Rehabilitation of Damaged Beam-Column Joint of High Strength Concrete By Using FRP

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Abstract- *The beam-column joint is considered as the most critical zone of any RC structure. The lack of joint region, the poor properties due to the use of plain round bars and inefficient anchorage into joint region, an improper provision of development length for beam joint, inadequate spliced reinforcement for the column can be attributed to poor seismic performance of these elements. As a result, many poorly designed and constructed buildings in earthquake-prone area often suffer shear and/or bond failure during earthquake, leading to partial or total collapse of a structure. During the last two decades, the studies and application of composites in a construction more partially in the strengthening of existing buildings, represented one of the fastest growing new areas within structural engineering. 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. 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. There are many conventional methods of retrofitting but there is 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 strength of damaged specimen was not enhanced as compared to control specimen using single layer wrapping of CFRP sheet. 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. The strength of rehabilitated specimen was found to be decreased in second cycle. The decrease is observed in the range of 4% to 5%. 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%. The performance or influence of different retrofitting techniques on the ultimate ductility and strength of the sub assemblage may vary depending upon the strength of concrete and load ratio.*

Keywords- Beam-column joint, Fiber reinforced polymer, Carbon fiber reinforced polymer, reinforced concrete

I. INTRODUCTION

The beam-column joint is considered as the most critical zone of any RC structure. The lack of joint region, the poor properties due to the use of plain round bars and inefficient anchorage into joint region, an improper provision of development length for beam joint, inadequate spliced reinforcement for the column can be attributed to poor seismic performance of these elements. As a result, many poorly designed and constructed buildings in earthquake-prone area often suffer shear and/or bond failure during earthquake, leading to partial or total collapse of a structure. During the last two decades, the studies and application of composites in a construction more partially in the strengthening of existing buildings, represented one of the fastest growing new areas within structural engineering. 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 necessity of ensuring the long-term sustainability of existing structures is rising. An important issue concerning existing reinforced concrete (RC) structures in seismically active regions is that a significant number of them lack the required earthquake-resistant capacities to meet the increased design earthquake demands. Inexpensive, fast and long-term strengthening strategies for repairing/strengthening RC structures are urgently required, not only after destructive earthquakes, but even before they occur. Studies on structural damages caused by earthquakes worldwide have shown that the joint areas of RC frame-system structures are the most vulnerable. A large number of the existing RC buildings have been constructed according to older regulations without particular planning for the reinforcement of the joints. The inadequate shear reinforcement in the joint area and especially in external joints has been proven to lead to brittle response and is the primary cause of the collapse mechanism formation during earthquake loading. The response of beam-column joints is affected by a variety of parameters such as bond, shear load, confinement and fatigue, which are not yet well understood even independently, and they progressively reduce the joint's stiffness and strength. Therefore, the successful repair or strengthening of joints that have previously been damaged during cyclic loading caused by earthquakes is essential in order to enable the use of the affected structure again. Detailed design recommendations have been introduced on the basis of the research and development of repair techniques in Europe and the United States in past decades. Regardless, the further development of cost-effective rehabilitating strategies for RC frame joints remains of great interest. A well-known repair technique commonly used after earthquake excitations is based on the infusion of thin resin under pressure in the cracking system of the damaged body. The effectiveness of this technique, which has been widely used, has been experimentally confirmed by Karayannis et al. In addition, the injection of resin into the crack system in combination with external fiber-reinforced polymer (FRP) sheet adhesion has been proven to be particularly effective in restoring and improving joint response. We discuss two sets of experiments that were carried out on full-scale RC beam-column joints. The specimens were subjected to cyclic loading and two different FRP rehabilitation methods were applied. Some specimens where rehabilitated using the technique widely applied in practice that combines high strength mortar with external application of carbon FRP (C-FRP) sheets, while others were strengthened using the recently proposed technique with C-FRP ropes. Some of the experimental specimens have previously been presented by the authors in recently published studies, however, the scope of the current study is to examine the effectiveness of the novel C-FRP rope strengthening method compared to the frequently used C-FRP sheet application. New experimental results of the application of the novel method are also presented to support the effectiveness investigation. Furthermore, a thorough description of the promising novel technique's application on external RC beam-column joints is also provided.

