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Balamuralikrishnan R
Asst. Professor, Department of Built and Natural Environment
Sultanate of Oman

Thirugnanasambandam S
Associate Professor
Department of Civil and Structural Engineering
Annamalai University
Tamilnadu, India

Correspondence
Balamuralikrishnan R
Asst. Professor, Department of Built and Natural Environment
Sultanate of Oman

Repair and rehabilitation of structures

Balamuralikrishnan R and Thirugnanasambandam S

Abstract

Repair and rehabilitation mean restoring the damaged structures to make them fit for serviceability condition. Rehabilitation of structurally deteriorated RC structures is one of the major tasks for the construction industries worldwide. Use of properly selected repair materials can solve this tough task. Durable repair can be obtained only by matching the properties of the base concrete with those of the repair material intended for use. The selection of repair materials is based on their properties, dimensional stability, modulus of elasticity, permeability, chemical resistance, adhesion with parent concrete, coefficient of thermal expansion, easy to use. This study mainly focusing on different repair technology with different materials and testing's.

Keywords: Durable repair, FRP, Polymer modified mortar, CFRP, Flexural strength

1. Introduction

1.1 Repair Technology, Material and Testing's

a. Patch Repairing

Once the corrosion process is initiated, repair is an important factor in extending the life span of structures. Patch repair consists of removal of the damaged concrete, cleaning of rust, and restitution of the original geometry with a patch material. Patch repairing is one of the common concrete repair technologies, especially when a localized corrosion occurs. The three types of patch materials available in the market are plain cement mortar, epoxy - resin mortar and cement - polymer mortar. The plain cement mortar repairing is not suitable for structural repair works because of their dimensional instability, weak adhesion, and durability. The resin mortars including acrylics, polyurethanes, polyesters, and epoxies have superior properties as repair mortars. But the use of these mortars is restricted because of their cost and incompatibility with most of the substrate concretes. The cement-polymer mortar has better adhesive properties, crack resistibility and compatibility. Styrene butadiene rubber (SBR) latex is being effectively used to modify cement mortar to be used as a repair system in practical application [1]. Some additional reinforcements are added partially or totally to restore the original area of bars.

b. Flexural Strengthening

The flexural capacity of member need to be enhanced either to withstand the additional increments of load beyond those for which the structures were originally designed, or to compensate the loss of capacity due to corrosion of the embedded steel reinforcement. Historically, RC members have been repaired by post - tensioning or jacking with new concrete in conjunction with a surface adhesive. Since mid - 1960s epoxy - bonded steel plates are being used to retrofit the flexural members. But corrosion may occur along the adhesive interface and affects the bond at the steel plate – concrete interface.

In the 1980s, fibre reinforced polymers (FRP) were developed and used in the form of thin laminates. They are constructed of high performance fibres such as carbon, aramid or glass, which are placed in a resin matrix. Selecting these fibres for particular application can alter the mechanical and durability properties.

The FRP laminates are being widely used for flexural strengthening because of their excellent properties including the following:

(i) High strength – to – weight ratio
(ii) Low weight (making them much easier to handle on site)
(iii) Immunity to corrosion
(iv) Excellent mechanical strength and stiffness
(v) Unlimited availability in length
(vi) Easy fabrication
(vii) Possibility of bonding to non - flat surfaces
(viii) Durability in adverse environments
(ix) High fatigue strength

Moreover, bonding of FRP plating does not need expensive scaffolding. Many researchers have done experiments on RC beams strengthened with externally bonded FRP laminates to the tension face to exhibit ultimate flexural strength greater than their original/damaged beams. They indicated that the ductility of RC beams using externally bonded carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer (GFRP) laminates gets reduced and the extent of reduction in ductility is dependent upon the characteristics of original beams [2, 4].

c. Repair of Beams Using Polymer Modified Concrete

The introduction of a polymer admixture results in modification of concrete structure, as a double matrix formation. One matrix is of concrete hydration product, while the other is polymerized skeleton made by means of the used polymer admixture. The making of the double matrix modifies ordinary concrete properties. The most important changes are the increase of tensile strength, ductility, bond strength, and improvement of durability of RC structures. Due to the corrosion damage, the cover concrete was weakened and there was a horizontal crack along the tension reinforcement.

Styrene Butadiene Rubber (SBR) latex was added to new cover concrete with a dosage of 10 litres per 50 kg of cement. The SBR has a specific gravity of 1.01. The compressive strength of polymer modified concrete was 56.24 N/mm^2 which was slightly higher than the original concrete compressive strength. The concrete was placed in the mould when the bond coat was a tacky state. The hardened concrete surface was covered with gunny bag and kept in wet condition for 24 hours and allowed to seven days dry curing.

