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Review on Reinforced Concrete Beam-Column Joint

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Abstract : The study of literature is an important part of a project to review the previous works done. In this chapter, some of the technical papers, related to retrofitting of structures, FRP and analytical studies, published in journals and conference proceedings have been discussed. Reinforced concrete beam-column joints have an important function in the structural concept of many structures. Often these joints are vulnerable to loads due to impact, explosion or seismic loads. These joints are also sensitive to corrosion of steel reinforcement. On the other hand, confinement has proven to be very efficient in increasing concrete strength and ductility of members. Wrapping by means of FRP reinforcement enhances the structural behaviour of concrete beam-column joints considerably. This chapter presents most of the available literature on the usage of FRP composites in the retrofitting of reinforced concrete beam-column joints.
Keywords: Beam-column joints, FRP, seismic loads

I.BEHAVIOUR OF RETROFITTED RC BEAM-COLUMN EXTERIOR JOINTS

There are some earlier studies carried out on the performance of FRP and the effect of retrofitting on the beam - column joints in experimental and analytical studies are discussed under this topic.

Ahmed Ghobarah et al. (2002) [2] presented shear strengthening of beam-column joints. The author conducted four reinforced concrete beam-column joints were designed to represent existing pre-seismic construction. In which two specimens were taken as control specimen. Then these two and remaining two specimens were subjected to cyclic loading, the damaged specimens were retrofitted with the four different types of retrofit schemes,

1. Repaired specimen after control test, then rehabilitated with one bi-directional "U" shaped GFRP sheet, same height as the joint with added cover plates and anchors through the joint (Method 1).
2. Repaired specimen after control test, then rehabilitated with two "U" shaped GFRP layers extending above and below the joint with added cover plates and anchors through the joint (Method 2).
3. Rehabilitated using one bi-directional "U" shaped GFRP sheet, same height as the joint, but without cover plates and anchors through the joint (Method 3).
4. Rehabilitated with three diagonal GFRP layers (Method 4).

From the test results a comparison between the performance of original specimens and rehabilitated ones shows that the GFRP jacket was capable of increasing the shear resistance of the joint and enhancing the performance of the connection from ductility point of view. Finally, the specimen repaired with method 2 and 4 showed better performance compare to other two types of repaired scheme.

Murthy et al. (2004) [4] conducted influence of fibre wrap retrofitting on gravity designed RC beam-column joints under cyclic loading. The author tested the two specimens of half scale exterior RC beam-column joint. One specimen was original and another one was retrofitted with GFRP. They designed the specimens as per IS 456:2000. The two specimens were subjected to cyclic loading. The increase in peak load was observed 33.7% in retrofitted specimens. Ultimate displacement was decreased from 20.0 mm to 18.1 mm for retrofitted specimens. The retrofitted specimens marginally increased the energy dissipation potential. From the test results GFRP retrofitted specimens shown increase in energy dissipation capacity, load carrying capacity. But there was no improvement in the ductility.

Abhijit Mukherjee et al. (2005) [1] carried out FRPC reinforced concrete beam-column joints under cyclic excitation. The author has tested the joints were cast with adequate and deficient bond of reinforcements at the beam-column joint. FRP sheets and strips have been applied on the joints in different configurations. The columns were subjected to an axial force while the beams were subjected to a cyclic load with controlled displacement. The hysteretic curves of the specimens were plotted. The energy dissipation capacity of various FRP configurations was compared. In addition, the control specimens were reused after testing as damaged specimens that are candidates for rehabilitation. The rehabilitation was carried out using FRP and their performance was compared with that of the undamaged specimens. Finally, energy dissipation capacity can be increased with the use of FRP composites. Test on rehabbed specimen suggests that FRP not only restores its original strength but there is considerable enhancement in its yield load, initial stiffness and energy dissipation capacity.