II. MATERIALS USED

Following materials are used for studying the mechanical properties of Concrete for this study use agricultural waste, eco-friendly material. Materials to be used are as follows:

Cement

There are various grades of Ordinary Portland Cement as OPc33, OPC 43, and OPC 53 which attain their compressive strength with respective time. In this experimental study, OPC 43 is used which attains its compressive strength as 43 MPa in 28 days.

Sand

Sand is sieved through 4.75mm sieve and complying with zone III. Indian standards 388:1970 and regional standards are acquired for the sand selection. Yellow and black sand is used in the proportion of 1:1.5.

Coarse aggregates

The aggregates which retain over IS sieve are called coarse aggregates and are classified as: -

i. Crushed gravels or stone acquired by crushing of rock or hard stone.
ii. Uncrushed rock or stone coming about because of the regular breaking down of rocks. Partially crushed rock acquired as result of mixing of above two types.

The Coarse aggregates of size 10mm and 12mm oversized aggregate are used to increase the interlocking property and are mixed in optimum proportion.

Fineness modulus = 7.648 Silica fumes

Silica fume is made of finest particles and the particles of silica fumes are around 100 times lesser than cement particles. Silica fume is widely used with cement in optimum proportion due to its fineness and silica content. Silica fume is added with cement to increase the properties of concrete Silica fume effect the slump of concrete, slump loss is directly proportional to the increase in the silica fume content. Ultimately, silica fume affects the workability of concrete and increases the cohesiveness of concrete. Therefore, these are the reasons silica fume is added.

Water

Water plays an important role in reacting with cement concrete and reinforcement and is important to keep the water free from harmful contaminants. Water from canal, river and streams can be used for mix design process. Organic substances i.e. sugar, oil, grease etc. affect the hydration process and strength of concrete. No special tests are required or carried out for the selection water but it should be free from harmful contaminants (suspended particles, sulfate and chloride). In this project, potable water is used that is free from such contaminants.

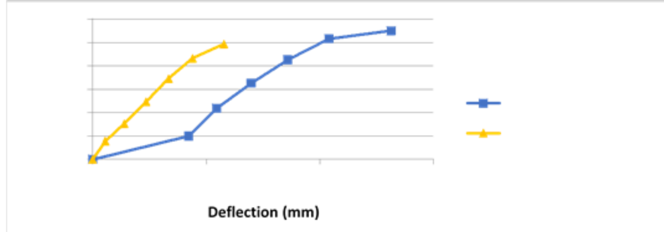
Super plasticizer

Super plasticizer is an admixture used here well-dispersed particle suspension is required and it is considered to be high rate water reducer HRWR. Conplast SP430G8 from Forsoc is used as super plasticizer to make high strength concrete as it is suggested by the experts that the use of HRWR should be in the range of 0.6% to 2% by weight of cement The characteristics of used super plasticizer are described below:

1) Suitable for high performance concrete.
2) Increases workability.
3) Chloride free.
4) Dispersing capability.
5) Water proofing characteristics.
6) Minimizes the segregation.
7) Suitable in using with concrete containing silica and other cement replacements.

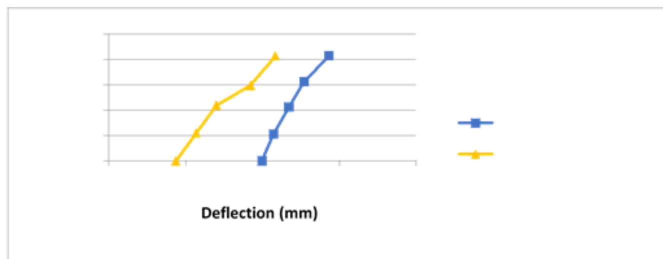
II. EXPERIMENTAL RESULTS

Load at which first crack appeared in undamaged specimen = 65.14 kN
Load at which first crack appeared in rehabilitated specimen = 15.83 kN



