Reverse Cyclic Behaviour of RC Exterior Beam-column Joints with Coupler Anchors: An Experimental Study

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Abstract

This paper presents the behavior of the beam-column joint with a new reinforcement technique under seismic condition. For this study, two categories of joint specimens are cast and tested under reverse cyclic loading conditions. The first category of the joint specimen named as "EBCJ-C" and the second category named as "EBCJ-IS456" (designed and detailed as per IS 456 - 2000). All the specimens are tested under displacement control method with increasing drift ratio. Each drift consists of three full cycles of reverse cyclic loading. The test results of the proposed coupler joint specimen (EBCJ-C) are compared with the control joint specimen (EBCJ-IS456) in terms of load carrying capacity, stiffness and ductility. From the observed results, the proposed technique (EBCJ-C) enhances the load carrying capacity, stiffness and ductility. Also, the provision of the coupler in the beam-column joint helps to reduce construction difficulties such as placement of concrete and compaction and reduce the anchorage length of the beam longitudinal bar. The important features of the coupler are an easy installation, increase the pullout resistance of beam longitudinal bars and control the development of cracks in the beam-column joint.

Keywords: beam-column joint; coupler; stiffness; ductility

1. INTRODUCTION

Beam-column joints (joints) are crucial zones and structurally less efficient in the reinforced concrete framed structure. The joint is defined as a portion of a column within the depth of the beam that frame into it [1]. The role of the joint is to enable the adjoining members to develop and sustain their ultimate capacity [2]. In general, the joints are classified based on the loading condition, structural behavior and geometrical configuration. Based on the geometrical classification ,the joints are classified as interior joint, exterior joint, corner joint, roof interior joint, roof exterior joint, roof corner joint [1]. Under the strong ground motion, the joint region is subjected to horizontal and vertical shear forces, and these forces are many times higher than the adjacent beams and columns. The effect of large shear forces during the earthquakes can be reduced by enhancing strength, ductility and energy dissipation capacity of the structure [3]. The strength and ductility can be achieved by providing adequate anchorage to the beam longitudinal bars and sufficient

confinement in the core joint. Many authors [4-9] were carried out the research on the anchorage of the beam longitudinal bar to find the effectiveness of the RC joints. They concluded that: a) The joint was deteriorating quickly due to diagonal tension cracking and anchorage breakdown. b) Slippage phenomenon in the joint has taken place due to the use of the smooth bar and inadequate anchorage. c) Load-displacement hysteretic behavior and shear resistance of the exterior joints mainly depends upon detailing of reinforcement and anchorage length beam. d) Load carrying capacity and energy absorption capacity of the specimen were considerably increased with the increasing of anchorage length. Also, the effective performance of joints strongly depends on the lateral confinement ensured in the joint. Many researchers [10-14] were experimentally investigated to find the behavior of RC joints with spiral reinforcement technique. From the above study, they observed that: (a) The use of rectangular spiral reinforcement in the beam enhances increased torsion capacity, higher shear strength and better ductile performance. (b) The use of rectangular spiral reinforcement in the RC joint region enhances improved shear capacity, increased load carrying capacity and better ductility performance of the joint. (c) The presence of spiral and inclined bars is successfully moving the plastic hinge away from the column face. However, use of standard hooks with larger development length and higher amount of hoop reinforcements in the joint region cause steel congestion and many construction difficulties such as fabrication of reinforcing bar, placing reinforcement bar, casting and compaction in the joint, etc., In order to overcome all the practical difficulties, a "joint coupler" has been introduced in the joint as an alternate solution and the effect of couplers in the joint region is presented in this article. The experimental results indicated that the proposed technique effectively reduces the reinforcement congestion in the joint area and improved ductility of the joint under reverse cyclic loading.