Yousef A. Al-Salloum et al. (2007) [20] performed performance of exterior RC beam-column joints upgraded with CFRP composites under seismic loading. The author has conducted the test with one exterior RC beam-column joint. The specimen was then subjected to cyclic lateral load histories so as to provide the equivalent of severe earthquake damage. The damaged specimen was then repaired through injecting epoxy into the cracks and externally bonding the specimens with CFRP sheets. The ultimate load for repaired specimen is substantially higher than its corresponding original specimen. The use of CFRP increases the deformation capacity of repaired specimens considerably. The application of CFRP sheets has improved the ductility of repaired specimen significantly. This increase in the ductility is up to 39% with respect to the before repaired specimen. Average peak load for repaired specimen is substantially higher than the original as-built specimen by 74%. The results of CFRP repaired specimen was compared with its corresponding before repair specimen and, in general, it was observed that CFRP sheets improve the shear resistance and ductility of the RC joint to a great extent.

Lakshmi et al (2008) [9] carried a detailed investigation on strengthening of beam column joints under cyclic excitation using FRP composites. The author has taken three typical modes of failure namely flexural failure of beam, shear failure of beam and shear failure of column were discussed. Comparison was made in the terms of load carrying capacity. Three exterior beam column joint sub assemblages were cast and tested under cyclic loading. All three specimens were retrofitted using FRP materials and the results were compared with controlled specimens. Finite element analysis has been carried out using ANSYS to numerically simulate each of these cases. They concluded that the shear failure was very brittle and hence retrofitting should be done in such a manner that the failure occurs in the beam in flexure.

Kien Le-Trung et al. (2010) [8] carried out an experimental investigation to strengthen the shear capacity of beam column joints using Carbon Fibre Reinforced Polymer materials. Eight exterior RC beam-column joint specimens including six retrofitted specimens with different configurations of CFRP sheets were cast and tested to find out an effective method to improve the seismic performance of the joints in terms of the lateral strength and ductility. The different configurations of CFRP sheets considered were T-shaped, L-shaped, X-shaped and combinations of them. The test results indicated that appropriate addition of CFRP composites significantly improved the lateral strength as well ductility of the test specimens. X-shaped configuration of wrapping, the strips on the column and two layers of the CFRP sheets resulted in a better performance in terms of ductility and strength.

Lee et al. (2010) [10] presented an effective rehabilitation strategy to enhance the strength and stiffness of the beam–column joints. An analytical model was proposed to predict the column shear of the joints strengthened with carbon fibre reinforced polymer. Three full scale interior beam–column joints, including two specimens strengthened with CFRP and one prototype specimen were tested. The experimental results indicated that the beam–column joints strengthened with CFRP can increase their structural stiffness, strength, and energy dissipation capacity. The rehabilitation strategy is effective in increasing the ductility of the joint. The rehabilitation strategy ensured the failure in the beam portion and delayed the shear failure mode.

Senthil kumar et al. (2010) [18] studied behaviour of retrofitted with FRP wrapped RC beam-column exterior joints subjected to cyclic loading. The author carried out non-linear analysis in ANSYS software. They have analysed an exterior beam-column joint of a five storey reinforced concrete building falling under seismic zone III, using STAAD.Pro. The specimens were designed for seismic load according to IS 1893(Part I):2002 and IS 13920: 1993. The maximum moment occurred at ground floor roof level. They have chosen that particular joint for the experimental study. The test specimen was reduced to 1/5th scale to suit the loading arrangement and test facilities. The authors compared the experimental study results with FEM analysis in ANSYS. The ductility, energy absorption and stiffness properties were studied. For the experimental study three specimens were casted and tested to failure for this investigation. One is control specimen test up to post ultimate load, and another two specimen test up to 70% of the ultimate Load. These two specimens were retrofitted with GFRP wrapping with single and double layer respectively. From the results the load carrying capacity of the retrofitted Specimen is 60% more than that of the control specimen. The enhancement in the energy absorption capacity of the retrofitted specimen was in the range of 30% to 60% over the control specimen.

