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Effect of Near Surface and Externally Bonded Retrofitting on Exterior Beam-Column Joint

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Abstract: ***To prevent the loss due to structural damages that can be resulted from the seismic activity, it is important that the structural elements should be retrofitted as soon as possible. Beam-column joints are the most vulnerable part of a structure, as the forces from adjacent beams and columns are transferred through the joint. In this study, a method for retrofitting RCC exterior beam–column joints using externally bonded Glass Fiber Reinforced Polymer (GFRP) sheet and Near Surface Mounted (NSM) GFRP strips (at different orientations such as 30^o, 45^o and 60^o) is proposed. All specimens were tested under reverse cyclic loading. The performance of beam-column joints was evaluated with respect to strength, ductility, energy absorption and stiffness degradation. The results show that the NSM retrofitted specimens with orientation of 30^o have significantly enhanced all the above properties.***

Index Terms: ***Beam-column joints, Near surface mounted retrofitting, Reinforced concrete.***

I. INTRODUCTION

In RCC structures, beam–column joints are the critical members for transferring forces and moments between beams and columns. Due to the moment reversal across beam–column joints, when subjected to seismic action, higher stresses are formed in the joint cores. Such beam–column joints become vulnerable members in moment resisting structures and display poor performance under seismic action according to post-earthquake investigations. Therefore, it is necessary to rehabilitate existing substandard beam–column joints for enhancing their seismic performance and extending their design life span [1]. Retrofitting can be done in two ways either in global manner or in local level. In the case of structures with higher level of flexibility or when no uninterrupted transverse load path is available, global retrofitting techniques are considered. This method includes addition of shear walls, bracings, infill walls, base isolation etc. In case of local retrofitting, the main aim is to improve the capacity of deteriorated isolated members. It is economical as compared to global retrofitting techniques. Local retrofitting techniques consist of jacketing of columns, beams, beam-column joints, strengthening of foundations etc. In this technique, the sheets of different materials such as GFRP, CFRP, ferrocement etc. will be bonded to the surfaces of the structural members to increase its strength. But debonding failure is a major disadvantage in these external retrofitting techniques, where rupture occurs suddenly once the ultimate strength is reached [2]. To improve this aspect in retrofitting, new strengthening methods are developed and Near Surface Mounted retrofitting is one among them.

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II. NSM RETROFITTING TECHNIQUE

In the NSM method, grooves are first cut into the concrete cover of an RCC element and the FRP reinforcement is bonded within it using an appropriate groove filler such as an epoxy paste or cement grout [3].

NSM steel rebars has been used in Europe for the strengthening of RCC structures which date back to the early 1950s. More recently, NSM stainless steel bars has been used for the strengthening of masonry buildings and arch bridges [2]. The advantages of FRP over steel as NSM reinforcement are better resistance to corrosion, increased ease and speed of installation due to its lightweight, and a reduced groove size due to the higher tensile strength and better corrosion resistance of FRP. Fig. 1 depicts the ways by which NSM systems can be applied to the structural component.

The objectives of this study are,

1) To study the effect of orientation of NSM Glass Fiber Reinforced Polymer (GFRP) strips on the performance of exterior beam-column joint

2)To compare the performance of the exterior beam-column joint retrofitted with NSM technique (GFRP strips) and with externally bonded GFRP wrapping

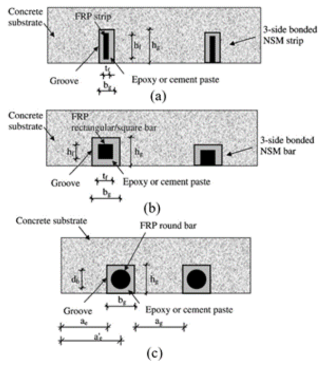

Fig. 1 NSM retrofitting with (a) Rectangular FRP strips, (b) Square FRP strips, (c) Round FRP bars [3]

III. EXPERIMENTAL STUDY

A. Materials used

Portland pozzolana cement, natural coarse aggregate with maximum size 20 mm, manufactured sand of fineness modulus 2.65, Glass Fibre Reinforced Polymer (GFRP) sheets and strips, epoxy adhesive. Table I shows the mechanical properties for both GFRP strips and sheets and Table II shows that of the epoxy resin supplied by manufacturer. Fig. 3 shows the GFRP sheets and strips used.