From the test results, it is seen that the beams repaired with polymer modified concrete exhibit an increase of 20% and 15% of strength with respect to 10% and 15% rebar corrosion damaged beams respectively at the initial cracking stage of loading. This increase in load carrying capacity is mainly due to increase in tensile strength of polymer-modified concrete. In the serviceability stage, these 10% and 15% corrosion damaged and repaired beams exhibit an increase of 15% and 19% respectively in load carrying capacity. In the yield stage, 10% corrosion damaged and repaired beam exhibit an increase of 11% of strength with respect to that of damaged beam. The 15% corrosion damaged and repaired beam show an increase of 8% of strength with that of damaged beam. In the ultimate stage, these repaired beams exhibit an increase of 15% and 19% respectively in load carrying capacity with respect to the corresponding degrees of corrosion-damaged beams. From the experimental results, it is indicated that the beams repaired with polymer modified concrete has shown an improvement in load carrying capacity when compared with damaged beams. But the beams repaired with polymer modified concrete exhibited a decreased strength at all the stages of loading when compared to the reference beams. The corrosion damaged (10% and 15% degree of corrosion) and repaired beams exhibited a decrease of 10% and 25% respectively in load carrying capacity at ultimate stage when compared to the reference beams. The corrosion damaged beam and rehabilitation process are shown in Figs. 1 to 7.

Fig 1: Corrosion damaged beam

Fig 2: Removal of cover concrete

Fig 3: Removal of dust and rust

Fig 4: Anti-corrosive coating

Fig 5: Application of bond coat

Fig 6: Application of polymer modified concrete

Fig 7: Curing of repaired beam

d. Rehabilitation of Beams by GFRP Laminates

This is mainly due to reduction in area of tensile reinforcements, which is in turn unable to enhance the strength of beams by mere removal and addition of cover concrete in tension zone. Hence it was decided to reinforce the corrosion-damaged beams by means of external plate bonding with 3 mm thickness GFRP laminates.

Prior to bonding of the laminates, the tension face of beams and bonding face of GFRP laminates were sandblasted to remove the surface laitance and to expose the rough surface. Then the surface was cleaned with a high-pressure air jet. After surface preparation, the longitudinal cracks caused by corrosion were sealed by using a low viscosity epoxy resin grouting namely corogrout EPLV. This epoxy resin has filled the crack with its own setting and the setting time taken was 45 minutes. Then the adhesive components Corocretin IHL – 18 were mixed thoroughly and applied to the surfaces using trowel. The ultimate tensile strength and the elastic modulus of adhesive were 34.80 N/mm^2 and 1500 N/mm^2. The thickness of adhesive was maintained at 2 mm. The GFRP laminates of 3 mm thickness were used for externally reinforcing the beams. The beams with severe corrosion required additional steel reinforcements to restore its original area of tensile reinforcements.

From the test results, it is seen that 10% corrosion damaged and GFRP laminated beam exhibits an increase of 50%, 25.5%, 38.9%, and 25.5% in strength with respect to reference beams at the initial cracking stage, serviceability stage, yield stage, and ultimate stage respectively. This beam exhibits an increase of 60% in strength when compared to the corresponding corrosion damaged beams. This increase in load carrying capacity is mainly due to increase in tensile cracking strength of concrete due to the bonding action of GFRP laminates and the corresponding increase in the moment of inertia of the section. It is clear that the bonding of GFRP laminates has beneficial effect even from the initial cracking stage itself.

The 15% corrosion damaged and GFRP laminated beam exhibits almost similar load carrying capacities at all the stages of loading when compared to the reference beam. The beam exhibits an increase of 62% load carrying capacity when compared to the corresponding corrosion damaged beams. The 20% corrosion damaged and GFRP laminated beam exhibits a decrease of 5%, 33%, 34%, and 33% in strength with respect to reference beams at the initial cracking stage, serviceability stage, yield stage, and ultimate stage respectively. This beam exhibits an increase of 69% in strength when compared to the corresponding corrosion damaged beams. This is mainly due to inadequate tensile strength of the section because of large reduction in tensile steel reinforcement as well as diseased concrete cover. Hence, 30%, 40%, and 50% corrosion damaged beams were repaired with removal of cover concrete, moulding with new polymer modified concrete, added tensile reinforcement and bonded with GFRP laminates of same 3 mm thickness.

The severely corroded beams with 30%, 40%, and 50% degree of corrosion and repaired with GFRP laminates added with tensile reinforcement exhibit an increase of 2.67 to 9 times the load carrying capacities when compared to their corresponding corrosion damaged beams. These 30% and 40% corrosion damaged and repaired beams exhibit an equal amount in load carrying capacity, and 50% corrosion damaged and repaired beam exhibits a decrease of 14% when compared to the reference beams.

