CHAPTER 2
REVIEW OF LITERATURE

2.1 Introduction

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 behavior of concrete beam-column joints considerably. This chapter presents most of the available literature on the usage of FRP composites in the strengthening of reinforced concrete beam-column joints.

2.2 Review of Literature

Ze-Jun Geng et al (1998) carried out an investigation on the ductility of concrete column-to-beam connection and the capability of connections containing insufficient development length. CFRP sheets were wrapped around the column near the joint region. Repeated loading-unloading-reloading were done on the specimens for simulating seismic loads. Nineteen concrete column-to-beam connection specimens were tested and it was reported that significant improvement in ductility was noticed and the ultimate loading capacity increased in the range from 24% to 35%.

Jianchun Li et al (1999) reported the results of tests on prototype reinforced concrete frame specimens which were designed to represent the column-beam connections in plane frames. The tests were devised to investigate the influence of fiber reinforcement applied to the external surfaces adjacent to the beam-column connection on the behavior of the test specimens under static loading to find the influence of reinforcement on the strength and stiffness. The hybrid FRP composites of glass and carbon with a vinyl-ester resin were designed to externally reinforce the joint of the concrete frame. The results indicated that retrofitting the critical sections of concrete frames with FRP reinforcement can provide strengthening and stiffening to concrete frames and improve their behavior.

Ahmed Khalifa and Antonio Nanni (2000) carried out an investigation on the shear performance of reinforced concrete beams with T-section. Different configurations of externally bonded carbon fiber-reinforced polymer sheets were used to strengthen the specimens in shear. The experimental program consisted of six full-scale, simply supported beams. One beam was used as a bench mark and five beams were strengthened using different configurations of CFRP. The experimental results indicated that externally bonded CFRP can increase the shear capacity of the beam significantly.

Yan Li et al (2000) reported that sisal fiber is a promising reinforcement for use in composites on account of its low cost, no health risk, availability in some countries and renewability. They presented a summary of recent developments of sisal fiber and its composites. The properties of sisal fiber interface between sisal fiber and matrix, properties of sisal-fiber-reinforced composites and their hybrid composites were reviewed.

Parvin.A and Granata.P (2000) carried out an investigation on the application of fiber-reinforced polymer composite laminates to exterior beam-column joints to increase their moment carrying capacity. Three beam-column joint models with various fiber composite laminates and wraps with various thicknesses made out of epoxy and fibers such as glass, carbon, and kevlar were examined. One beam-column joint model without FRP reinforcement was used as a control specimen for comparison. The other two beam-column joint models used for the investigation included laminates bonded to the tensile faces with and without wraps. The wraps were provided to prevent the peeling of the laminates. The results of the finite element analysis indicated that the choice of the fiber composite materials, the laminate, arrangement of wraps and thickness affected the enhancement of the structural joint performance significantly. Furthermore, an increase in the moment capacity of up to 37% was observed when the joints were reinforced with FRP laminates compared to the control specimen

Ahmed Ghobarah and Said.A (2002) reported that shear failure of beam-column joints is identified as the principal cause of collapse of many moment-resisting frame buildings during recent earthquakes. Effective and economical rehabilitation techniques to upgrade the shear-resistance capacity of the joints in existing structures are needed. Different fiber-wrap rehabilitation schemes were applied to the joint panel with the objective of upgrading the shear strength of the joint. The tested rehabilitation techniques were found to be successful in improving the shear resistance of the joints and in eliminating or delaying the shear mode of failure.

Costas P. Antonopoulos and Thanasis C.Triantafillou (2002) presented the details of the analytical models for the analysis of reinforced concrete joints strengthened with composite materials in the form of externally bonded reinforcement comprising unidirectional strips. The models provide equations for stresses and strains at various stages of the response. Solutions to these equations are obtained numerically. The models provide useful information on the shear capacity of FRP-strengthened joints in terms of the quantity and configuration of the externally bonded reinforcement and may be used to design FRP patching for inadequately detailed beam-column joints.

El-Amoury.T and Ghobarah.A (2002) presented the techniques for upgrading reinforced concrete beam–column joints. Glass fiber-reinforced polymer sheets were wrapped around the joint to prevent the joint shear failure. Three beam–column joints were tested namely, a control specimen and two rehabilitated specimens. The control specimen exhibited combined brittle joint shear and bond failure modes while the rehabilitated specimens exhibited ductile failure mode.

