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Strengthening of High Strength Concrete Beam Column Joints using FRP

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ABSTRACT

The entire world built-up space is being made with concrete being the basic construction material. The advancement in the construction technique has raised the height of buildings as compared to the past. Although the design of structures follows the safety and serviceability rules according to the specialized codes formulated by different countries as per the geographical location, the greatest threat to all the frame buildings is the phenomenon of earthquake. The sudden vibration of the earth on which the structure is resting makes the Beam Column joints the vulnerable part. This experience of large deformations during the seismic excitation is not feasible because this join is the first element which overtakes cracks in such situations. Many research scholar have formulated one of the best solutions to this problem is the confinement of beam column joints. From literature review it is found that use of fiber reinforced plastic can strengthen the joints and are being effectively used for retrofitting due to ease of accessibility and placement. This experimental study is carried out to investigate the behavior and/or performance of RC interior beam column joints by using FRP. In total four specimens have been casted and rehabilitated with CFRP (Carbon Fiber Reinforced Polymer), the specimens were subjected to incremental cyclic loading applied by hydraulic jacks under constant axial or gravity load, deflection was recorded corresponded to load. The behavior of rehabilitated specimen is compared to the undamaged specimens. It has been observed that the wrapping with double layer over double layers of overlay of CFRP sheets exhibit the great and satisfactory results among the entire wrapping scheme applied to the specimens.

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1. INTRODUCTION

The main reason for collapse of any building is the weak column beam joints found in the aftermath of the earthquake investigation. This does not only affect the economic fundamentals but also possess a great risk to the life of multitudes. In the last some decades, the studies and application of composites with respect of the building construction is focused more towards the strengthening of existing buildings in order to be sustainable. The growing interest of using FRP (Fiber reinforced polymer) are due to several advantages compared to traditional ones such as their lightweight, noncorrosive character and high tensile strength moreover these materials are available in several forms: unidirectional strips, sheets or fabrics made by fibers in one or two directions and in the form of bars. Carbon fiber reinforced polymer (CFRP) strips in the form of laminates and fabric are generally constructed of high-performance carbon fibers which are placed in resin matrix. These composites can be easily bonded to RC elements externally as discussed they are very easy to use and handle. Less human efforts and machines are required in this method of strengthening that is why FRP method has been become one of the recent methods for retrofitting. The problem of non-seismically designed reinforced concrete (RC) frame structure before 1970s is common among all the seismically active region in the world. Beam-column joints are regarded as one of the most vulnerable and critical structural element. As studies has shown that inadequacy of existing structures has been repeatedly highlighted by heavy damage or total collapse caused by earthquakes. Infact, many RC buildings were designed mainly for the action due to static gravity loads with no consideration given to the lateral strength required to resist the inertial forces of the structure's mass. In addition, deficiencies in seismic performance are generally a consequence of the lack of ductility which is a consequence of two major failures in the design process; poor detailing of reinforcement and the lack of capacity of design philosophy. It is of crucial importance to devise effective and economical rehabilitation techniques to mitigate the vulnerability of existing structures and to increase the safety of the occupants for future earthquake events. Therefore, many techniques have been used for strengthening as jacketing, shotcrete, post- tensioning etc. which have some disadvantages and limitations. FRP is also one of them and has been widely used nowadays due to its properties and accessibility. FRP is available in various forms i.e. mesh, rods, fabric, laminates etc. which is being used according to requirements for proper strengthening and rehabilitation of damaged or deteriorated specimens.

1.1. FRP Strengthening System

The system of wrapping the column beam joints is along the length because of the homogeneity of the structural joint. The primary function of FRP is to carry the load along its length and provide strength and stiffness. There are three main types of FRP system which includes Aramid, Glass, and Carbon FRP. The Carbon fiber reinforced polymer plate which has high strength amongst all the type of FRP is generally used. These materials are used in various forms such as laminates, rods, fibers (sheets), mesh differently according to the need or requirement. An epoxy is generally used as an adhesive material to establish a good bond. Beam Column joint is the weakest part of the structure as it is not casted monolithically unlike slab and beams which are casted together and making a stronger joint. During earthquake, it causes large inelastic deformations in the beam-column joints which eventually develop cracks. FRP can be used in different ways to repair the cracked beam column joints.