From the experimental results, it was observed that the GFRP laminated beams have shown an improvement in the load carrying capacity when compared to the damaged beams. During the testing, it was observed that at the ultimate stage, flexural mode of failure occurred in the beams 10%, 15%, and 20% degree of corrosion and repaired with GFRP laminates and bond failure occurred with longitudinal cracks along tension reinforcement in severely corroded beams with 30%, 40%, and 50% degree of corrosion and repaired with GFRP laminates. The sand blasting and bonding of CRRP laminates are shown in Figs. 8 to 16.

Fig 8: Sand blasting on tension face of damaged beams

Fig 9: Roughening of GFRP laminates

Fig 10: Cleaning of dust

Fig 11: Sealing of cracks in web

Fig 12: Sealing of cracks at soffit

Fig 13: Mixing of adhesive

Fig 14: Application of adhesive

Fig 15: Fixing of GFRP laminates

Fig 16: Application of weight

e. Rehabilitation of Beams By CFRP Laminates

Strengthening with externally bonded CFRP fabric has shown to be applicable to many kinds of structures. Currently, this method has been applied to strengthen such structures as column, beams, walls, slabs, etc. The use of external CFRP reinforcement may be classified as flexural strengthening, improving the ductility of compression members, and shear strengthening. It is well known that reinforced concrete beams strengthened with externally bonded fibre reinforced polymer (FRP) or CFRP to the tension face can exhibit ultimate flexural strength greater than their original flexural strength. However, these FRP and CFRP strengthened beams could lost some of their ductility due to the brittleness of FRP and CFRP plates strengthened reinforced concrete beams with Glass Fibre-Reinforced Polymers (GFRP) or FRP plates [5, 6]. They concluded that the flexural strength of reinforced concrete beams could be significantly increased by externally bonded GFRP of FRP plated to their tension surface. However, they indicted in their experimental research that the ductility of reinforced concrete beams using externally bonded GFRP or FRP was reduced, and the extent of reduction in ductility was dependent upon the original beams. A relatively new technique involves replacement of the steel plates by fibre-reinforced polymers (FRP) in the form of fabric or wraps [7-11]. FRP offers the engineer an outstanding combination of properties such as low weight, easier site handling, immunity from corrosion, excellent mechanical strength and stiffness, and the ability of formation in long lengths, thus eliminating the need for lap joints. Further, there has been a rapid progress in concrete technology that has resulted in the evolution of concretes having specified characteristics. The present study evaluates the performance of RCC beams with bonded CFRP fabric in single layer and two layers at the soffit of the beam under static and cyclic loading. CFRP fabric has shown great promise to upgrade structural systems. An emphasis has been given to the strength and deformation properties of CFRP fabric strengthened RC beams. The theoretical moment curvature relationship and the load - displacement response of the strengthened beams and control beams were predicted by using FEA software ANSYS. Comparison is made between the numerical (ANSYS) and the experimental results and suitable conclusions are drawn based on the results obtained from laboratory experiments and numerical analysis.

f. Experimental Investigation

The test program consisted of casting and testing of ten beams, of which two were control beams, all of size 150×250×3200 mm length and designed as the beams of under reinforced section (as per IS 456-2000), reinforced with 2-Y12 at bottom, 2–Y10 at top using 6mm dia stirrups @ 150 mm c/c (Fig. 17). The beams were cast using M 20 Ordinary Portland cement, natural river sand and the crushed granite of maximum size 20 mm were used. High yield strength deformed (HYSD) bars of 12 and 10 mm diameter with mean strength of 512 N/mm^2 were used as longitudinal reinforcement and 6 mm diameter mild steel bars were used for internal links. The elastic modulus of the concrete is $2.4\text{x}10^4$ N/mm^2. After 28-day curing, companion cubes (150 mm) and cylinders (150 mm diameter x 300 mm height) cast along with the beams were and tested in compression to determine the 28-day compressive strength and modulus of elasticity. In two series of strengthened beams, first series having four beams with bonded CFRP fabric in single layer which is parallel to beam axis of which two beams were subjected to static loading, and remaining two beams were subjected to compression cyclic loading. In second series having four beams with bonded CFRP fabric in two layers which are parallel and perpendicular to beam axis of which two beams were subjected to static loading and remaining two beams were subjected to compression cyclic loading under virgin condition and tested until failure. The CFRP fabric (Nitowrap EP (CF) from Fosroc Chemicals Limited) available in coil form of standard width of 1.0 m and orientation of fibre is unidirectional shown in Fig.18.