II. SPECIMEN DETAILS AND MIX PROPORTION

In the present study, two categories of four half scaled specimens were cast and tested under reverse cyclic loading. The dimension and details of reinforcement of the joints are given in Fig. 1 (a) & (b). The proposed category of the joint specimen named as "EBCJ-C" and control joint specimen named as EBCJ-IS456. The control specimen (EBCJ-IS456) was designed and detailed as per IS 456-2000. All the

categories have the same grade of concrete and same geometrical properties. The cross-section of the column for both EBCJ-C and EBCJ-IS456 was 175 mm x 125 mm and the beam was 125 mm x 175 mm. The length of the column and beam for both EBCJ-C and EBCJ-IS456 was 1500mm and 900mm respectively.

For the EBCJ-C specimen, the column main reinforcement was 4Ø10 and shear reinforcement was 6Ø125mmc/c. The beam reinforcement was 2Ø10 at both top and bottom and shear reinforcement was 6Ø110 mm c/c (Refer Fig.1). For the EBCJ-IS456 specimen, the column main reinforcement was 4Ø10 and shear reinforcement was 6Ø125mm c/c. The beam reinforcement was 2Ø10 at both top and bottom and shear reinforcement was 6Ø110mm c/c (Refer Fig.1). All the specimens have been cast with M20 grade concrete and Fe500 grade steel.

The OPC [Ordinary Portland Cement] 43 grade conforming to IS: 8112-1989 (BIS.1989) was used. Locally available river sand has been used as fine aggregate passing through 4.75mm IS sieve and fineness modulus was 2.61. Crushed granite aggregate has been used as coarse aggregate passing through 12.5mm and retained on 4.75mm and having a fineness modulus of 6.83.

III. TEST SETUP AND LOADING PROCEDURE

All the four specimens were tested using the push-pull jack machine of 30kN capacity. A constant axial load of 40kN was applied to the column for holding the test specimen by means of a 500kN capacity hydraulic jack. The reverse cyclic load at the end of the beam was applied by push-pull jack with increasing drift ratio. LVDTs and strain gauges used to monitor the behavior of the specimen. All the specimens were tested under displacement control method with the predetermined drift ratio. For each drift ratio, three full reversed cycles were applied at the beam tip. Drift ratio is defined as the ratio of applied displacement at the beam tip (Δ_l) and length of the beam from the column face to the point of application of displacement (l_b) i.e., Drift ratio (%) = $\Delta l/l_b$. The Fig.2 & 3 shows the experimental load set up and reverse cyclic loading history of testing specimens.
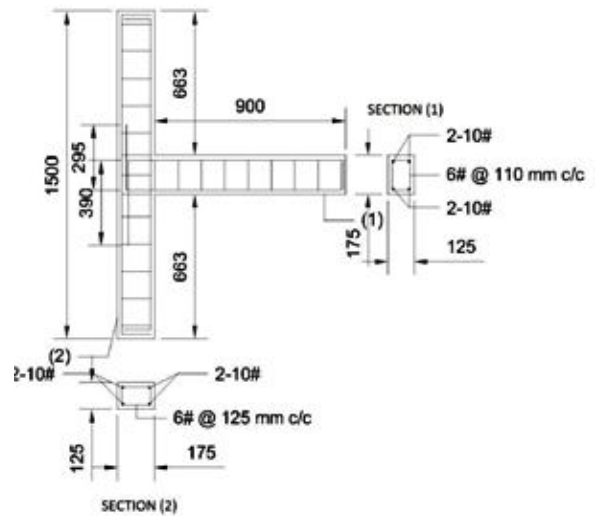
(b) Category B: Control specimen (EBCJ-IS456)