1.2. Wrapping Schemes of FRP

There are three major wrapping schemes that applied in the shear strength of reinforced concrete.

- Complete wrapping
- U-shaped wrapping
- Two side wrapping

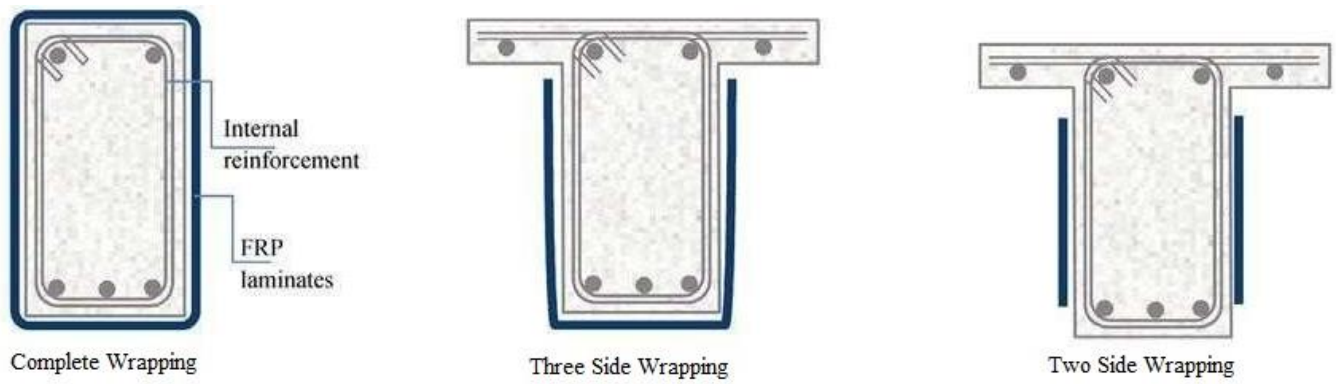

Fig 1: Wrapping Scheme for Shear Strength Using FRP

Apart from the scheme and illustration of wrapping the following table shows the arrangement of application of FRP

Table 1 Application

S. No.	Types	Application of FRP	Fiber direction
1.	Flexural	Apply in tension zone, and/or side face of beam	Along longer axis of the beam
2.	Shear	Side face of beam	Perpendicular to the longer axis of the beam
3.	Confinement	Around column	Circumferential

2. Investigations

This technique has been into the system from a very long time and various investigation ranging from the strength parameters to the shear and stiffness capabilities has been checked by the various researchers.

2.1. Previous Investigation

In the year 1999, Li et al.[1] had presented the experimental solutions for selecting FRP materials according to the needs and requirements of any RC structure. In the experiment, the prototype size RC beam-column joint specimens wrapped with FRP laminates. The strand mat, glass fiber tape and vinyl-ester resin was used as an adhesive material and the connection strength was observed under static loading. The conclusion was made that the FRP can be used for better strengthening of damaged beam-column joints. Similarly, Mukherjee A. et al.[2] in the year 2005 had done the experimentation on the behavior of beam-column joints under cyclic loading. It showed that the glass fiber and carbon fiber can be used to strengthen the RC joints efficiently. Carbon fiber reinforced polymer came out to be stiffer than Glass fiber reinforced polymer.

In one of the recent investigation in the year 2016 Kharva Hardik and Dhayani Dhruti[3] displayed the results of experimental investigation of application of Uni- directional Carbon Fiber Reinforced Polymer (CFRP) and Chopped Strand Mat (CSM) to strengthen the beam-column joints. The whole experiment was consisted of 12 interior beam-columns as control specimens. Three specimens were wrapped with CFRP and three were wrapped with CSM while other six specimens were wrapped using hybrid system. After treating the specimens they were tested till failure under static loading. The performance of rehabilitated specimens was then compared to the original specimens and it was found that the use of both CFRP and CSM increased the load carrying capacity and decreased the deflection.

2.2. Current Study

It is quite evident from the various studies that the weakest link is the column-beam junction joint and therefore special attention is required in that area. Despite the diversity of the research the investigation did not involve the effects of different epoxy raisin on the joint. Furthermore the FRP has been used on the single side of either beam arm or the column face and that too on the normal grade of concrete. Hence the objective of the current study was aimed at increasing the strength of strengthened specimen (beam-column joints of HSC) over undamaged specimens. The strength of damaged specimens can be upgraded by using different materials and proper configuration of FRP materials.