Robert Ravi et al. (2010) [17] presented an experimental Investigation on behaviour of reinforced concrete beam column joints retrofitted with GFRP-AFRP hybrid wrapping. Three exterior reinforced concrete beam-column joint specimens were cast and tested to failure. Two specimens had reinforcement details as per code IS 456:2000. The other specimen had reinforcement details as per code IS 13920:1993. The failed two beam-column joint specimens designed as per code IS 456:2000 were retrofitted with GFRP-AFRP/AFRP-GFRP hybrid fibre sheets wrapping to strengthen the specimens. The test results showed load carrying capacity, energy absorption capacity of the reinforced concrete beam-column joint specimens designed and detailed as per code IS 13920:1993 was found to be more than the specimens detailed as per code IS 456:2000. The load carrying capacity, energy absorption capacity of the reinforced concrete beam-column joint specimens retrofitted with AFRP-GFRP and GFRP-AFRP hybrid sheet was found to be more than the control specimens. Particularly the specimens retrofitted with AFRP-GFRP hybrid wrapping was found to be more than the specimens retrofitted with the GFRP-AFRP hybrid wrapping.

Rajaram. et al. (2010) [15] studied an experimental Study on behaviour of Interior RC beam column joints subjected to cyclic loading. The author carried out non-linear analysis in ANSYS software. They have analysed an interior beam-column joint of a five storey reinforced concrete building falling under seismic zone III, using STAAD.Pro. They have designed the joints for seismic load according to IS 1893:2002 and IS 13920:1993. The maximum moment occurred at ground floor roof level. They have chosen that particular joint for the experimental study. The test specimen was reduced to 1/5th scale to suit the loading arrangement and test facilities. The authors compared the experimental study results with FEM analysis in ANSYS. The ductility, energy absorption and stiffness properties were studied. From this study the authors concluded that the experimental and numerical analysis results were same.

Gencoglu et al. (2010) [6] conducted the strengthening of the deficient RC exterior beam-column joints using CFRP for seismic excitation". The author taken four half-scaled exterior beam-column joint specimens were prepared with only one of them conforming to the guidelines of ACI 318-02. The other three specimens were insufficient from view point of joint hoops and main reinforcements of beam and column. The performance and behaviour of the reinforced concrete exterior beam-column joints rehabilitated using carbon-fibre-reinforced polymer (CFRP) fabric was experimentally studied under the cyclic loads that simulate seismic excitation. In order to strengthen the deficient external beam-column joints, two types of CFRP fabrics were laid. First type was one layer of L-shaped CFRP wrapping. Second type was two layers of CFRP wrapping. Experimental results were compared against the sample designed in accordance to the ACI guidelines. The use of CRFP fabrics attached on the exterior surface of concrete was extremely effective on the ductility, absorbed total, dissipated and recovered energy in addition to ultimate displacement and load carrying capacity. From the test results it was seen that the RC exterior beam-column joint strengthened by two layers L CFRP sheets has the highest reversed cyclic load carrying capacity and the total absorbed energy amounts among other beam-column joint specimens.

Prince Arulraj et al. (2010) [16] investigated experimental investigation on the behaviour of retrofitted reinforced concrete beam – column joints with GFRP wrap subjected to load reversal. The author made an attempt to study the behaviour of reinforced concrete beam-column joints retrofitted with glass fibre reinforced polymer sheets. Totally six exterior reinforced concrete beam-column joint specimens were cast and tested to failure. Three specimens had reinforcement details as per code IS 456:2000. Remaining three specimens had reinforcement details as per code IS 13920:1993. Various percentage of load carrying capacity of column was given as axial load in the column. Push and pull load was applied at the free end of the cantilever beam till failure. The failed three beam-column joint specimens had reinforcement details as per code IS 456:2000 were retrofitted by removing the concrete in the joint portion and recasting with concrete of same grade and subsequently wrapped with Glass fibre reinforced polymer (GFRP) sheet to strengthen the specimens. From this study the performance of the specimens had reinforcement details as per code IS 13920:1993 given the maximum load carrying capacity, energy absorption capacity when compared to the specimens had reinforcement details as per code IS 13920:1993. The specimens retrofitted with the double layer of GFRP given the results more than the control specimens.

