Effect of end anchorage in external CFRP confinement on shear damaged RC beams

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Abstract

In recent days many structures are strengthened or restored to make use of the existing structure to the current needs. Upgrading a structure by restoration and strengthening eliminates the need of devastating and reconstruction also saves energy. In repair and retrofitting of a structural elements or a structure, appropriate techniques has to be choose according to the damage level or the requirement. Epoxy or any polymer injection is a kind of method to repair the cracked region. Fiber reinforced polymer (FRP) wrapping is a kind of external strengthening techniques being in practice to retrofit a reinforced concrete (RC) structure without increasing the dead load. In this study the effectiveness of externally bonded carbon-fiber-reinforced polymer (EB-CFRP) system with end anchorage on retrofitting of damaged RC beams has been examined. To represent a severe damage condition, control beams are tested to failure, retrofitted, and then retested to failure for a second time. The test results demonstrated that retrofitting of severely damaged RC T-beams with EB-CFRP composite with proper end anchorage can fully restore the original shear capacity of the beams without increasing the dimension of the structural member. Also this end anchorage system significantly restricts the delamination of FRP during severe loading than EB-CFRP method.

Keywords: shear strength; end anchorage; retrofitting

1. Introduction

Nowadays in many reinforced concrete structures across the world requires reconstruction or remodelling because of ageing, lack of maintenance and up-gradation in different standards and recommendations. Nowadays many structures are facing problems in change in occupancy due to the sustainable environment and society needs.
Strengthening of the structures is mandatory rather than demolishing and reconstruction. This kind of strengthening techniques avoids the unnecessary expenses in accordance with reconstruction. In recent years numerous research studies have focused on the effect of externally bonded fiber reinforced polymer (EB-FRP) using different FRP on shear strengthening of reinforced concrete (RC) elements [1-3]. In EB-FRP method, FRP debonding is one of the major problems which lead the structure to fail in brittle mode. Many of those studies encountered debonding failure during post yield loading [4-9]. Especially in RC beam strengthening this debonding failure restricts the significance of the employed strengthening technique during severe loading. This is because of the insufficient anchorage and weaker bond between FRP and concrete surface. This study aims at investigating the shear behavior of RC beams retrofitted and strengthened using external CFRP wrapping. This study reports the experimental study on the effectiveness of external anchorage in retrofitted region of beams.

This study is totally different from the earlier works and focuses on the aspect of the structural behavior of RC T-beams retrofitted and strengthened in shear with externally bonded CFRP sheets on side of the T-beams with different wrapping techniques. In this study, load – deflection behavior, stiffness, ductility and mode of failure are considered as most important parameters.

2. Experimental Program

2.1. Test specimens and strengthening schemes

The experimental program consists of three types of 1.4m long RC T-beam to examine the effect of CFRP sheets on retrofitting of damaged RC beams. The longitudinal and transverse reinforcement ratio and detailing are kept same in all beams to compare the performance of different CFRP strengthening techniques with control beams.

The control specimen is labeled as TBR1. In TBR2 and TBR3 the damaged concrete portion has been thoroughly removed and replaced with Steel fiber reinforced concrete (SFRC) in order to attain the required strength. Epoxy coating was also applied on the existing concrete surface to have better bond between old and fresh concrete. After proper curing, the U-shape CFRP wrapping was done on the shear deficient side of the beam. Fig. 1 shows the techniques employed to restore the damaged T-beams. All specimen configurations are summarized in Table 1.

In Specimen TBR3, CFRP sheet was used for external wrapping in “U” shape. Further the “U” shaped CFRP wrapping was properly anchored using steel strips and steel rods. In beam, near flange region 12 mm diameter holes were made in 135mm interval distance before CFRP sheet wrapping. For anchoring, steel rods were used as the source material with the size of 10mm diameter and 60mm depth. After “U” shaped wrapping, one steel strip has been placed on CFRP sheet as shown in Fig. 1(f). Later those holes were filled with special adhesive and then the steel rods were inserted into the holes to provide anchoring.

| Specimen ID | Strengthening schemes                      | Longitudinal reinforcement | Transverse Reinforcement |
|-------------|--------------------------------------------|----------------------------|--------------------------|
| TBR1        | Control beam                               | @ top 4 numbers 8mm diameter bars | @ bottom 4 numbers 16mm diameter bars | size 6Ø | spacing 250 | size 8Ø | spacing 100 |
| TBR2        | Externally bonded reinforcement (EBR)       |                           |                          |
| TBR3        | Anchorage technique                         |                           |                          |

Table 1. Details of test specimens
2.2. Materials specification

Ordinary Portland Cement (OPC-43 grade) and 12.5mm downgraded coarse aggregates are used for the preparation of concrete. The mix design is carried out for M 30 grade of concrete with an average cube compressive strength of 34 MPa at 28 days is used to prepare the specimens. In R.C T - beam preparation Fe415 grade reinforcement as stirrups and Fe 500 grade as main reinforcement has been used. CFRP sheet 0.15 mm in thickness, with an average tensile strength of 4137 MPa and 242 GPa elastic modulus is used for strengthening. The steel strip of 50mm width and 3mm thick is used for different end anchorage system. Epoxy bonding agent is used to fill the cracks. SFRC using crimped steel fiber \((d_f = 0.3\text{ mm and the } l_f = 29\text{mm})\) is used to fill the damaged concrete section of the beam.

