Retrofitting of Reinforced Concrete Beams using Reactive Powder Concrete (RPC)

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Abstract. Strengthening of existing damaged structures is one of the leading studies in civil engineering. The purpose of retrofitting is to structurally treat the member with an aim to restore the structure to its original strength. The focus of this project is to study the behaviour of damaged Reinforced Concrete beam retrofitted with Reactive Powder Concrete (RPC) Overlay. Reinforced concrete beams of length 1200 mm, width 100 mm and depth 200 mm were casted with M30 grade of concrete in the laboratory and cured for 28 days. One beam is taken as control and are tested under two point loading to find out ultimate load. Remaining beams are subjected to 90% ultimate load of control beams. The partially damaged beams are retrofitted with Reactive Powder Concrete Overlay at the full tension face of the beam and side overlay depends upon the respectable retrofitting techniques with 10 mm and 20 mm thick layer to find optimum. Materials like steel fibres are added to enhance the ductility by eliminating coarse particle for homogeneity of the structure. Finally, the modes of failure for retrofitted beams are analysed experimentally under two point loading & compared the results with Control beam.

Key words: RPC, Retrofitting, reinforced concrete beam, steel fibre, silica fume.

1. Introduction
1.1. General
For a variety of reasons, subsist concrete structures may become deficient and found to be perform not satisfactory which leads extreme deflections and cracking, or results in not enough ultimate strength [1]. For this purpose, retrofitting is the suitable way of strengthening the structures by means of adding new features or technologies to the structural member. The main aim of retrofitting is to structurally treat the member with an aim to restore the structure to attain its original strength. Some of the commonly used repairing and retrofitting techniques are patch repair, resin injection, stitching, bonding of external reinforcement, routing and sealing, drilling and plugging. Depending upon the type of distress, the techniques used for carrying out repair of damaged structures vary from one structure to the other. Although these techniques are favourable in particular cases, but there are lot of specialized specifications according to ACI 440.2R-08 [2] and disadvantages to follow the same in field work [1, 3]. The suitable way to deal with subsist problem for retrofitting is cement-based mortars. Fibre based composites has step-up a lot of notice in strengthening the flexural members [4]. From literature studies, retrofitting by use of FRP materials have gained lot of benefits in corrosion resistance, can be adhesively bonded, and have a stiffness greater compared to that of steel. Despite its benefit over other methods, the strengthening technique using FRP is not entirely problem-free. The
cost of resins is also high and it affects the manual worker by release of toxic fumes during application pose potential hazards [5].

From the earlier literature studies, the new generation of cement-based materials called reactive powder concrete (RPC) which is also called as ultra-high performance concrete (UHPC) has gained a lot of attention in achieving maximum compressive strength in the range of 200–800 MPa due to its super-high strength, superior toughness and extreme durability [6]. Elimination of coarse aggregate for homogeneity by incorporating steel fibres to improve ductility with addition of silica fume which is a micro-cementitious materials into the concrete substance to enhance pozzolanic reaction and to reduce the water/cement ratio with the use of superplasticizers [7]. RPC proves to have higher flexural strength and ductility of about 250 times when compared to that of normal concrete. Generally production cost of RPC is high as cement dosage varies from 800–1000 kg/m$^3$. Due to high mechanical performance of RPC, it has some economic advantages by reducing the thickness of concrete members which effect in materials and cost savings. It is also implemented in other applications such as for special type of precast and pre-stressed concrete members [8]. In the literature studies, reported on RPC they gained importance regarding the increase in compressive strength and also finding the optimized curing conditions. But narrow studies have been described in increasing the flexural capacity of a member with various repair techniques. This study has been done to increase the flexural capacity of a RC beam as retrofit with RPC overlay in tension side of a beam and also sides of the beam where crack is applicable for economical purpose with three different repair techniques to compare and find the optimum. The main purpose of an overlay is to extend the service period of the structure and increase the structural performance and durability of a wearing surface.

In this paper, seven RC beams of M30 grade with same dimension are measured for experimental purpose. For partial loading, beams are subjected to 90% of the ultimate load of control beam. The partially loaded beams are then retrofitted with 10 and 20 mm thickness with RPC overlay and allowed for normal curing 28 days and tested for its flexural behaviour.

1.2 Significance of work
The objective of this work is to find out the effective thickness of RPC overlay in strengthening for reinforced partially loaded beams and also finding the suitable retrofitting techniques to achieve higher ultimate load.

