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Analytical study on reinforced concrete beam column joint wrapped with CFRP

NAGUMALLI KEDAR NATH, T. M. JEYASHREE
Department of Civil Engineering, SRM University, Kattankulatur, Chennai, India
Email: nkedarnath92@hotmail.com

Abstract: Buildings are collapsed due to brittle failure of reinforced concrete (RC) beam column joint, which faces severe damages by earthquakes of high magnitude. The focus of this study is to evaluate the behavior of beam column joint retrofitted with carbon fiber reinforced polymer wrapping (CFRP). Five beam column joint specimens including one conventional specimen and four retrofitted specimens of different configurations of CFRP sheets were modeled using ANSYS and was analyzed to find the improvement in various parameters of beam column joint. Parametric study is carried out by varying thickness of CFRP wrapping and the thickness considered are 2 mm and 6 mm for both single layer and double layer. From the analysis output, it is observed that CFRP reduces the deflection and improves stiffness, maximum principal stress and minimum principal stress.

Keywords: *Retrofitting, CFRP, Beam Column Joint*

Introduction:

The interaction portion of beam and column is called beam column joints. These joints have low load carrying capacity and strength due to insufficient reinforcement. When natural calamities like earthquake occurs, it create creates large forces which may cause severe damage to the joints of the building or total collapse of the building. The building should survive the earthquake, may be with severely damaged joint but not total collapse of the building. To decrease the vulnerability of earthquake, joints need to be retrofitted. There are many retrofitting techniques like bonded steel plates, steel or concrete jacketing, textile reinforced concrete and using FRP sheets available in the market. But using FRP sheets has been better option due to its results of significant improvement in lateral strength, stiffness & ductility. CFRP is used for present study because of its properties like corrosion resistant, high strength to weight ratio, good fatigue & fire resistant. Modeling and analysis of reinforced concrete beam-column joints have been carried out using ANSYS to understand the behavior of retrofitted RC beam column joint specimens retrofitted with carbon fiber wrapping sheets. The different thickness of CFRP sheets used in our work are 2 mm CFRP sheet single layer, 2 mm CFRP sheet double layer, 6 mm CFRP sheet single layer and 6mm CFRP sheet double layer.

Research Background: ROBERT RAVI S. et al. (2010) carried out non linear analysis for three beam column joints. i.e., non seismic designed specimen, seismic designed specimen and non seismic designed specimen wrapped with GFRP sheet. Comparison results show greater reduction in deflection by using GFRP sheets.

S PATEL. et al. (2013) worked on analysis of reinforced beam column joint subjected to monotonic loading. Analysis was done to both corner and external beam column joints under different support conditions. It was observed that fixed support condition for both joints shown less displacement, principal stresses when compared to hinge support condition.

Kien Le-Trung, et al. (2009) conducted experimental study on strengthening the shear capacity of non-seismic joints using (CFRP).The specimens with different configurations of CFRP application and tested under seismic loading. It was concluded that seismic resistance was improved when orientation of wrapping was inclined at 45^{o} to beam axis. Increasing number of layers of CFRP improves strength and ductility.

Saleh H. ALSAYED. et al. discussed about performance of retrofitted corner beam column joint by CFRP.Damaged corner beam column joint was repaired, CFRP sheet was wrapped to the joint and mechanical anchorage was given. Experimental results show that CFRP helped repaired joint to gain the load carrying capacity by 88% and ductility by 97%

Murat Engindeniz, et al. (2008) investigated experimental adequacy of corner beam-column joints which are designed according to old codes of USA. Tests were conducted on retrofitted CFRP and conventional specimens. Retrofit with CFRP composites in low strength concrete have shown joint strength improved but significant reduction in overall stiffness.

N. H. Hamid, et al (2013) checked adequacy of beam column joint with corbel was tested under lateral cyclic loading. Retrofitted specimens were tested and checked for crack propagation until its failure. Results shows that lateral strength and stiffness is increased after retrofitted.

Modelling:
The models of beam column joint used for the present study are shown in Figure -1 and Figure -2. Both beam and column reinforcements are designed for non seismic consideration using IS 456: 2000 and SP 16. Beam having a length of 1000 mm with 4 number of 20 mm diameter steel bars are used as main reinforcements and 8 mm diameter steel bars stirrups are used as transverse reinforcement with 130 mm c/c. Column having a length of 1000 mm with 4 number of 20 mm diameter steel bars are used as main reinforcement and 8 mm diameter steel bars are used as lateral ties with 200mm c/c.