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B. Mix Design

Mix design for M20 was done by the method given in IS 10262:2009 [4]. Water cement ratio was fixed as 0.45. The fresh properties of the mix were evaluated by measuring the slump according to IS 1199-1959 [5].


(a) (b)

Fig. 2 (a) GFRP sheet, (b) GFRP strips

TABLE I: Properties of GFRP sheet*

Particulars	Values
Fibre thickness	0.90mm
Tensile strength	3400 N/mm^2
Tensile modulus	73000 N/mm^2

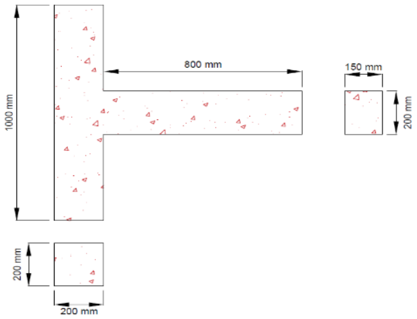
TABLE II: Properties of EP103 epoxy resin*

Particulars	Values
Application temperature	15- 400C
Density	1.25-1.26 gm/cc
Pot life	2 hours at 300C
Full cure	5days at 300C

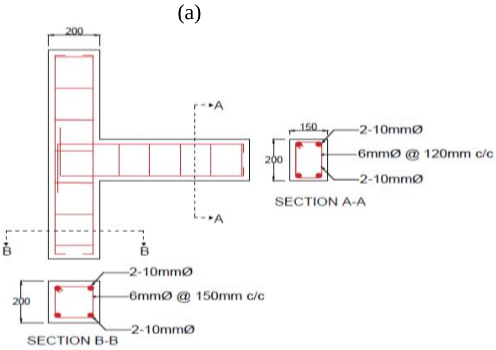
* (Source: Obtained from the supplier)

C. Casting of exterior beam-column joint specimen

A total of 10 numbers of exterior beam-column joints were prepared. The dimensions of the specimens are as shown in Fig. 2 and the specimen designation are shown in Table III. The size of the beam-column joint was selected as a scaled down model of 1/3rd of its original dimension.



(a)



(b)

Fig. 3 (a) Dimensions of the beam-column joint specimen, (b) Reinforcement detailing of beam-column joint [6]

TABLE III: Specimen designation

Sl. No.	Specime n name	Strengthening method	No. of specimen
1	BCJC	Control specimen	2
2	BCJN30	NSM retrofitting at 30°	2
3	BCJN45	NSM retrofitting at 45°	2
4	BCJN60	NSM retrofitting at 60°	2
5	BCJEB	Wrapping of GFRP sheets on the beam-column joint	2

D. Test setup

All the specimens were tested under reverse cyclic loading, in a 1000 kN capacity loading frame. The bottom end portion of column is kept partially fixed and top end is kept as hinge support. The hinged condition was incorporated by using a steel ball which is placed in-between the groove portions of the two identical plates made of steel. To make joint in stable condition during reverse cyclic load, 20% of the axial load carrying capacity of the column was applied over it by using a hydraulic jack. Reverse cyclic load was applied at the tip of beam through a hydraulic jack. A load cell, attached to the plunger measures the load. The deflection of beam tip is measured at every 2 kN load interval for forward and backward cycles using LVDTs. A schematic diagram of the test setup is shown in Fig. 3. The control specimens (BCJC), were tested as mentioned above and the ultimate load was obtained.

E. Pre-loading of specimens

The beam-column joint specimens designated as BCJ30, BCJ45, BCJ60 and BCJEB were subjected to a preload of 67% of ultimate load of BCJC specimen in reverse cyclic loading condition.

Fig. 4 Test setup of beam-column joints

F. Strengthening methods

The following strengthening methods were adopted for retrofitting the beam-column specimens. Fig. 5 shows the specimen after strengthening.