Graphical representation of first cycle of loading of single wrapping CFRP sheet

experimental results of undamaged and strengthened specimens of cycle 1 and cycle 2 are represented in the form of graph. Where, rehabilitated and undamaged specimens are shown in respective colors. Whereas, Y-axis is showing load and X- axis is showing deflection with respect to load.
Further, for loading under cycle 1 it is indicating that the strength of damaged specimen is not enhanced as compared to control specimen using single layer wrapping of CFRP sheet.



Graphical representation of second cycle of loading of single wrapping CFRP sheet

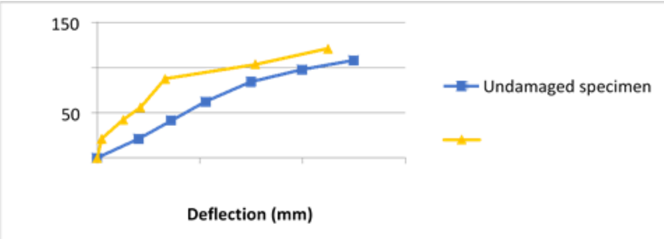
Experimental results of undamaged and rehabilitated specimens using CFRP sheet in double layer wrapping.

In this experiment, 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.

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
2nd cycle Of loading	00	8.65	00	10.09
	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



Graphical representation of first cycle of loading of double wrapping CFRP sheet

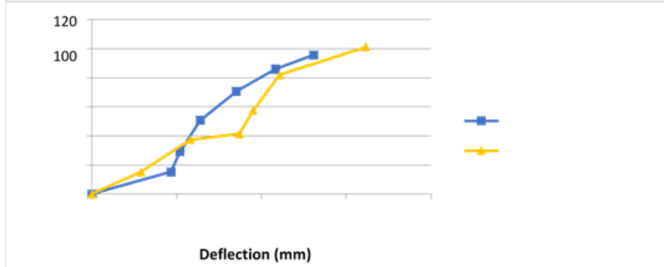
In second cycle of loading, the strength of rehabilitated specimen is decreased by 4% whereas the deflection is increased. On comparing, undamaged specimen carried more load in second cycle than rehabilitated one.

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

Results of single layer wrapping with CFRP sheet over CFRP laminate

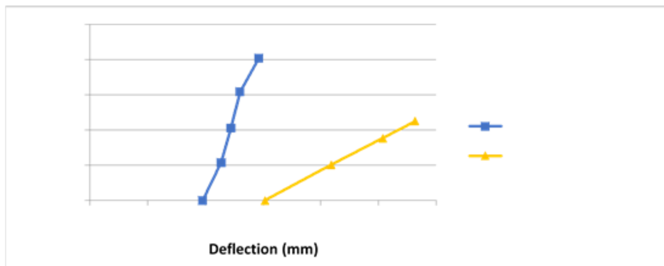
	Undamaged specimen		Strengthened Specimen	
	Load (KN)	Deflection (MM)	Load (KN)	Deflection (MM)
1st Cycle Of loading	00	00	0	0
	15.27	4.67	**15.21**	2.90
	29.17	5.19	37.42	5.80
	50.82	6.39	41.40	8.70
	70.58	8.51	57.67	9.50
	85.99	10.83	81.98	11.07
	95.69	13.09	101.19	16.15
2nd cycle Of loading	00	9.75	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 = 50.82 kN
Load at which first crack appeared in rehabilitated specimen = 15.21 kN



Graphical representation of first cycle of loading of single layer wrapping with CFRP sheet over CFRP laminate

It is observed that, the single layer wrapping over the laminate helped in increasing the load carrying capacity of rehabilitated specimen. Though the strength was not achieved as high as desired but it was capable of bearing considerable load. The increase in strength is found to be 6%.