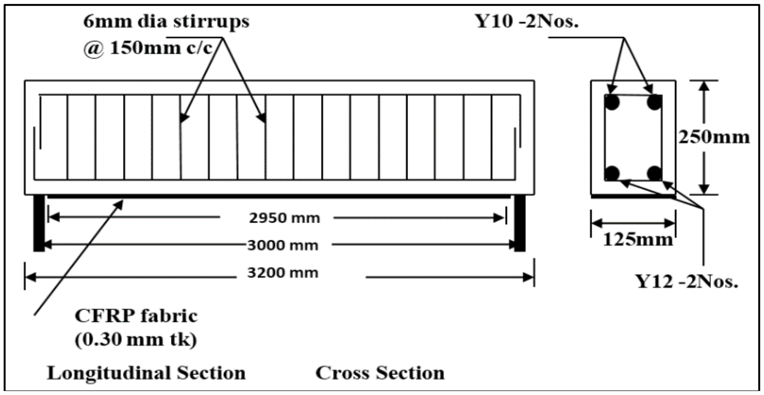

Fig 17: Beam Details

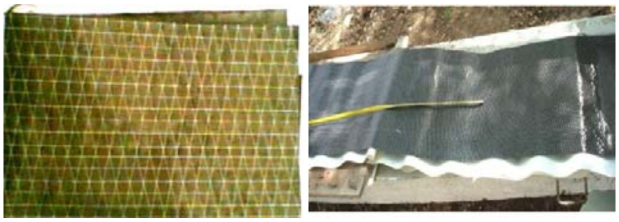

Fig 18: Carbon Fibre

The soffit of the beams were sand blasted to remove the surface laitance and then blown free of dust using compressed air. The CFRP fabric from is a carbon fibre composite wrapping system were adopted, in which Nitowrap (CF) is used in conjunction with an epoxy sealer cum primer Nitowrap 30 applied over the soffit of the beam, allow them to dry and then apply as a high build epoxy saturant Nitowrap 410 over the primer coat.

The high build epoxy pot life is 2 hours at 30 ºC. The CFRP fabric in single layer cut to size of 125×0.3×2950 mm were placed over the beam which is parallel to beam axis and uniform pressing was done by grip roller head.

The system is protected by a polyurethane top coat of Nitowrap 512 in case of atmospherically exposed structure. The strengthened beams were tested after the interval of 7-days. The coin tap was conducted to identify areas of debond, if any. The same procedure was adopted bonding CFRP fabric in two layers one over other which are perpendicular and parallel to beam axis and finished protective coating over second layer shown in Fig.19.

Fig 19: Finished With Protective Coating

Load, displacement and strains have been recorded. For each specimen electrical strain gauges were fixed at mid span of tension reinforcement and at the mid span of bottom surface of bonded CFRP fabric in the longitudinal direction. Concrete having mean cube compressive strength of 27.54 MPa was used.

For all the test beams, the parameters of interest were ultimate load, mid-span deflection, 1/3 span (both left and right) deflections, composite action, and failure modes. All the test beams were over-designed for shear to avoid the undesirable brittle failure. The CFRP fabric thickness of 0.3 mm and bond line thickness 300 microns were kept constant for all the test specimens.

g. Testing and Measurements

All the beams were tested over a simply supported span of 3000 mm under four-point bending, the load of which was monotonically increased under static loading and compression cyclic loading. (Fig.20 and 21).

The vertical mid-span and 1/3rd span deflections were measured using mechanical dial gauges of 0.01 mm accuracy and electrical strain gauges were used for finding the steel strain and composite strain. The crack development and propagation were monitored and marked during the progress of the test. The crack widths were measured using a crack detection microscope of
0.02 mm precision.

Fig 20: Test Set Up For Static Loading

Fig 21: Test Set Up for Compression Cyclic

2. Conclusion

Based on the results obtained from experiments, and theoretical analyses, the following conclusions are drawn:

1. CFRP fabric properly bonded to the tension face of RC beams can enhance the flexural strength substantially. The strengthened beams exhibit an increase in flexural strength of 18 to 20 percent for single layer and 40 to 45 percent for two layers both static and compression cyclic loading respectively.
2. At any given load level, the deflections are reduced significantly thereby increasing the stiffness for the strengthened beams. At ultimate load level of the control specimens, the strengthened beams exhibit a decrease of deflection up to 80 percent.
3. All the beams strengthened with CFRP fabric in single layer and two layers experience flexural failures. None of the beams exhibit premature brittle failure.
4. A flexible epoxy system will ensure that the bond line both in single layer and two layers CFRP strengthened beams does not break before failure and participate fully in the structural resistance of the strengthened beams.
5. In this investigation CPRP strengthened beam shows poor ductility when compared to control beam.
6. From the experimental results it is clear that minimum two layers of CFRP fabric should be bonded to get the desired results. The strengthened beam RB1(single layer) and RB3 (two layer) exhibit 20 percent and 45 percent increase in flexural strength when compared to the control specimen and has close agreement with the experimental and numerical (ANSYS) results.

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