1) Externally bonded retrofitting of specimens

Specimens designated as BCJEB, after preloading were retrofitted as follows

- A length equal to the effective depth of beam was selected on all the three sides of the joint for retrofitting
- The surface of the concrete was made smooth and free of grout holes

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- Epoxy base and hardener were mixed in a ratio of 10:1 and was applied over the dust free surface of concrete
- GFRP sheet was then cut in to required size and then the sheet is pressed on the epoxy paste applied area by gloved hand and a surface roller was rolled over the surface to remove air bubbles
- One more coat was applied over the glass fabric after drying and the retrofitted specimens were cured for 2 days

2) NSM retrofitting of specimens

Specimens designated as BCJ30, BCJ45 and BCJ60, after preloading were retrofitted as follows:

- Grooves were cut at angles of 30o, 45o and 60o for specimens designated as BCJ30, BCJ45 and BCJ60 respectively
- The spacing between the NSM-GFRP strips remain as 50 mm in all the cases
- The surface was cleaned from dust and loose particles and the groove was filled halfway with epoxy adhesive and GFRP strip was inserted and pressed to let the adhesive flow around the strips
- The specimens were cured for 2 days

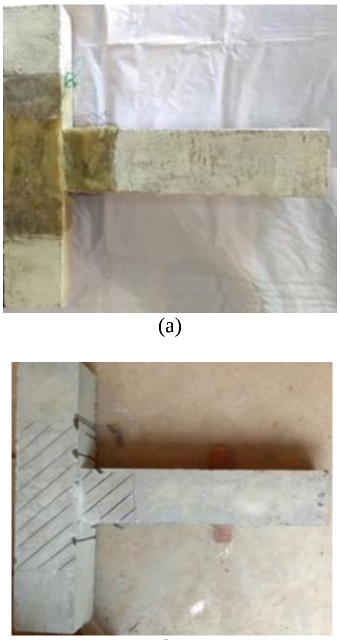


Fig. 5 (a) Externally bonded beam-column joint, (b) Grooves cut on beam-column joint

IV. RESULTS AND DISCUSSION

A. Crack pattern

In all specimens, the cracks propagated towards the joint and initial cracks started widening. The crack pattern is shown inFig. 5 (a) - (f).

From the figures it can be observed that the cracks were considerably reduced in the NSM retrofitted specimens and the major crack was observed closer to the joint than in the control specimen. No cracks were found in between the retrofitted grooves.

B. Load-deflection plot

The load-deflection plots of specimens are shown in Fig. 6. The retrofitted specimens have wider loops. Among the retrofitted specimens, the BCJN30 specimens show better load carrying capacity than that of the BCJEB specimens. The reason for lesser performance of BCJEB specimen may be due to the debonding of GFRP sheet.

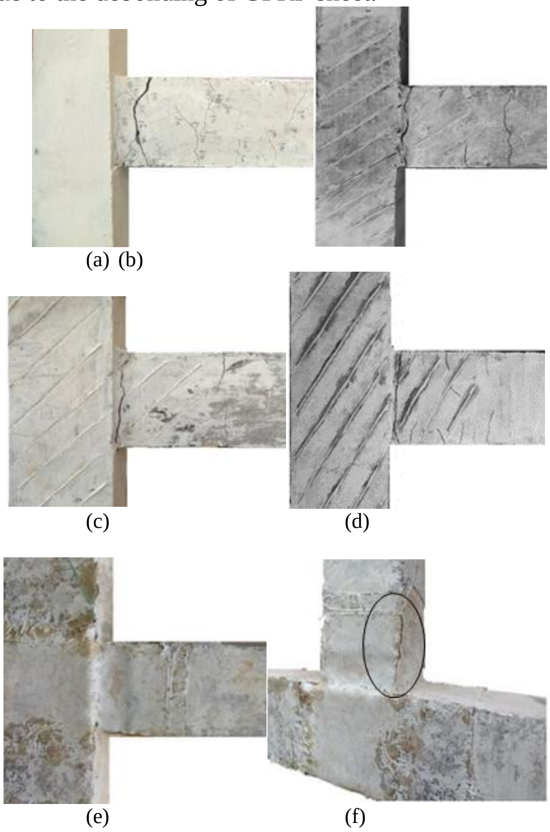
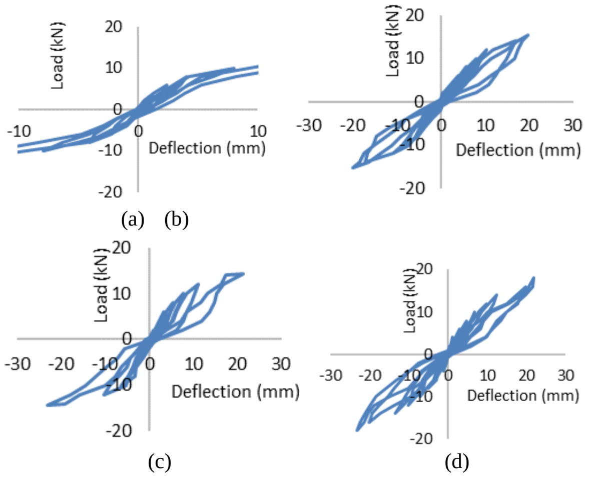


