Flexural Retrofitting of RC Beams Using Extra Rebars and U-Wraps

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Abstract: More recently, near-surface mounted (NSM) FRP reinforcement has attracted an increasing amount of research as well as practical application. In this experimental study, the effectiveness of NSM bars as a means of restoring or upgrading the flexural capacity of RC beams is investigated. A total of nine beam specimens of grade M20, length 1m and cross-section of (150mmx200mm) were casted and tested by two point load method. Out of these, beams were retrofitted with steel rods and GFRP rods using Near Surface Mounted (NSM) technique, externally bonded with FRP U-wraps after applying 75% of the ultimate load. A comparative study was made with the test results.

Keywords: Fiber Reinforced Polymer (FRP), Near Surface Mounted (NSM), energy absorption capacity, ductility, debonding.

1. Introduction

Over the last few years, external bonding/wrapping of fibre-reinforced polymer (FRP) composites has become a very popular method for the strengthening of deficient reinforced concrete (RC) structures. Consequently, extensive research has been carried out on this strengthening technique. FRP composites are formed by embedding continuous fibres in a resin matrix which binds the fibres together. Common fibres include carbon, glass, and aramid fibres while common resins are epoxy, polyester, and vinyl ester resins. The most widely used FRP composites are glass fibre reinforced polymer (GFRP) composites, carbon fibre-reinforced polymer (CFRP) composites, and aramid fibre-reinforced polymer (AFRP) composites.

Table 1: Qualitative Comparison between E-Glass, Aramid and Carbon Fibres

| Criterion         | E-Glass Fibres | Carbon Fibers | Aramid Fibers |
|-------------------|----------------|---------------|---------------|
| Compressive Strength | Very Good      | Very Good     | Inadequate    |
| Tensile Strength   | Good           | Very Good     | Very Good     |
| Young's Modulus    | Adequate       | Very Good     | Good          |
| Long-Term Behaviour| Adequate       | Very Good     | Good          |
| Fatigue Behaviour  | Adequate       | Excellent     | Good          |
| Bulk Density       | Adequate       | Good          | Excellent     |
| Alkaline Resistance| Inadequate     | Very Good     | Good          |
| Price              | Very good      | Adequate      | Adequate      |

A. Objectives

The objectives of this study includes

- To investigate the improvement in flexural strength of reinforced concrete beams using Near Surface Mounted (NSM) technique and Externally Bonded Reinforcing (EBR) technique.
- To evaluate the mode of failure of beams before and after the strengthening of beams.

B. Methodology

1) Externally Bonded Reinforcing (EBR) technique:

Fibre Reinforced Polymer can be effectively used for upgrading and strengthening concrete structures. The FRP sheets are generally applied externally on the surface of the structural element to be strengthened using an adhesive. This is called Externally Bonded Reinforcing (EBR) technique. Epoxy resin is used as adhesive.

2) Near Surface Mounted (NSM) technique:

Near Surface Mounted (NSM) strengthening technique is based on the concept of embedding FRP bars into grooves made on the concrete cover of the elements to be strengthened. Application of near surface mounted reinforcement consists of the following working steps.

- Grooves are cut in the concrete cover on the element to be strengthened.
- Further preparation of the groove consists of cleaning the surface from dust and loose particles using vacuum or compressed air. Then the groove is filled halfway with adhesive.
- Afterwards the FRP bar or strip is inserted and pressed to let the adhesive flow around the FRP. High strength epoxy resin grout is used for groove filling.

2. Experimental Investigations

A. Materials

The cement used is OPC of 53 Grade. The fine aggregate used is fine sand, which conforms to zone II of IS: 383 – 1970. The coarse aggregate used conforms to IS: 383 – 1970. GFRP sheet is used for flexural strengthening of reinforced concrete beams in this study. Nitowrap EP (GF) is a 1.3mm thick glass fibre composite wrapping system, used in this study. Its mechanical properties include density of 1800kg/m³ and tensile strength of 1600MPa. The 10mm dia GFRP bars had density of 1990kg/m³ and modulus of elasticity of 40GPa whereas the 10mm dia steel bars had modulus of elasticity of 200GPa. Abrick epoxy resin was used to bond the GFRP sheet to the concrete. The resin was mixed with the hardener in the ratio of 100:18. The GFRP bars as well as steel bars of 10mm diameter each were used for flexural strengthening of reinforced concrete beams in this study. High strength epoxy resin grout is used for groove filling in NSM method.
B. Beam Specimen Details
A total of 9 beams of length 1m and cross-section of (150mmx200mm) were tested in this study. For each type, three specimens were prepared. The specimen details are given in Fig. 4 and Table 2.