Graphical representation of second cycle of loading of single layer wrapping with CFRP sheet over CFRP laminate

Above figure is the representation of second cycle of loading using CFRP sheet with CFRP laminate where it is being seen that the strength of rehabilitated specimen is decreased.

Experimental results of undamaged and rehabilitated specimens using double layers of wrapping with double layers of overlays

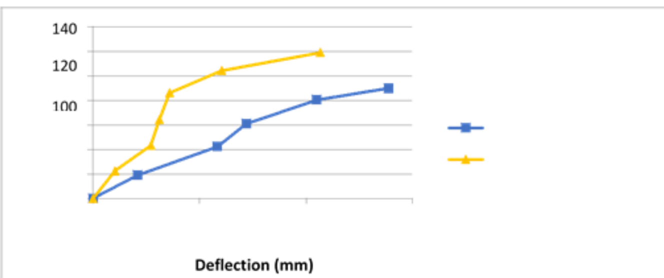
This type of wrapping gave the best result when compared to other scheme of wrapping.

Results of double layers of wrapping with double layers of overlays

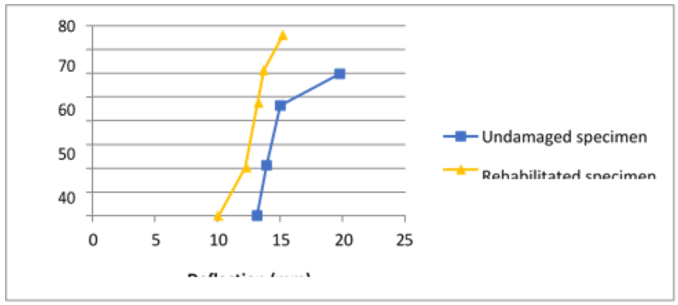
	Undamaged specimen		Strengthened Specimen	
	Load (KN)	Deflection (MM)	Load (KN)	Deflection (MM)
1st cycle Of loading	00	00	0	0
	19.04	2.09	**22.66**	1.02
	42.47	5.83	43.17	2.71
	61.04	7.19	64.59	3.11
	80.65	10.50	86.23	3.59
	89.9	13.87	104.40	6.04
	-	-	119.02	10.67
2nd cycle of loading	00	13.16	00	1.010
	21.16	13.94	20.30	12.21
	46.29	15.03	47.56	13.20
	59.68	19.78	61.17	13.68
	-	-	75.99	15.22

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

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



Graphical representation of first cycle of loading using double layers of wrapping with double layers of overlays



Graphical representation of second cycle of loading using double layers of wrapping with double layers of overlays

In second cycle of loading, the specimen still performed better and is persistent in exhibiting the good strength. On comparing, the double layers of wrapping with double layers of overlays gave the best and satisfactory results among all the techniques that were adopted during an experiment. It was observed that it helped in increasing the specimen's strength by 33%

Results of pull-off test

Test no	Fiber Type	Dolly no.	Test disc dia (mm)	Test disc (mm^2)	Effective load rate (MPa/s)	Pull-off trength (MPa)	Mode of failure
1	Single CFRP sheet on Concrete cube	1	50	1963	0.016	5.78	Bond failure between dolly and adhesive
2	Double CFRP sheet on Concrete Cube	2	50	1963	0.016	6.93	Bond failure between dolly and adhesive
3	Double CFRP sheet on Concrete Cube	3	50	1963	0.016	6.63	Bond failure between dolly and adhesive

The experimental results of pull-off test have been shown as.

- It has been observed that the pull-off strength for single CFRP sheet on concrete is 5.78 MPa.
- It has been observed that the pull-off strength for double CFRP sheet on concrete is 6.93 MPa and 6.63 MPa.
- FRP material with bonding agent (epoxy Sika 330) was not failed during test.
- The dolly was pulled out from adhesive.
- The minimum pull-off strength has been recommended as 1MPa and during test 5.25MPa has found for CFRP sheet with Sika 330 over HSC. Hence, used adhesive material is good for rehabilitation.

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