after rehabilitation. The crack patterns on the CFRP rehabilitated beams are shown in Figure 6 (a) to (c) as a typical example.

(a) CFRP – 70% DISTRESS

(b) CFRP – 80% DISTRESS



(c) CFRP – 90% DISTRESS

Figure 6 Crack patterns in beam specimens tested after rehabilitation with CFRP
(Distress levels before rehabilitation are noted)

The cracking patterns showed that after rehabilitation, most of the cracks happened at the same location as the previously happened minor cracks. It may due to the fact that, since the strengthening was given only to the soffit of the beams without repairing the minor cracks, the stress in steel was more at the previously cracked region which tends to widen the cracks during reloading. Failure of the FRP rehabilitated beams was mainly due to FRP rupture, diagonal shear crack at the laminate end and delamination/debonding initiated by shear cracks. FRP rupture failure appeared in 70% distressed beams only. Other beams were failed due to shear cracks at laminate ends.

The load versus midspan deflection for the beams with different damage levels rehabilitated with GFRP, CFRP and ferrocement are shown in Figures 7 to 9. Figure 10 represents the ultimate load reached by the rehabilitated beams.

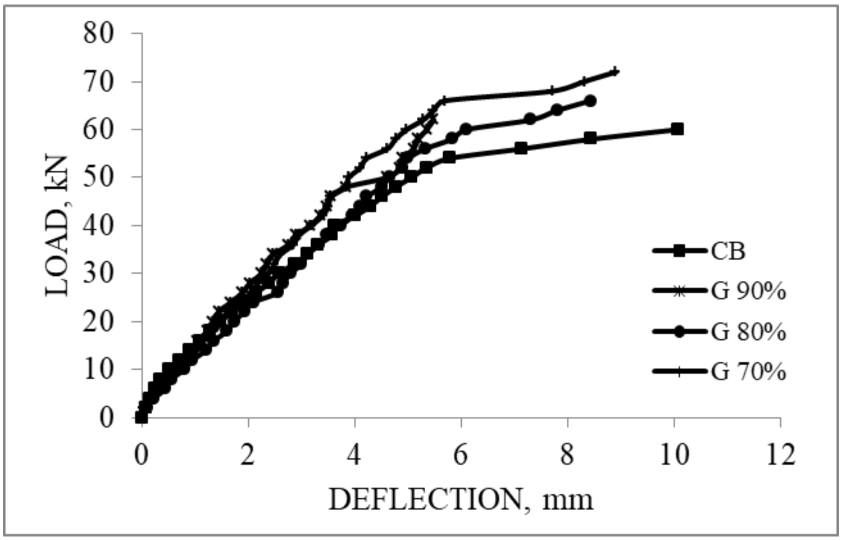


Figure 7 Load versus midspan deflection for beams rehabilitated with GFRP

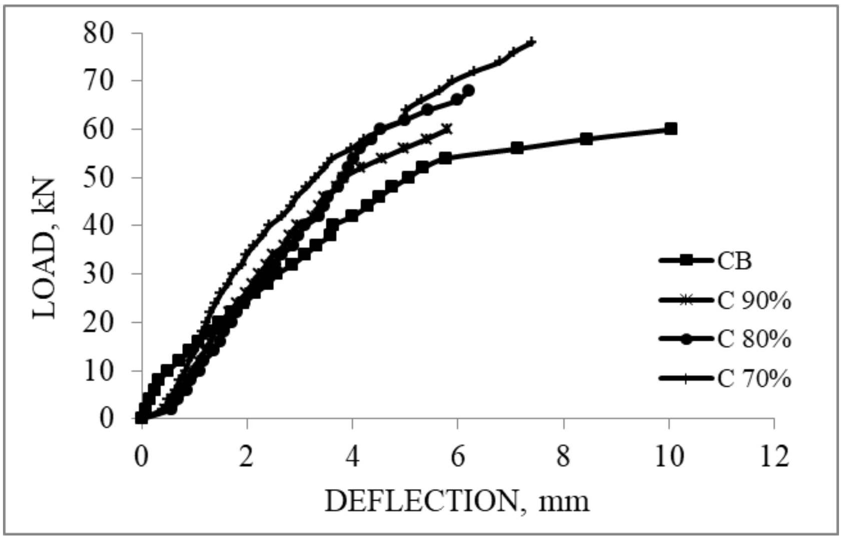


Figure 8 Load versus midspan deflection for beams rehabilitated with CFRP

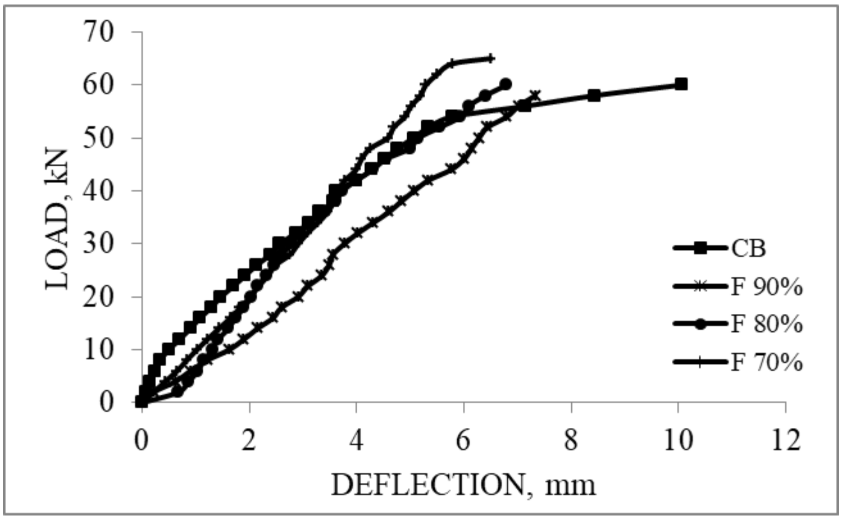


Figure 9 Load versus midspan deflection for beams rehabilitated with ferrocement

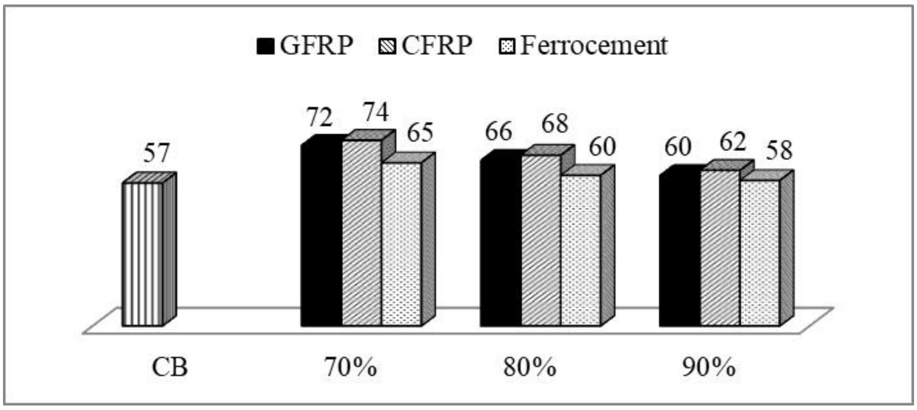


Figure 10 Ultimate loads (kN) of unstrengthened control beam and beams having various levels of distress after rehabilitation

Ferrocement strengthened beam with 70% distress failed in flexure. The flexure cracks at the pure bending region widened through the ferrocement layer and extended through the original beam. However, the other distressed beams were ultimately failed in shear even though they showed a large number of flexure cracks. This shows that if the beams suffered a higher distress level, it may prone to have a brittle failure.

The load-deflection results showed that the ultimate load capacity has increased by strengthening with three of the materials, and a higher percentage of increase appeared when the distress level was lower. The FRP strengthening showed slightly better results when compared to ferrocement strengthening. Figure 11 depicts the energy absorption capacities of the rehabilitated beams, which were determined by calculating the area under the load-deflection curves. This can be considered as a measure of ductility showed by the beams after rehabilitation. The ductility of the rehabilitated beams appeared as reduced as the member loaded in the virgin state, mainly due to the fact that, the rehabilitated members suffered premature shear failures initiated by the already happened cracks during the preloading stage to induce distress. When comparing the materials, ferrocement rehabilitation showed consistent energy absorption, while the FRPs showed a gradual decrease as the distress level increased, in which GFRP showed a fast reduction. Ultimate deflection also showed a reduction in values as the levels of distress increased. It is because at higher distress level, the extent of cracking is more, hence shows a lower ultimate deflection.