2. Experimental Program
2.1 Reactive Powder Concrete
The mix design details of RPC are presented Table 1. The RPC mix is prepared by the following constituents: Ordinary Portland cement (C) 53 grade as per IS 12269:1987, with quantity of cement content high as 1000 Kg/m$^3$ than that used in common concrete with 3.15 as a specific gravity. Silica fume (SF) is used as a secondary binder with specific gravity of 2.2, to neglect the micro-particulate voids in the binder paste. Fine aggregate (FA) according to IS 650–1991 with a specific gravity of 2.65 and size as 4.75 mm, hooked micro steel fibres (ST) of 30 mm length and 0.96 mm diameter, Nitobond EP epoxy adhesive for bonding old concrete and new concrete, Super plasticizer (SP) and ordinary tap water.

2.2 Reinforced concrete beams
The mix design of M30 grade concrete are shown in Table 1. Totally 7 RC beam are casted with a dimension of 1200 mm length, 100 mm wide and 200 mm depth. The control beam details are shown in Table 2. The schematic diagram of beam are represented in Figure 1. The characterstic strength of the steel $f_y$ is 500 N/mm$^2$. Three types of retrofitting techniques are considered for the study are grooving (A), meshing (B) and stitching (C).
Table 1. Mix ratio of M30 and RPC

| MIX NAME | C (Kg/m³) | FA (Kg/m³) | CA (Kg/m³) | SF | QP (Kg/m³) | WATER (Lit/m³) | SP (by weight) | STEEL FIBRE (by volume) |
|----------|-----------|------------|------------|----|-----------|----------------|---------------|------------------------|
| M30      | 380       | 711        | 924        | -  | -         | 160            | 0.5%          | -                     |
| RPC      | 970       | 1080       | -          | 244| -         | 272            | 3%            | 2%                    |

Table 2. Control beam details

| Description | Main reinforcement | Ultimate load (KN) |
|-------------|--------------------|--------------------|
| CB          | 2 no’s of 12 mm    | 123.68             |

Figure 1. Schematic diagram

Table 3 Retrofitted beams details

| Group | Induced partial load | Retrofit beam | Overlay thickness (mm) |
|-------|----------------------|---------------|------------------------|
| A     | 90% of the ultimate load of CB | A1           | 10                     |
|       |                      | A2           | 20                     |
| B     | 90% of the ultimate load of CB | B1           | 10                     |
|       |                      | B2           | 20                     |
| C     | 90% of the ultimate load of CB | C1           | 10                     |
|       |                      | C2           | 20                     |

Two numbers of 12 mm diameter steel rod is used as bottom main reinforcement and 2 numbers of 8 mm diameter steel is used as anchorage bars and 6 mm diameter is used as stirrups to avoid shear failure and are placed at 100 mm c/c distance.

2.3 Casting of RPC overlay

The overlay thickness is chosen based on the literature study [4]. The retrofitted beams details are given in Table 3. The overlay is applied by using a Nitobond EP epoxy in the tension region of the partially loaded beam for effective bonding.

2.4 Testing

The casted control beam and retrofitted beams are tested under two-point loading. The centre to-centre distance between supports is 1100 mm. In a 1000 kN load cell unit, the load is applied under a rate of
10 kN/min. The tested beams are placed with two LVDT one at centre of the span and the other at quarter span just below the loading points. To locate the progression of the crack, the specimens are white washed and grids are drawn of size 50 mm x 50 mm on two sides of surface of beam.

3. Results and Discussion

3.1 Mechanical properties

The mechanical properties of conventional M30 grade concrete and RPC for 28 days with an average value are shown in Table 4.

| Description   | Compressive Strength (N/mm²) | Split – Tensile Strength (N/mm²) |
|---------------|------------------------------|----------------------------------|
| M30           | 32.24                        | 3.45                             |
| RPC           | 65.7                         | 6.31                             |

To achieve higher compressive strength than the conventional concrete the water content usage must be reduced than the optimum amount, so that the part of cementitious constituents remains anhydrate which affects the microstructure of RPC [9].

3.2 Bending behaviour of control beam

The control beam is tested to find the ultimate load. With formation of minute cracks, a slight decrease in the stiffness of the beam is seen during testing. Visible cracks are seen at 58 KN. The crack develop upwards due to complete yielding of reinforcement and a mid-span deflection of 6–8 mm with crushing of concrete can be seen in the compressive region.