Fig. 6 Crack pattern of (a) BCJC specimen, (b) BCJN30 specimen, (c) BCJN45 specimen, (d) BCJN60 specimen,(e) BCJEB specimen,(f) Delamination of BCJEB specimen



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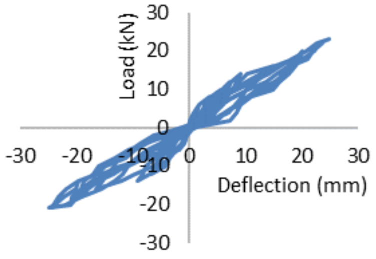

(e)

Fig. 7 Load-deflection plot of (a) BCJC specimen, (b) BCJEB specimen,(c) BCJN60 specimen,(d) BCJN45 specimen, (e) BCJN30 specimen

C. *Load-deflection envelope plot*

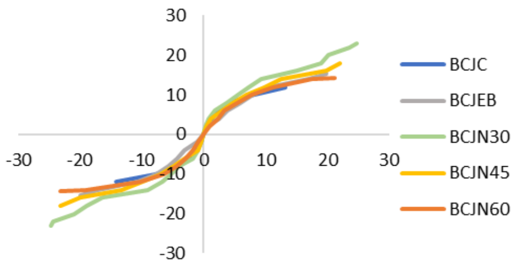

Fig. 8 Load-deflection Envelope curve of specimen

D. *First crack load and ultimate load*

The first crack load and ultimate load of the specimens are given in Table IV. First crack load was determined from the envelope curve of the load deflection plot corresponding to the point atwhich the curve deviated from linearity. From the table it can be observed that, first crack load increased for the NSM retrofitted specimens, which may be due to the better bond between NSM strips and specimens. Among the retrofitted specimens BCJN30 specimen had the highest first crack and ultimate load.

TABLE IV: First crack and ultimate load of specimens

Specimen Designation	First crack load (kN)	Ultimate load (kN)			Percentage increment
		Forward cycle	Reverse cycle	Average	
BCJC	4.20	12.10	-12.00	12.05	-
BCJEB	6.00	15.30	-15.00	15.15	26.00
BCJN60	6.00	14.30	-14.60	14.45	20.00
BCJN45	6.20	18.10	-18.00	18.05	50.00
BCJN30	10.00	23.00	-22.80	22.90	90.00

E. *Energy absorption*

The area under the load deflection plot indicates the energyabsorption capacity. Energy absorption capacity was calculatedand the values obtained are given inTable V. From the table it is clear that all the retrofitted specimens have greater energy absorption capacity than the control specimen and it is maximum for BCJN30 specimen.BCJEB specimen had a much lower energy absorption capacity than that of NSM retrofitted specimens. This may be due to debonding failure of BCJEB specimens.

In NSM retrofitted specimens, the narrow GFRP strips maximize the surface area to sectional area ratio for the given volume and thus minimize the risk of debonding. But this is not the case for BCJEB specimen. As soon as the bonding between the retrofitted material and concrete surface is broken, the specimen will not be able to take up much load.

TABLE V: Energy absorption capacity of specimens

Specimen Designation	Energy absorption capacity (kNmm)			Percentage increment
	Forward cycle	Reverse cycle	Average	
BCJC	113.19	125.01	119.10	-
BCJEB	199.42	198.51	198.97	67.00
BCJN60	218.06	251.87	234.97	97.00
BCJN45	257.60	273.75	265.68	123.00
BCJN30	357.50	351.33	354.42	198.00

F. *Energy dissipation capacity*

Energy-dissipation capacity is an important indicator of theseismic performance of a structure. The structural elements can withstandstrong ground earthquake motions only if they have sufficient abilityto dissipate seismic energy. This energy dissipation is providedmainly by inelastic deformations in critical regions of the structuralsystem and requires adequate ductility of the elements andtheir connections. It can be estimated from the area withinthe load–displacement hysteretic loop for every cycle of load.The cumulative energy dissipated by the specimens was calculatedby summing up the energy dissipated in consecutive load displacementloops throughout the test [8]. The cumulative energy dissipationof the specimens during each cycle is shown in Fig. 8. From the plot it is clear that the NSM retrofitted specimen has more cumulative energy dissipation in each cycle. BCJN30 specimen performed the best among all the other retrofitted specimen.