Bakir.P.G and Boduroglu.H.M (2002) developed a new design equation for predicting the shear strength of monotonically loaded exterior beam column joints. For this purpose, the influence of beam, influence of joint and influence of stirrups were considered as variables. The results of the parametric studies on an experimental database compiled from a large number of exterior joint tests indicated that the proposed design equation predicts the joint shear strength of exterior beam column connections accurately.

Jianchun Li et al (2002) modeled complex concrete column–beam connection with hybrid fiber reinforced polymer reinforcement. Results of the analysis indicated that designed hybrid FRP reinforcement greatly improved the stiffness and load carrying capacity of its concrete counterpart. It also delayed the crack initiation at the joint through confinement due to FRP reinforcement

Costas P. Antonopoulos and Thanasis C.Triantafillou (2003) studied the behavior of shear-critical exterior reinforced concrete joints strengthened with fiber reinforced polymers under seismic load. The role of various parameters on the effectiveness of FRP was examined through testing of 18 numbers of 2/3-scale exterior RC joint models. Conclusions were drawn on the basis of certain load versus imposed displacement response characteristics such as strength, stiffness, and energy dissipation capacity. The results demonstrated the important role of mechanical anchorages in limiting premature debonding.

Andrea Prota et al (2004) presented the key issue of strengthening of RC frames by the strengthening of beam-column connection. For upgrading the beam-column joint, the proposed technique was based on the combined use of externally bonded FRP laminates and Near Surface Mounted (NSM) FRP bars. The results of the experimental investigation indicated that FRP laminates which were used in joint region improved the shear capacity. It is reported that the NSM bars improved the flexural capacity.The experimental results indicated that the strength of control specimens increased by 39 %.

Oral Buyukozturk et al (2004) presented the use of fiber reinforced polymer composite materials for strengthening and repair of structural members. From a structural mechanics point of view, an important concern regarding the effectiveness and safety of this method is the potential of brittle debonding failures. Such failures, unless adequately considered in the design process, may significantly decrease the effectiveness of the strengthening or repair application. In recent years, there has been a concentration of research efforts on characterization and modeling of debonding failures.

Abhijit Mukherjee and Mangesh Joshi (2005) carried out an investigation on the performance of reinforced concrete beam-column joints under cyclic loading. 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 amplitude of displacement is increased monotonically using a dynamic actuator. 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.

Balsamo.A et al (2005) assessed the performance of Carbon Fiber Reinforced Polymer composites for the seismic repair of reinforced concrete structures using a full-scale system in the laboratory. The aim of the CFRP repair was to recover the structural properties that the frame had before the seismic actions by providing both columns and joints with more deformation capacity. The driving principles in the design of the CFRP repair and the outcomes of the experimental tests were presented. Comparisons between original and repaired structures were made in terms of global and local performance. In addition to the validation of the proposed technique, the experimental results will form a reference database for the development of design criteria for the seismic repair of RC frames using composite materials.

Yao.J et al (2005) investigated the behavior of bond between FRP and concrete as a key factor controlling the behavior of concrete structures strengthened with FRP composites. They carried out an experimental study on the bond shear strength between FRP and concrete using a near end supported single shear pull test. The test results were found to be in close agreement with the predictions of Chen and Teng's (2001) bond strength model.

Mathur.V.K (2006) presented an overview of building materials from local resources with a particular attention on natural fibers based composites. Natural fibers have low-cost, locally available in abundance and obtained from renewable resources. At the Central Building Research Institute, Roorkee, the potential of sisal and jute fibers as reinforcements were systematically investigated to overcome their well defined problems of moisture absorption. The performance of polymer composites made from these natural fibers and unsaturated polyester/epoxy resin was evaluated under various humidity, hygrothermal and weathering conditions. Consequent to this composite product such as laminate have been prepared and the suitability to these product is assessed as an alternate material.

Ozgur Anil (2006) compared the various methods available for strengthening reinforced concrete beams with T section against shear. Six RC beams with T section were tested under cyclic loading. Inclined CFRP straps were bonded along the shear spans of shear deficient beams for strengthening against shear by using epoxy. Arrangements and width of the inclined CFRP straps were the main parameters that were changed during the investigation. The test results confirmed that all CFRP arrangements improved the strength and stiffness of the specimens significantly.