3. Experimental Methodology

The main methodology revolves around the selection of material and casting the high strength concrete column-beam specimens. The selection of FRP was also based on the pattern and to the requirement of rehabilitation. Lastly, the investigation proceeded to the structured performance under the cyclic loading. Before applying the FRP material on the surface of beam-column joint of damaged specimens, surface preparation is done which includes removal of all the debris and damage concrete is removed through air pressure. The sealing and grouting is done to fill the wide cracks of damaged specimens. After strengthening process, the Strengthened specimens is tested again in load frame machine as it was done for control specimen to examine the structural performance of specimen. Thereafter, the results are compared before and after the strengthening for the proper selection of FRP material.

3.1. Material Used

The selection of materials are done considering the codal requirements. Two types of concrete grades are prepared and those are M70 as high strength grade and M20 as normal strength grade. The guide-lines of ACI and IS are being followed to prepare the different concrete grades. The materials that are used are:

- Cement (replaced by 10% with silica fume)
- Sand (yellow and black)
- Coarse aggregates
- HRWR
- Silica fumes
- Water.

3.2. Casting of Specimens

Beam-column joint is casted in steel form work. has been used to cast beam-column joints. At First, surface of the steel mould is cleaned perfectly and oil is applied thereafter for the easy removal of specimen without disintegrated or without causing any damage to the specimen. The mixed concrete of M70 and M20 is placed inside the formwork respectively by using compressor for compaction. The central portion is made of M70 and remaining part is of M20 therefore a partition plate is used to separate the both calculated area as required and after compaction those plates are removed from formwork. 4 specimens are carried out of same dimensions as control specimen for testing and cured for 28 days have been casted as control specimens for testing and cured for 28 days for getting designed strength. 8 mm dia. of main reinforcement is used for beam and column and 150mm c/c spacing is provided in stirrups and ties as well as for beam and column respectively.

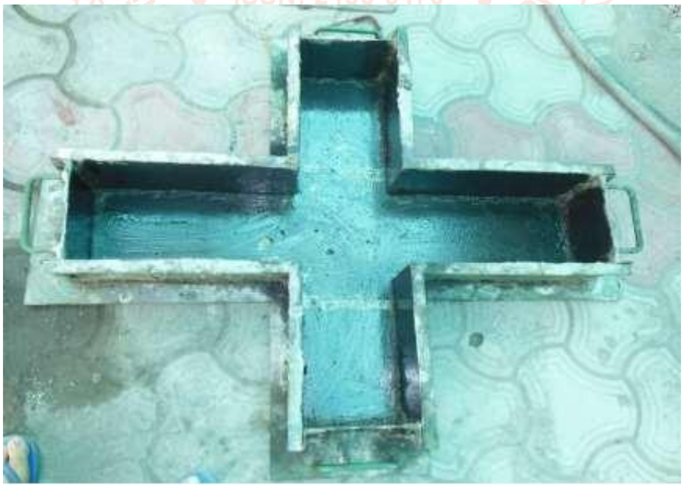

Figure 2 Formworks

3.3. Testing of Specimen

After the casting of beam-column joint, they are tested for comparing the structural performance with strengthened specimens. The specimens are tested in load frame machine by applying the hydraulic loading at the tip of the beam to determine the load specimen can carry and deflection with respect to the load is also recorded for every 10seconds. Cyclic load was applied according to the strength of the specimen, control specimens failed after 3 cycles of loading because of its high strength. The results are made in view of first cycle as it has given the maximum load.

Fig 3: Testing of Controlled Specimen

Four specimens are carried out for the experimental study and same procedure are followed for all the three specimens. It has been shown that different specimens have given different results on the basis of carried load by specimen and got deflection in beam before failure of junctions.