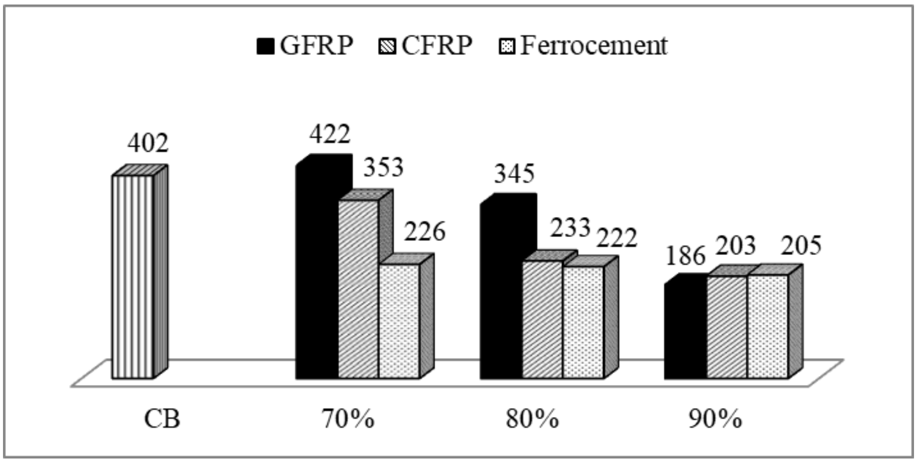
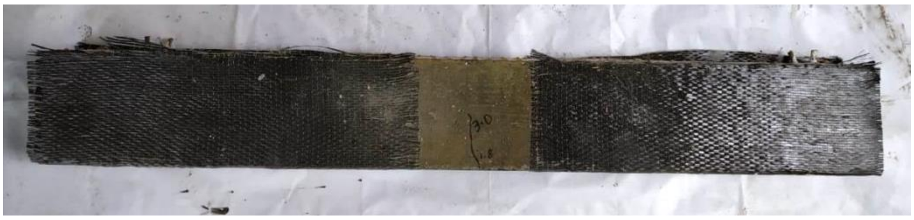


Figure 11 Energy absorption capacities (kN-mm) of unstrengthened control beam and beams having various levels of distress after rehabilitation

Behaviour in Shear Strengthening

Figure 12 shows the 70% distressed beams, which were shear deficient, tested after rehabilitation. Debonding of the laminates occurred in the FRPs, and finally failed due to shear cracks. Ferrocement failed with large shear cracks.

(a) GFRP rehabilitated beam (Top view)



(b) CFRP rehabilitated beam (Side view)

(c) Ferrocement rehabilitated beam (Side view)

Figure 12 Crack patterns on the shear strengthened beam specimens tested after rehabilitation

Figure 13 shows the load-deflection relationship of shear deficient beams which subjected to a distress level of 70% of ultimate load, rehabilitated using GFRP, CFRP and ferrocement overlays as a continuous U-wrap in the shear span region. As expected, no beams showed any ductility, since all were prone to shear failure which is a brittle failure. Both the FRP strengthening showed a similar level of improvement in behaviour, as the percentage increase in ultimate load was 32% for GFRP and 38% for CFRP strengthened beams. However, the strengthening with ferrocement showed only a 16% increase, which means ferrocement seems less effective when compared to FRP. The energy absorption capacities were 193, 189, 99 and 157 kN-mm for GFRP, CFRP, ferrocement and the unstrengthened control beam respectively, which shows that FRP performs well when compared to ferrocement in ductility point of view.