Yousef A. Al-Salloum and Tarek H. Almusallam (2007) presented the efficiency and effectiveness of carbon fiber-reinforced polymers in upgrading the shear strength and ductility of seismically deficient beam-column joints. Four reinforced concrete interior beam-column sub-assemblages were constructed with inadequate joint shear strength with no transverse reinforcement. Two specimens were used as baseline specimens and the other two were strengthened with CFRP sheets under two different schemes. Response histories of control, repaired, and strengthened specimens were then compared. The results were compared through hysteretic loops, load-displacement envelopes, and maximum horizontal displacements of column along its height, ductility, and stiffness. The comparison indicated that CFRP sheets improved the shear resistance of the joint and its ductility. Results of two chosen schemes of strengthening were also compared and the importance of beam upgrading was highlighted.

Tarek H. Almusallam and Yousef A. Al-Salloum (2007) presented a procedure for analytical prediction of joint shear strength of interior beam-column joints, strengthened with externally bonded fiber-reinforced polymer sheets. To implement the available formulation for shear capacity prediction, a program was developed. Using this program, shear capacity of the joint and joint shear stress variation at various stages of loading were predicted and compared with experimental observations. It was observed that even a low quantity of FRP can enhance shear capacity of the joint significantly.

Murali Mohan Rao.K and Mohana Rao.K (2007) investigated about the use of natural fibers such as vakka, date and bamboo fibers as lightweight composites for load carrying structures. The cross-sectional shape, the density and tensile properties of these fibers, along with sisal, banana, coconut and palm fibers were determined experimentally under similar conditions and compared. The fibers introduced in the present study could be used as an effective reinforcement for making composites, which have an added advantage of being lightweight.

Alexander G. Tsonos (2008) carried out an experimental investigation to evaluate the retrofitting methods to address the particular weaknesses that are often found in reinforced concrete structures, especially older structures, namely the lack of sufficient flexural and shear reinforcement within the columns and the lack of adequate shear reinforcement within the joints. Thus, the use of a reinforced concrete jacket and a high-strength fiber jacket for cases of post-earthquake and pre-earthquake retrofitting of columns and beam–column joints was investigated experimentally and analytically. The effectiveness of jacket styles was also compared. The results indicated that the beam-column joint specimens strengthened with carbon-epoxy jacketing were effective in transforming the brittle joint failure mode of specimens into a ductile failure mode with the development of flexural hinges into the beams.

Azadeh Parvin and Shanhong Wu (2008) used a numerical method to investigate the effect of ply angle on the improvement of shear capacity and ductility of beam-column connections strengthened with carbon fiber reinforced polymer wraps under combined axial and cyclic loads. Three-dimensional nonlinear finite element models for the beam–column connections were developed and simulated using finite element analysis. It indicated that the behavior of three beam–column connections strengthened with the CFRP wrapping with various combination of angles such as 0^o, 45^o and 90^o. The results indicated that four layers of wrapping placed successively at 45^o ply angle with respect to the horizontal axis is the most suitable upgrade scheme for improving shear capacity and ductility of beam–column connections under combined axial and cyclic loads.

Sandeep S. Pendhari et al (2008) reviewed the applications of fiber reinforced polymer composites (FRPC) for external strengthening in civil constructions. They focused on experimental as well as analytical and numerical research contributions. The main structural components such as beams, columns and beam-column joints were reviewed and structural behavior of each component was discussed briefly. General concluding remarks were made along with possible future directions of research.

Lakshmi.G.A et al (2008) carried a detailed investigation on strengthening of beam column joints under cyclic excitation using FRP composites. 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) carried out an experimental investigation to strengthen the shear capacity of beam column joints using Carbon Fiber 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.W.T et al (2010) 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 fiber 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.

2.3 Conclusion

Based on the review of literature, it is found that only very few experimental investigations and analytical modeling of beam-column joints were carried out to study the behavior of the reinforced concrete beam-column joint specimens retrofitted with FRP sheets. Also it is found that comparison of performance of different types of fiber reinforced polymer sheets has not been done. Hence an attempt has been made to carry out an investigation to understand the behavior of the reinforced concrete beam-column joint specimens retrofitted with GFRP, CFRP, AFRP, Sisal & Hybrid wrapping sheets. Ansys modeling has also been done to verify the results.