4. Results

The experimental values for load and deflection of undamaged and rehabilitated specimens are given below. Comparison of performance and strength of undamaged and rehabilitated specimen is discussed below

Table 2 Results of single layer wrapping of CFRP sheet

	Undamaged specimen		Strengthened Specimen	
	Load (KN)	Deflection (MM)	Load (KN)	Deflection (MM)
1st cycle of loading	00	00	0	0
	20.10	4.23	**15.83**	0.56
	43.65	5.46	30.55	1.39
	65.14	6.97	49.29	2.35
	85.29	8.59	69.32	3.34
	103.23	10.39	86.60	4.40
	110.16	13.13	98.72	5.78
2nd cycle of loading	00	9.96	00	4.37
	21.04	10.71	22.04	5.68
	42.56	11.71	43.72	6.99
	62.42	12.70	59.62	9.23
	82.85	14.33	82.95	10.85

Load at which first crack appeared in undamaged specimen = 65.14 KN
Load at which the first crack appeared in the rehabilitation specimen = 15.83 KN

In second cycle of loading, the load carried by undamaged specimen is more than the rehabilitated specimen. Therefore, single layer wrapping scheme did not exhibit the good results.

4.1. Experimental results of undamaged and rehabilitated specimens using CFRP sheet in double layer wrapping.

In this the specimen is rehabilitated with double layer of CFRP sheet which exhibited the better performance as compared to single layer wrapping. Below are the results in the form of table and as well as graph.

Table 3 Results of double layer wrapping of CFRP sheet

	Undamaged specimen		Strengthened Specimen	
	Load (KN)	Deflection (MM)	Load (KN)	Deflection (MM)
1st Cycle of Loading	00	00	0	0
	21.48	2.02	**21.52**	0.21
	41.65	3.60	42.79	1.26
	62.34	5.28	56.34	2.10
	84.43	7.48	87.61	3.30
	98.13	9.98	103.96	7.70
	108.03	12.49	121.02	11.24
	00	8.65	00	10.09

2^{nd} cycle of loading	23.47	9.57	15.51	11.57
	43.03	10.68	36.38	12.59
	58.16	11.56	53.01	12.10
	70.44	13.21	65.17	14.56

Load at which first crack appeared in undamaged specimen = **41.65 kN**
Load at which first crack appeared in rehabilitated specimen = **21.52 kN**

4.2. Experimental results of undamaged and rehabilitated specimens using CFRP sheet over CFRP laminate.

	Undamaged specimen		Strengthened Specimen	
	Load (KN)	Deflection (MM)	Load (KN)	Deflection (MM)
1^{st} Cycle Of loading	00	00	0	0
	15.27	4.67	**15.21**	2.90
	29.17	5.19	37.42	5.80
	50.82	6.39	41.40	8.70
	70.58	8.51	57.67	9.50
	85.99	10.83	81.98	11.07
	95.69	13.09	101.19	16.15
2^{nd} cycle Of loading	00	9.75	00	15.17
	21.62	11.37	20.36	20.92
	41.10	12.21	35.37	25.38
	61.78	13.01	45.16	28.17
	80.95	14.63	-	-

Load at which first crack appeared in undamaged specimen = **61.04 kN**
Load at which first crack appeared in rehabilitated specimen = **22.66 kN**

5. Conclusion and Future Scope

The objective of the study were to carry out the column- joint performance of undamaged and strengthened specimens by using CFRP to draw out some conclusions to recommend method of rehabilitation or retrofitting. To achieve above objective, the experiment was carried out in two cycles.

There are many conventional methods of retrofitting but there are some limitation which cause aesthetic degradation and consumes time on the other hand, FRP system has many advantages over conventional system that is why FRP is considered to be more effective in strength of existing structure as well as it is less time consuming.

The followings are the conclusions:-

A. The strength of damaged specimen was not enhanced as compared to control specimen using single layer wrapping of CFRP sheet.
B. Double layer wrapping technique exhibited better results as compared to single layer wrapping technique. The increase in strength is observed by 12% in first cycle of double layer wrapping.
C. The strength of rehabilitated specimen was found to be decreased in second cycle. The decrease is observed in the range of 4% to 5%.
D. The double layers of wrapping with double layers of overlays exhibited the best and satisfactory results among different wrapping technique which carried higher load and showed lesser corresponding deflections. The strength was enhanced by 33%.

5.1. Future Scope

There is always a scope to do something which has not been done and continuing with this there are a lot of scope of this kind of investigations. Higher grade, Aramid Fiber Reinforced Polymer with wrapping can be used. Durability and various other related parameters can be studied.

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