3. Test Setup and Instrumentation

All specimens are tested under three point monotonic loading with shear span to effective depth \((a/d)\) ratio equal to 3.24. The tests are carried out using 100 ton hydraulic jack and corresponding load and deflections are observed using load cell and Linear Variable Differential Transducer (LVDT). Fig. 2 shows the loading setup.

4. Results and Discussion

In specimen TBR1, vertical cracks were initially found in the mid region at 83 kN with less than 1mm crack
width. After continuous loading, numerous vertical cracks were formed throughout the span. As the load increases inclined cracks were started to occur and the first diagonal crack was noticed at 145 kN. The presence of stirrups with higher spacing in one side of the beam was unable to restrict the growth of inclined cracks. Thus various inclined cracks were created in the weaker section of beam than the well confined region. Inclined cracks also appeared in the well confined region, but the failure took place in weaker side of the beam. The observed deflection at failure was 7.5mm. Finally the beam experienced sudden shear failure as shown in Fig.5.

![Fig.3. Failure pattern of test specimen TBR1](image)

Energy dissipation has been measured to estimate the ductile property by calculating the area under the load deflection curve. The measured average energy dissipation of control specimen TBR1 was 1773 kN-mm.

![Fig.4. Load – deflection curve of test specimens TBR1 and TBR2](image)

Figure 4 shows the load deflection curve of TBR1 and TBR2. It shows decreased initial stiffness of specimen TBR2 compared to control specimen TBR1. This shows the ineffectiveness of employed strengthening technique. It is also due to the damaged longitudinal reinforcement and insufficient stirrups along with the employed U shape wraps. The Fig. 5(a) shows fiber debonding near beam web region which is due to the inadequate anchorage capacity of U- shape CFRP wrap. Finally the specimen exhibits brittle shear where the previous failure exists, as shown in Fig.5(a). Also the observed 1372 kN-mm energy dissipation shows the poor ductile behaviour of specimen TBR2 compared to control beam TBR1.
Specimen TBR3 shows enhanced deflection behaviour and nearly equates the load carrying capacity of control beam. Fig.6 shows the better load carrying capacity of specimen strengthened with EBR technique than TBR2. In specimen TBR2, immediate debonding have been noted after reaching its ultimate load, whereas in specimen TBR3 CFRP unzipped vertically rather not fully detached were noticed in the laminated region Fig. 5(b). The observed energy dissipation shows 36% and 75% higher than specimens TBR1 and TBR2 respectively. The measured stiffness at yield shows 63% higher yield stiffness over specimen TBR2. Although the yield stiffness is comparatively higher than the control specimen. The employed end anchorage techniques made the specimen to sustain for higher deflection which is considerably 25% higher than control specimen TBR1. Thus the end anchorage imparts ductility to the retrofitted structure. Even at failure level little debonding failure took place, but not up to the level of specimen TBR2. Fig. 5(b) shows the failure pattern of specimen TBR3.

In end anchorage system the provided anchorage near the flange section holds the CFRP to sustain the higher load carrying capacity than EBR technique. This is due to the provided interlocking of CFRP in the grove using epoxy. This anchorage restricts the initial slip movement along the direction of loading. Though some part of wrapping get cracked in the region where higher shear stress exists during severe loading. But the hold at top acts as effective barrier in debonding and sudden de-lamination after initial cracking as experience in EBR technique. It is concluded that the external wrapping with additional anchorage may enhance the structural performance better than the conventional wrapping technique.
5. Conclusions

- Results from this experimental study indicate that CFRP wraps with end anchorage restore the designed strength of a damaged beam.
- The EBR technique clearly shown to be less effective than the end anchorage system. The failure pattern also proves that the EBR technique did not resist the applied load effectively as compared to the end anchorage technique.
- The experimental data reveals that the provided external anchorage for U wrap enhances the energy dissipation and deflection property over EBR technique.
- The stiffness of both the retrofitted beams were less as compared to control specimens, this is because of yielded reinforcement at tensile zone. Though the end anchorage stiffness is comparatively higher than EBR technique.
- This better performance is likely due to the establishment of additional end anchorage and its enhanced resistance to the premature debonding failure.

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