Sharma et al. (2010) [19] reported the results of a full scale RC structure repaired and retrofitted using a combination of CFRP and GFRP sheets. The structure had been tested earlier under pushover loads till failure. Now the structure was retrofitted and re-tested. The FRP design criterion was set as to bring back the structure to almost at same level as original structure. It was found that the structure could reach 90% of the base shear as was recorded for original structure , but the stiffness of the retrofitted structure was reduced and delaminating was quite pronounced due to surface unevenness in locations that were critical but difficult to reach in practise. Although, in general the joint behaviour was improved due to prevention of spalling of concrete, the failure could not be prevented.

Mahini et al. (2011) [12] conducted numerical investigation on the behaviour of FRP-retrofitted RC exterior beam-column joints under cyclic loads. The author reported on the capability of nonlinear finite element modelling in simulating the behaviour of FRP retrofitted reinforced concrete exterior beam-column joints under cyclic loads. For the purpose of investigation, three concrete beam to column joint specimens were selected. The ANSYS finite element software was used for modelling RC exterior joints. The specimens were loaded using a load increment procedure to simulate the cyclic loading in testing. The results show that the hysteretic simulation was satisfactory for both un-strengthened and FRP-strengthened specimens. When FRP strengthening was employed, strengthened beam-column joints exhibit a better structural performance than the un-strengthened specimens. The modelling performed in this study on three specimens before and after being retrofitted, shows that finite element modelling can evaluate the cyclic performance of RC joints. Therefore, the most effective retrofitting schemes under earthquake load mat be easily recognized using the low cost finite element models.

Halil Sezen et al. (2012) [7] investigated repair and strengthening of reinforced concrete beam-column joints with Fibre Reinforced Polymer Composites. Three exterior reinforced concrete beam-column joint specimens were tested under reverse cyclic loading. The joint region of these specimens suffered significant damage, whereas limited damage was observed in the beams. The damaged specimens were repaired and strengthened to prevent shear damage and strength deterioration inside the joint region and to achieve more ductile response. First, the damaged loose concrete was removed and replaced by high strength non shrink mortar. Then, fibre-reinforced polymer (FRP) strips were diagonally wrapped over the joint region, and longitudinal FRP strips were applied and anchored on the beams. Deformation capacities of the strengthened specimens were much larger than those of the original specimens. This goal was achieved by applying diagonal FRP strips in the joint region, and no damage was observed in the column or joint regions of the strengthened specimens.

Parvin et al. (2012) [14] performed performance of CFRP wrapped connections. In this study, interior as-built reinforced beam-columns joints were compared to their CFRP wrapped counterparts through finite element analysis. The joints are subjected to constant axial and lateral cyclic loads. Four one-fourth scale exterior beam-column connections were modelled. Different element types were utilized in this study; solid for the concrete, truss for the steel reinforcement, and shell for the CFRP sheets. The CFRP upgrade consist of each layer was 0.18 mm thick. This was modelled by assigning a thickness of 0.36 mm to all of the shell elements. The CFRP upgrade scheme improved the maximum lateral load capacity of the exterior joint by 35.0%. The CFRP upgrade enhanced the ductility of the exterior control joint by 23.5% and 45.7% the push and pull directions, respectively. The CFRP upgrade enhanced the performance of the exterior joint in terms of lateral load, ductility and energy absorption capacity. From this study the CFRP upgrade scheme increased the lateral load capacity by 27-35% and the maximum displacement by 18-45% of the exterior models as compared to the control joint counterparts.

Balasubramanian et al. (2012) [3] performed evaluation of performance of retrofitted reinforced concrete beam - column joints–A simplified model. The author has proposed an experimental investigation on the behaviour of retrofitted beam-column joints subjected to cyclic loading. The experimental program consisted of testing four RC beam-column joint specimens. The beam - column joints cast were retrofitted with four different methodologies as detailed below.

1. Providing CFRP laminates in the top face of the beam (Method 1).
2. Providing CFRP laminates in the top face of the beam and confining the junction with CFRP sheets (Method 2).
3. Providing MS flat section in the top face of the beam, anchored with MS bolts on both faces (Method 3).
4. Providing additional reinforcement in the top face by cutting a groove and filling the groove with non-shrink cementitious material and confining the joint with CFRP sheets (Method 4).