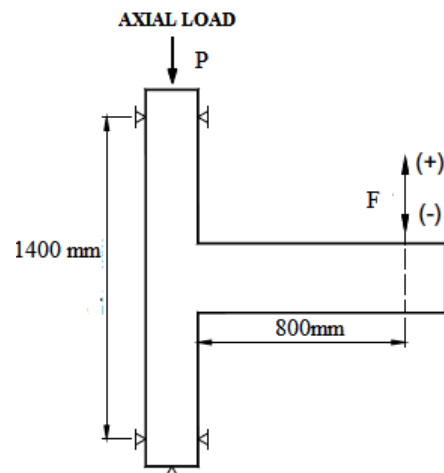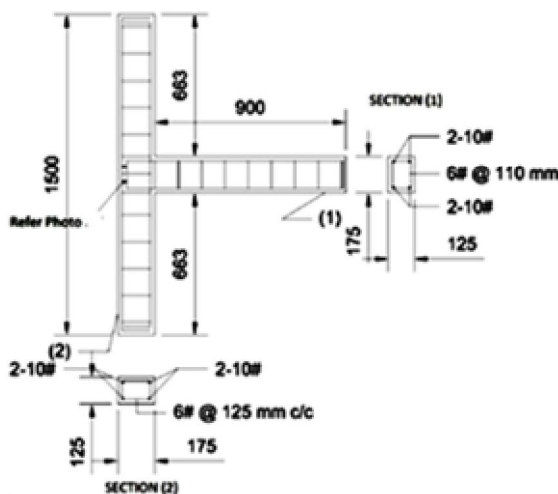*Fig. 1: Reinforcement details of Coupler joint specimen (EBCJ-C) and Control specimen (EBCJ-IS456)*

Fig. 2 : Experimental Load setup

Fig. 3: Reverse cyclic loading history.

(a) Category A: Coupler joined specimen (EBCJ-C)
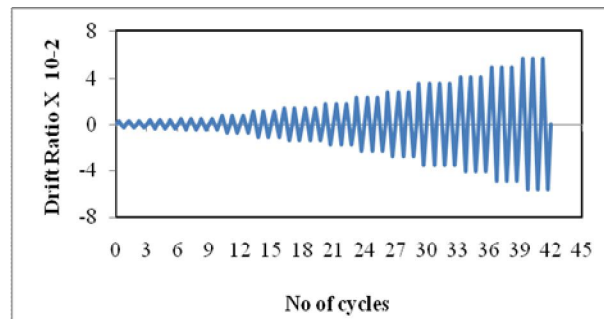
IV. RESULTS AND DISCUSSION

A. *First crack and Ultimate Load Carrying Capacity*

For each value of the ultimate load, two specimens were tested and the difference in the value of the test specimens was found that less than 10%. The average first crack and ultimate load carrying capacity of specimens were tabulated in Table 1. The ultimate load carrying capacity of EBCJ-C specimen was found to be 18.41kN in the push direction (Negative) and 18.46kN in the pull direction (Positive). For the specimen EBCJ-IS456, the ultimate load was found to be 18.41kN in the push direction (Negative) and   18.40kN in the pull direction (Positive). The average ultimate load carrying capacity of EBCJ-C specimen was 18.44kN and EBCJ-IS456 specimen was 18.40kN. From the above result, it is observed that the load carrying capacity of the coupler fitted specimen (EBCJ-C) is similar to that of the control specimen (EBCJ-IS456) in resisting the load. The first crack load of coupler fitted specimen (EBCJ-C) was 13.00kN and control specimen (EBCJ IS-456) was 6.58kN. From the results, it is observed that the first crack load of coupler fitted specimen (EBCJ-C) was improved i.e. the first crack load was delayed due to the effective anchorage of beam longitudinal bars by means of coupler arrangements.

B. *Ductility Factor*

Ductility is an important parameter to describe the behavior of joints under seismic forces. Ductility is defined as the ability of a structure to undergo large deformation in the inelastic range without a substantial reduction in strength [15]. The large deformation in the structure generally measured in terms of a displacement ductility factor. (μ) which is the ratio of ultimate deformation (Δ_{max}) to the corresponding deformation when yielding (Δ_y) occurs. i.e. $\mu = (\Delta_{max} / \Delta_y)$ .The yield, ultimate deformation and displacement ductility of tested specimens were presented in Table 2 & 3. From the observation of tested specimens, the ductility factor of proposed coupler joint specimen, i.e., EBCJ-C was 17.5 which is approximately three times higher than the control specimen (EBCJ-IS 456). Hence the proposed coupler joint specimen (EBCJ-C) is more ductile than the control specimen (EBCJ-IS 456).