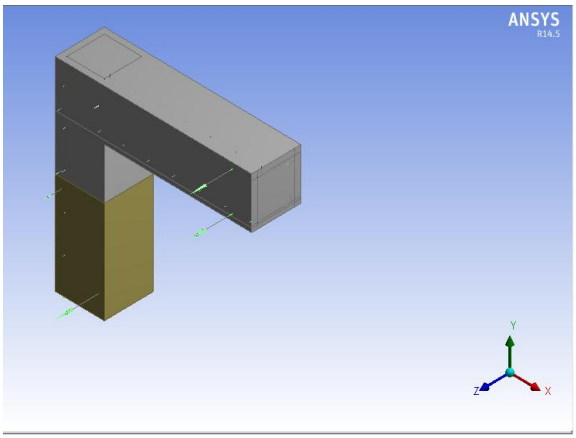

Figure -1 *ANSYS model of conventional specimen*

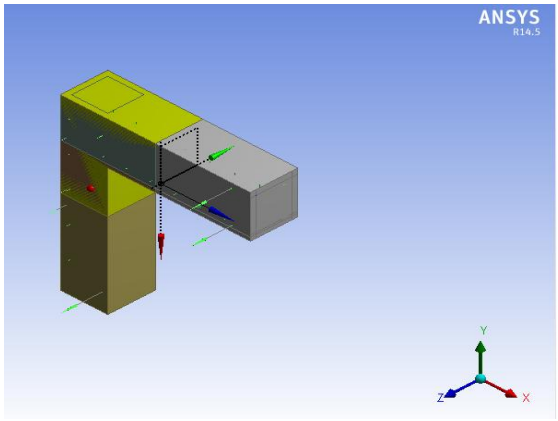

Figure -2 *ANSYS model of specimen wrapped with CFRP*

Modelling of beam column joints has been done using ANSYS package which is used to solve the difficult model analytically with high precision. The beam column joints are modelled as mentioned earlier. Deformable joint connections are given in between concrete and steel. Solid 186 and beam 188 elements are used to model concrete and reinforcement in ANSYS respectively. The CFRP sheets which are used as wrapping material in this work are modelled using shell 181. After modelling of these joints, meshing has been carried out. Boundary conditions of these joints are fixed and free conditions for column and beam respectively. Typical meshed views of specimens are shown in figure -3 and figure -4.

Non–linear analysis was done for five beam-column specimens subjected to static incremental loading. A 30 kilo Newton (kN) static loading is applied at the edge portion of free end of the beam with incremental rise of 6 kN for every beam column joint specimens.

Results and Discussions:
After analysing the specimen, post processing shows the required results. In the present study, the parameter like deflection, stiffness, maximum principal stress, minimum principal stress are analysed for beam column joints under static loading and results are shown in the Table -1, Table - 2, Table - 3, Table - 4 respectively. Figure 5 shows load versus deflection curve for both conventional and retrofitted specimen. Figure – 6, Figure – 7 and Figure – 8 shows the results of deformed specimens under static loading. Figure 11 shows the load vs. deflection curve of conventional and retrofitted specimens.