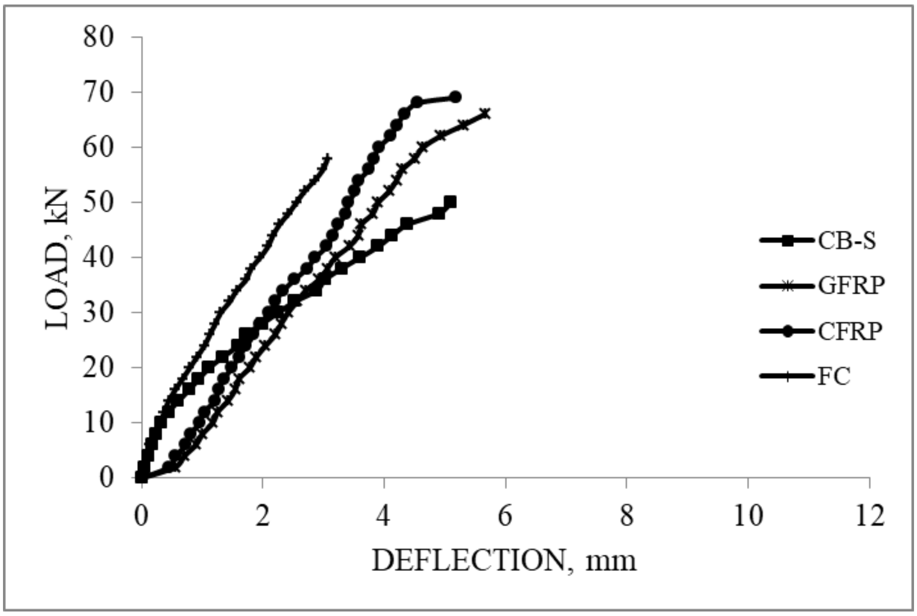


Figure 13 Load versus midspan deflection for shear strengthened beams

CONCLUDING REMARKS

- In flexural strengthening, each 10% increase in the distress level of RCC beams over and above the service load causes a reduction of 50% each in the percentage increase in efficiency level of rehabilitation using FRP as well as ferrocement.
- Ferrocement shows a consistent performance irrespective of the level of distress in the flexural strengthening of beams. But both FRPs show a gradual reduction in performance as the distress level increase, in which the performance of GFRP decreases at a faster rate than CFRP.
- FRP and ferrocement rehabilitation are equally effective at the very high level of distress, in the flexural strengthening of beams. At lower distress levels, FRP is more effective.
- In the shear strengthening of beams, FRP appears as more effective when compared to ferrocement.

REFERENCES

1. AL-SALLOUM Y A AND ALMUSALLAM T H, Rehabilitation of the infrastructure using composite materials: Overview and Applications. Journal of King Saud University, Eng. Sci (2), 2002, A.H. 1423/2002.
2. BASUNBUL I A, GUBATI A A, AL-SULAIMANI G J AND BALUCH M H, Repaired Reinforced Concrete Beams. ACI Materials Journal, Vol.87, No.4, July-August 1990, pp 348-354.
3. GRACE N F, ABDEL-SAYED G, SOLIMAN A K AND SALEH K R, Strengthening reinforced concrete beams using fibre-reinforced polymer (FRP) laminates. ACI Structural Journal, Vol. 96, No. 5, September-October 1999, pp 865-874.
4. SHEIKH S A, DEROSE D AND MARDHUKI J, Retrofitting of concrete structures for shear and flexure with fibre-reinforced polymers. ACI Structural Journal, Vol.99, No.4, 2002, pp 451-459.
5. SARKER P, BEGUM M AND NASRIN S, Fibre reinforced polymers for structural retrofitting: A review. Journal of Civil Engineering (IEB), Vol.39, Issue 1, 2011, pp 49-57.
6. ARAVIND N, SAMANTA A K, ROY D K S AND THANIKAL J V, Retrofitting of reinforced concrete beams using fibre reinforced polymer (FRP) composites – A review. Journal of Urban and Environmental Engineering, Vol.7, No.1, 2013, pp 164-175.
7. BAGGIO D, SOUDKI K AND NOEL M, Strengthening of shear critical RC beams with various FRP systems. Construction and Building Materials, Vol.66, 2014, pp 634–644.
8. SPADEA G, BENCARDINO F, SORRENTI F AND SWAMY R N, Structural effectiveness of FRP materials in strengthening RC beams. Engineering Structures, Vol.99, 2015, pp 631–641.
9. AL-KUBAISY M A AND JUMAAT Z, Ferrocement laminate strengthens RC beams. Concrete International, Vol. 22, No. 10, Oct 2000, pp 37-43.
10. KAISH A B M A, JAMIL M, RAMAN S N, ZAIN M F M AND NAHAR L, Ferrocement composites for strengthening of concrete columns: A review. Construction and Building Materials, Vol.160, 2018, pp 326–340.
11. AMERICAN CONCRETE INSTITUTE, ACI 440.2R - 2008: Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures. Farmington Hills, MI, USA, 2008, 80p.
12. VENKATESWARLU C AND NATARAJAN C, Performance assessment of RC beams with CFRP and GFRP Sheets. Advances in Structural Engineering (III), Springer, 2015, pp 1987-2000.
13. BELARBI A AND ACUN B, FRP Systems in shear strengthening of reinforced concrete structures. Procedia Engineering, Vol.57, 2013, pp 2-8.
14. NAYAK A N, KUMARI A, SWAIN R B, Strengthening of RC beams using externally bonded fibre reinforced polymer composites. Structures, Vol.14, March 2018, pp 137–152.