C. Flexural Strengthening Schemes
All specimens with one and two grooves (15x15 mm each) along the beam were made dust and debris free before the application of the repair epoxy-bonding agent (Abrick) which was applied in two layers. Fig 5 gives an illustration of the groove size and position in the specimen. The second layer was applied after insertion of the required steel or GFRP bars. After application of epoxy, it was levelled with the adjacent concrete level and left for curing. In NSM method, GFRP strip is reinforced on the surface of the beam. In the first type two 10mm dia GFRP bars are reinforced on the tensile face of the beam. In second type two 10mm dia steel strip are reinforced. Details of NSM method are shown in Fig 5, 6 and 7.

| No: of Specimens | Specimen designation | FRP strengthening system |
|------------------|----------------------|-------------------------|
| 3                | CB                   | No strengthening        |
| 3                | FRG                  | 2 NSM GFRP reinforcing bars with GFRP U-wrap |
| 3                | FRS                  | 2 NSM Steel reinforcing bars with GFRP U-wrap |

Figure 5: Near Surface Mounted (NSM) Technique
For flexural strengthening EBR and NSM methods were used. In EBR method, GFRP sheet was glued on the concrete surface as U wrap. Details of EBR method are shown in Fig.7 and 8.

**D. Test Procedure**

The specimens are simply supported, 1 m long, concrete beams casted and tested under the Universal Testing Machine (UTM). A two-point loading system is adopted for this test. An LVDT was kept at the middle of the beam to find the midspan deflection. At the end of each load increment, deflection and crack width were observed. The ultimate load and maximum deflection was noted for each specimen. The test setup of a control beam specimen is shown in Fig 9 below.

**3. Results and Discussions**

The specimens were of M20 mix designed as per IS 1026:2009 guidelines. Selected mix proportion was 1:1.63:3.04. Total number of beam specimens used in this study is 9. For each type 3 specimens were tested after 28 days of curing. The load deflection behaviour of reinforced concrete beams are discussed here. Fig 10, 11 and Table3 shows the load deflection behaviour of control specimen and the retrofitted beams with EBR and NSM method.

**Table 3: Test result**

| Beam Designation | First crack load (kN) | Ultimate load (kN) | Preload (kN) | % Increase in ultimate load |
|------------------|-----------------------|--------------------|--------------|---------------------------|
| CB               | 5                     | 15.5               | -            | -                         |
| FRG1             | 5                     | 18.6               | 11.5         | 20                        |
| FRG2             | 5                     | 20                 | 11.5         | 29                        |
| FRG3             | 5                     | 18.3               | 11.5         | 18                        |
| FRS1             | 5                     | 17.2               | 11.5         | 10.96                     |
| FRS2             | 5                     | 17.5               | 11.5         | 12.90                     |
| FRS3             | 5                     | 17.7               | 11.5         | 14.19                     |
3.1 Ultimate Load

Compared to the conventional reinforced beams, the result shows an increase in the ultimate applied load up to 20%. All beams retrofitted with NSM GFRP rods and externally with GFRP U-wraps exhibit an increase of the ultimate load of 20%, and 14% for specimens retrofitted with NSM steel rods and GFRP U-wraps respectively. The retrofitted beams with NSM GFRP rods performed at the highest ultimate load (20kN) compared to those specimens retrofitted with NSM steel rods.

3.2 Deflection Behaviour

Figures 10 and 11 shows the load-deflection behaviour for conventional reinforced beams and retrofitted beams respectively. The result shows that all beams retrofitted with NSM bars behaved in a ductile manner. Beams were stiffer compared to plain reinforced beams. The ascending part in deflection curves of all beams was analogous to the deflection curve of plain reinforced beams. Nevertheless, the curves of retrofitted beams lay slightly above the path of the deflection curves of the plain reinforced beams. Deflection curves of the retrofitted beams, however, have a continuing increasing in line up to an elastic point higher than the elastic point of plain reinforced beams by 5.88%, 10.4% for steel, and GFRP bars respectively, with relatively less deflection compared to control beams. This retrofitting technique has significantly enhanced the strength and increased the ultimate applied load of the preloaded beams and gave better performance than the conventional reinforced beams.

3.3 Cracking and Failure Mode

The failure modes of all the beams are shown in Fig 11 and 12. The cracking and crushing patterns of all beams have been shown, since beams in each category have performed similar cracking and crushing behaviour. All beams were designed to fail in flexure. Shear cracks were noticed in all beams. Some shear cracks remained open and some cracks were small and were closed after the dropping of the load to zero. Flexure and shear cracks in control beam specimens were initiated simultaneously. Only flexure cracks were propagated with the increase of applied loads until failure. The main cracks started to perform near the two point loads, the initiative cracks started to be observed diagonally from the point load toward the bottom of the beam. These cracks were between the point loads and the supports, but closer to the point loads. Then flexure cracks started to perform and propagate in-between and under the two point loads until failure. Prior to failure, crushing on top of the beam at the retrofitted material occurred. Unlike the plain reinforced beams, where shear and flexure cracks initiated
simultaneously, the retrofitted material at the bottom section strengthened the beam at the mid span, which delayed the initiation of cracks at the flexural zone until an appropriate applied load had been reached that was adequate to initiate the flexure cracks.

- Retrofitted beams were relatively stiffer than control beams and they produce higher elastic point than the elastic point of control beams by 13% for GFRP rods and 7% for steel rods respectively.
- Prior to failure, flexural cracks were propagated with the increase of load. Subsequently, beams fail in flexural.

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