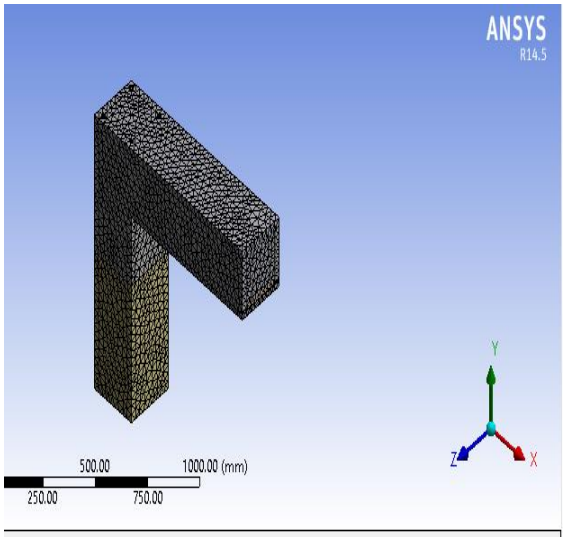

Figure -3: *Typical meshed model of conventional specimen*

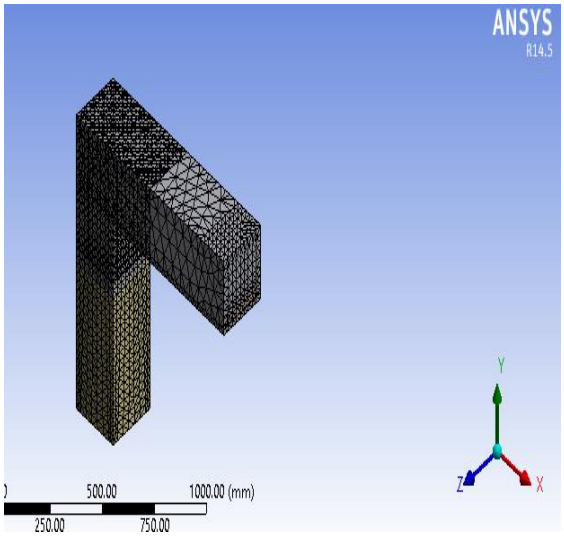

Figure – 4: *Typical meshed model of CFRP specimen*

Table -1: *Deflection of beam column joint specimen under incremental static loading*

Load (kN)	Deflection (mm)				
	Conventional specimen	2 mm CFRP single layer	2 mm CFRP double layer	6 mm CFRP single layer	6 mm CFRP double layer
6	0.4324	0.41766	0.40618	0.38287	0.35346
12	0.86481	0.83402	0.81109	0.76454	0.70581
18	1.2972	1.2491	1.215	1.145	1.057
24	1.7296	1.6629	1.6176	1.5243	1.4072
30	2.162	2.0755	2.0188	1.9025	1.7562

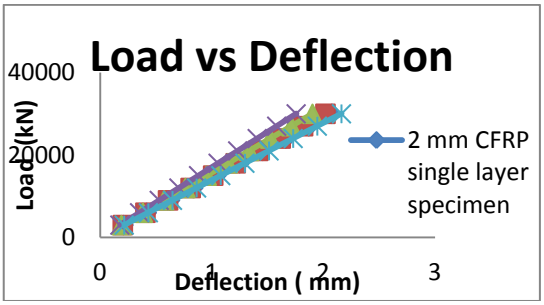

Figure – 5 *Load vs. deflection curve for beam column joint specimens*

Under incremental static loading, deformations of specimens are increasing. CFRP specimens show lesser deflection when compared to conventional specimen. Beam column joint retrofitted with 6 mm CFRP double layer shows 19 % reduction in deflection compared to conventional specimen.

For every increase in 2 mm thickness of CFRP wrapping single layer causes decreases in deflection by 4%.

From Table 2 it is observed that CFRP wrapping increases stiffness with the increase in loading whereas for the conventional specimen stiffness remains same. At the load of 30 kN, 2mm CFRP single layer has 4.2% increase in stiffness compared to the conventional specimen and 6mm CFRP single layer has 13% increase in stiffness.

Beam column joint specimen's shows increase in maximum principal stresses with increase in loading. A conventional specimen shows lesser stress than retrofitted specimen. Retrofitted specimens having higher CFRP thickness specimen shows lesser deflection than lesser thickness one.

Table- 2 *Stiffness of conventional and retrofitted beam column joints*

Load (N)	Stiffness (N/mm)				
	Conventional specimen	2 mm CFRP single layer	2 mm CFRP double layer	6 mm CFRP single layer	6 mm CFRP double layer
6000	13876.04	14365.75	14771.78	15671.12	16975.05
12000	13876.04	14388.14	14794.91	15695.71	17001.74
18000	13876.04	14410.38	14814.81	15720.52	17029.33
24000	13876.04	14432.62	14836.8	15744.93	17055.14
30000	13876.04	14454.35	14860.31	15768.73	17082.34

Table – 3 Maximum principal stress results under incremental static loading for beam column joint

Load (N)	Maximum principal stress (MPa)				
	Conventional specimen	2 mm CFRP single layer	2 mm CFRP double layer	6 mm CFRP single layer	6 mm CFRP double layer
6000	0.58079	0.9295	0.87227	0.75512	0.62575
12000	1.1616	1.8583	1.7439	1.5097	1.2512
18000	1.7424	2.7865	2.5551	2.2639	1.8763
24000	2.3232	3.7141	3.4858	3.0175	2.5012
30000	2.9039	4.6411	4.3557	3.7706	3.1257

Table - 4 Minimum principal stress results under incremental static loading for beam column joint

Load (N)	Minimum principal stress (MPa)				
	Conventional specimen	2 mm CFRP single layer	2 mm CFRP double layer	6 mm CFRP single layer	6 mm CFRP double layer
6000	4.0159	3.8131	3.4368	3.293	3.1614
12000	8.0319	7.6181	6.8719	6.5787	6.3212
18000	12.048	11.415	10.305	9.857	9.31
24000	16.064	15.204	13.737	13.128	12.639
30000	20.08	18.985	17.169	16.392	15.794

From Table 4 it is observed that there is a gradual increase in minimum principal stress with increase in loading. There is a reduction in stress with increase in thickness of CFRP.