From the test results there was a sharp increase in the load carrying capacity, ductility and energy absorption capacity of the joint in fourth method when compared to other three methodologies adopted. This retrofitting methodology shows significant improvement in the load carrying capacity and overall performance.

Faella et al. (2012) [5] investigated seismic upgrade of exterior RC beam-to-column joints with CFRP jacketing an experimental investigation. They has done experimental program includes a total of eight RC beam-column joints to subject to reversed cyclic forces. Six specimens were strengthened by using different FRP systems while the remaining ones were used as control members. After being damaged, some specimens were also repaired, retrofitted with FRP systems and subjected to cyclic tests again. The retrofitting scheme was carried out by two ways. First scheme of retrofit was performed by using CFRP wrapping w/o steel profiles and threaded rods. The second scheme was characterized by the use of two layers of longitudinal CFRP sheets. The considered FRP retrofitted systems have allowed restoring and in some cases improving the cyclic response of the original specimens. From the test results it was observed that the retrofitted specimen of first scheme has exhibited behaviour significantly more ductile than the counterpart of original specimen. For the specimen retrofitted with the scheme two a slight strength increase over the original member was also observed. It is noted a substantially identical behaviour in terms of strength between original and retrofitted members, and a greater ductility for FRP retrofitted members. Finally, tests performed on FRP retrofitted members have allowed to restore the strength and significantly increase the ductility of the original members.

Mariappan et al. (2013) (11) studied behaviour of RCC beam-column joint retrofitted with Basalt Fibre Reinforced Polymer Sheet. Totally nine RC beam-column joint specimens were cast and tested to failure during the present investigation. Load reversal tests were conducted on beam-column joint specimens. Among the nine specimens, three specimens were with reinforcement detailing as per code IS 456:2000 and the other three specimens with reinforcement detailing as per code IS 13920:1993. Retrofitting with Basalt FRP was done on another three specimens which has reinforcement detailed as per code IS 456:2000. From the experimental results the specimens detailing with IS13920:1993 have maximum load carrying capacity and energy absorption capacity compared to specimens detailing with IS 456:2000. The specimens retrofitted with Basalt Fibre Polymer Sheet was an increase of 35.3% in load carrying capacity and 31.5% increase in energy absorption capacity than the specimens with reinforcement detailing as per code IS 456:2000.

Mohamed et al. (2013) (13) studied strengthening of defected beam–column joints using CFRP. The author reported an experimental study for the structural performance of reinforced concrete exterior beam–column joints rehabilitated using carbon-fibre-reinforced polymer (CFRP). The experimental program consists of testing 10 half-scale specimens divided into three groups covering three possible defects in addition to an adequately detailed control specimen. Three different strengthening schemes were used to rehabilitate the defected beam–column joints including externally bonded CFRP strips and sheets in addition to near surface mounted (NSM) CFRP strips. For group 1, the strengthening configuration represented two perpendicular overlaying fabric sheets on the beam–column joint. As for group 2, the strengthening configuration represented four layers of 100 mm wide sheets in the form of U shape that were bonded to the lower side of the beam parallel to its axis. For group 3, the configuration represented near-surface mounted, NSM CFRP strips on the outer surfaces of the specimen. From the test results the author concluded that the strengthening configuration of group 2 showed the maximum energy absorption capacity, load carrying capacity and less deflection, decreased ductility of the strengthened specimens when compared to the other two groups of strengthening configuration.

II CONCLUSIONS FROM THE LITERATURE REVIEW

From the review of literature presented above, the following are the major conclusions:

- FRP wrapping is widely applied in strengthening and retrofitting of concrete structures due to its very high specific strength and light weight compare to other techniques.
- Among many retrofitting techniques, utilization of FRP wrapping is a promising method. The approach possesses not only an effective retrofitting technique but also the advantage of a low cost and an ease of installation.
- The effect of FRP wrapping improves energy absorption capacity, ductility and stiffness of the retrofitted specimens.
- The process of retrofitting improves ultimate load carrying capacity and first crack load of the damaged specimens.

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