3.3 Damaged beams

The ultimate load are found out by testing the control beam till failure. Remaining beams are partially loaded till 90% of ultimate load of control beam [4]. The pre damage load of RC beams is 110 kN. The partially loaded beams are retrofitted with three different retrofitting techniques – Grooving (A), Meshing (B), Stitching (C) with 10 mm and 20 mm thick overlay and its load vs deflection response is shown in Fig 2.
3.4 Adhesive epoxy bonding

The thickness overlay is selected based on literature [1, 10, 11 and 12]. Table 3 shows the detail of a retrofitted beams. Different methods are adopted in literature to improve strong bonding between normal concrete and Ultra - high performance concrete [13, 14]. In this study, a simple method to bond RPC strips with old concrete is explained. The partially loaded beams are cleaned from dust and angle grinder are used to roughen the surface before bonding the retrofit strips. To retrofit the partial loaded beams, three types of technique are adopted, they are grooving, meshing and stitching. The contact area into the faces of the beams are to be increased for grooving method. In such a way that a diagonal grooves 10–15 mm deep at a spacing of 200 mm is cut as shown in fig.3 (a). The meshing method is implemented by wrapping a G.I mesh in U- shape as shown in fig.3 (b) [15]. For stitching technique, a holes are made by drilling on either sides of the crack and a stitching dogs that is a 5 mm rod is bent in a U- shape as shown in fig. 3 (c) is inserted into that holes and extra spacing of holes are filled by epoxy. For good adhesive bonding, the two mixture of the epoxy is mixed thoroughly and applied to the bottom side of the partially loaded beams and at the sides of the beam maintaining a constant thickness of 3 mm. Uniform pressure is applied on the retrofitted specimens using L clamp during hardening of adhesive 24 hr to ensure good bonding.
3.5 Performance of RPC overlay

Strengthening Criterion: Considering the strengthening criteria, the ultimate load carrying capacity of the retrofitted beams should be increased. From Table 5, it is clear that in grooving technique, the beam retrofitted with 20 mm thick overlay is able to regain the earlier attained original strength whereas 10 mm overlaid beam fails to get original strength when compared with control beam. The meshing with 20 mm overlay shows a higher load carrying capacity of 152 kN than all other retrofitted beams. The ultimate load carrying capacity of A2, B1, B2, C1 and C2 compared to control beam of series increased up to 8.6%, 10.2%, 22.9%, 4.1%, and 13.5% respectively. A peak load for control beam and all retrofitted beams are shown in Fig. 4. With the increase in overlay thickness in strengthening techniques, we observed the lower deflections with increase in ultimate load which shows the increased flexural capacity of retrofitted beams.

| DESCRIPTION | OVERLAY THICKNESS (mm) | ULTIMATE LOAD (kN) | % INCREASE IN ULTIMATE LOAD |
|-------------|-------------------------|--------------------|---------------------------|
| CONTROL BEAM| –                       | 123.68             | –                         |
| GROOVING    | 10 mm                   | 118.7              | –                         |
|             | 20 mm                   | 134.3              | 8.6%                      |
| MESHING     | 10 mm                   | 136.2              | 10.2%                     |
|             | 20 mm                   | 152                | 22.9%                     |
| STITCHING   | 10 mm                   | 128.7              | 4.1%                      |
|             | 20 mm                   | 140.3              | 13.5%                     |
Figure 4. Peak Load

Figure 5. (a) Crack patterns showing control beam

Figure 5. (b) Crack patterns showing retrofitted beam A1

Figure 5. (c) Crack patterns showing retrofitted beam B1
4. Conclusion

From the experimental results obtained it is clear that the Reactive Powder Concrete can be used as a retrofitting material and Nitobond EP epoxy adhesive is used for bonding new concrete with old and no debonding is observed during the experimental investigation. The results obtained are:

- The retrofitted beams were able to regain its original strength after strengthening in tension and acted monolith under bending.
- In Grooving method, the ultimate load for beam with 10 mm thick overlay is equal to the ultimate load of control beam but for beam retrofitted with 20 mm overlay thickness in tension side shows 8.6% increase in ultimate load.
- In meshing method increase in load is 10.2% and 22.9% for beams retrofitted with RPC thickness of overlay 10 mm and 20 mm respectively when compared with control specimen.
- In stitching method increase in load is 4.1% and 13.5% for beams retrofitted with RPC thickness of overlay 10 mm and 20 mm respectively when compared with control specimen.
- Beams retrofitted with meshing method with 20 mm RPC overlay shows high load carrying capacity than other retrofitted beams with a slight spalling of concrete.
- In consideration of cost, the grooving method and stitching method will be more economical when compared with meshing method.
- All the three retrofitting methods can be used for strengthening beams by overlay of RPC. This method can be successfully implemented to damaged structural member under flexure, since no debonding is observed.

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