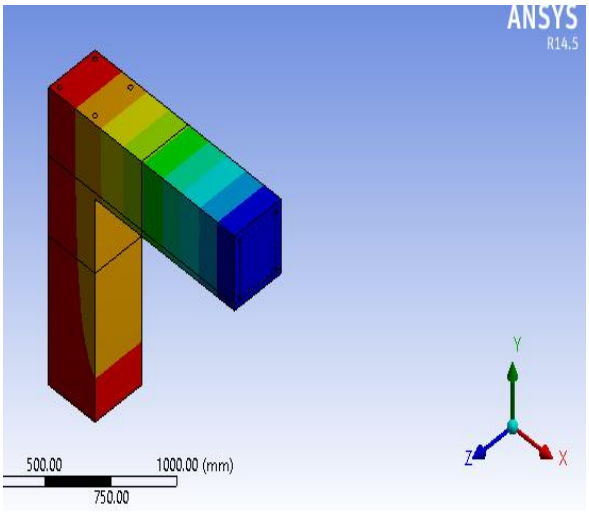

Figure – 6 *Deformed specimen of conventional specimen*

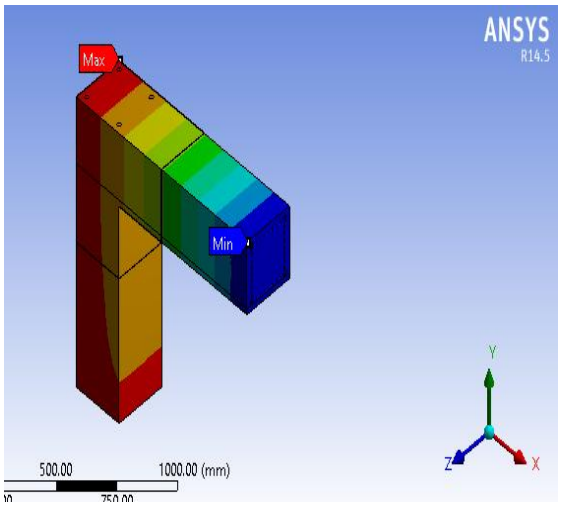

Figure – 7 *Deformed joint of typical CFRP single layer specimen*

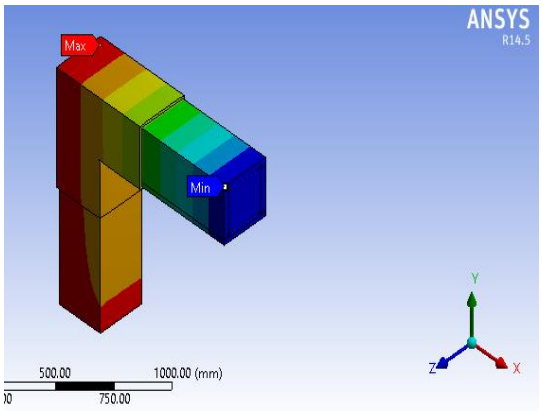

Figure – 8 *Deformed joint of typical CFRP double layer specimen*

Conclusion: In this present study effectiveness of using CFRP wrapping for beam column joint was studied. From the analysis study it is observed that CFRP improves load carrying capacity of beam column joints. Change in thickness of CFRP sheets used for retrofitting shows significant change in deformation of specimen. From this analytical study, the following observations are made:

1. Compared to conventional specimen, single layer 2mm CFRP swrapped specimen has 4 % reduction in deflection.
2. Compared to conventional specimen, double layer 2mm CFRP sheet wrapped specimen has 7 % reduction in deflection.
3. Compared to conventional specimen, single layer 6 mm CFRP sheet wrapped specimen has 12 % reduction in deflection.
4. Compared to conventional specimen, double layer CFRP wrapped specimen has 19 % reduction in deflection.
5. CFRP wrapped specimen has more stiffness compared to the conventional specimen. For the conventional specimen, stiffness remains same with the increase in loading and for CRFP wrapped specimen, stiffness increases with the increase in loading.

   From the present study, it is concluded that CFRP wrapping improves the performance of the beam column joint.

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