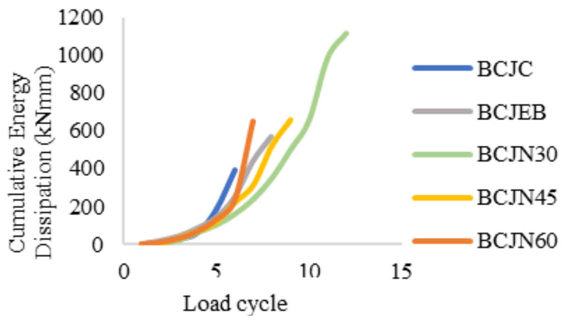

Fig. 9 Cumulative Energy dissipation capacity plot

G. *Displacement ductility factor*

Ductility of a structural element is its ability to undergo deformation beyond the initial yield deformation, while it is still sustaining load. The ductility factor, which is a measure of ductility of a structure, is defined as the ratio of maximum deflection (δ_u) to the deflection at yield (δ_y) [8]. The ductility factors were calculated and the results obtained are given in Table VI. From the Table it can be seen that NSM retrofitting influence the ductility. The ductility factor increased for all the retrofitted specimens. BCJN30 specimen had the highest ductility factor. Compared to the BCJEB specimen, the ductility factor is increased by 2.3 times for BCJN30 specimen.

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TABLE VI: Displacement ductility factor for specimens

Specimen Designation	Displacement ductility factor	Percentage increment
BCJC	1.52	-
BCJEB	1.69	11
BCJN60	1.78	17
BCJN45	2.51	65
BCJN30	3.49	129

H. Stiffness degradation

Application of cyclic or repeated loading on the RCC beam–columnjoint causes reduction in the stiffness of the joint. This reductionin stiffness of the specimens can be assessed by computing thesecant stiffness which provides a measure of the stiffness degradationin the specimens. The secant stiffness in each cycle wascalculatedusing a line drawn between the maximum positive displacementpoint in one half of the cycle and the maximum negativedisplacement point in the other half of the cycle [8]. Stiffness degradation plot is shown in Fig. 9. It may be noted that BCJEB specimen has a low initial stiffness when compared to the NSM retrofitted specimen. The use of NSM strips significantlyincreased the initial secant stiffness value of the specimens. As the number of cycles increase, NSM strips intercept the macro cracks and control the widening of thesecracks. This action willcontrol further propagation of cracks andwill result in higher energy demand for debonding. From the plot it can be observed that the initial stiffness for the BCJN30 specimens are greater than the other specimens.

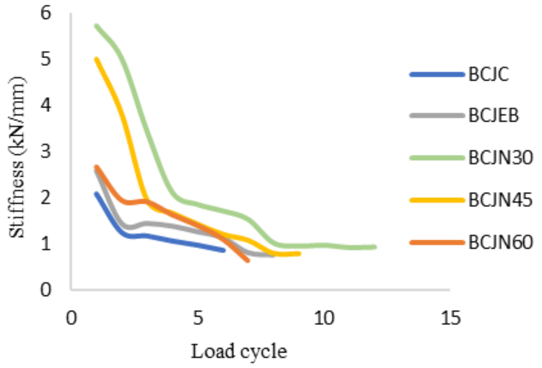

Fig. 10Stiffness degradation plot

V. CONCLUSIONS

The following conclusions were obtained from this study.

1) No visible cracks were found in the case of BCJEB specimens at failure
2) The cracks shifted more towards the joint region for BCJN30, BCJN45 and BCJN60 specimens when compared to BCJC specimen. This may be due to confining action in the critical region
3) The ultimate load carrying capacity, energy absorption and energy dissipation capacity of all the NSM retrofitted specimens were higher when compared to BCJC and BCJEB specimens. This may be due to bridging action of NSM strips across the cracks as well as the better bond between NSM strips and specimen. Among the NSM retrofitted specimens, BCJN30 performed the best
4) Debonding may be the factor that caused BCJEB specimens to fail at lesser load when compared to NSM retrofitted specimens
5) Initial stiffness of NSM retrofitted specimens were found to be more when compared to other specimens. The rate of degradation of stiffness was observed to be greater for BCJN30 specimen

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