TABLE 1. EXPERIMENTAL FIRST CRACK & ULTIMATE LOADS OF SPECIMENS

Designation of Specimen	First Crack Load (kN)	Ultimate Load (kN)		Average Ultimate Load (kN)
		Neg.	*Pos.*	
EBCJ-C	13.00	18.41	18.46	18.44
EBCJ-IS456	6.58	18.41	18.40	18.40

TABLE 2. EXPERIMENTAL YIELD AND ULTIMATE DISPLACEMENT OF SPECIMENS

Designation of Specimen	Yield Displ. (mm)		Average Yield Displ. (mm)	Ultimate Displ. (mm)		Average Ultimate Displ. (mm)
	Neg.	*Pos.*		*Neg.*	*Pos.*	
EBCJ-C	3.22	2.41	2.82	48	48	48
EBCJ-IS456	11.57	8.42	9.99	42	48	45

TABLE 3 . OBSERVED DUCTILITY AND INITIAL STIFFNESS OF SPECIMENS

Designation of Specimen	Displ. Ductility Factor		Average Displ. Ductility Factor	Initial Stiffness (kN/mm)		Average Stiffness
	Neg.	*Pos.*		*Neg.*	*Pos.*	
EBCJ-C	15.00	20.00	17.5	5.44	7.23	6.3
EBCJ-IS456	3.62	5.71	4.66	1.58	2.19	1.84

C. *Stiffness*

Under the seismic condition, the joints of reinforced concrete structure are subject to a large amount of shear force. During reversal loading, micro cracks are being initiated inside the joint. The initiated crack will increase the deformation of the joint. This deformation may consequently reduce the stiffness of the joint. Therefore,   it is necessary to evaluate the stiffness degradation in the joint. Fig. 4 shows the stiffness degradation of tested specimens with lateral displacement. The load required for the unit deformation is known as stiffness which *is calculated from the load-displacement curve. Fig.* 5(a) & (b) shows the load-deflection behavior of EBCJ-C and EBCJ-IS456 specimens. To calculate the stiffness, a tangent has been drawn at a load of 0.75 times of maximum load and then the slope of the tangent has been drawn for each cycle of the hysteresis loop.

From the stiffness degradation curve, it is observed that the stiffness degradation rate of the proposed joint specimen is similar to that of the control specimen. This uniform degradation may be due to the presence of transverse reinforcement and anchoring the beam longitudinal bars within the joint. The initial stiffness values of the control (EBCJ-IS456) and proposed joint (EBCJ-C) specimens are given in Table 3. The initial stiffness value of proposed specimen (EBCJ-C) is 6.3 and the control specimen (EBCJ-IS456) is 1.84 which is about approximately 3.5 times higher than the control specimen (EBCJ-IS456). The behavior of the proposed joint (EBCJ-C) specimen is similar to that of the control specimen (EBCJ-IS456). Hence the proposed joint (EBCJ-C) is performed better under the seismic condition and this can be used in low to medium seismic zone areas.
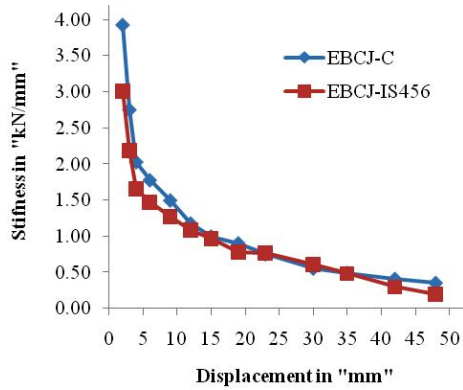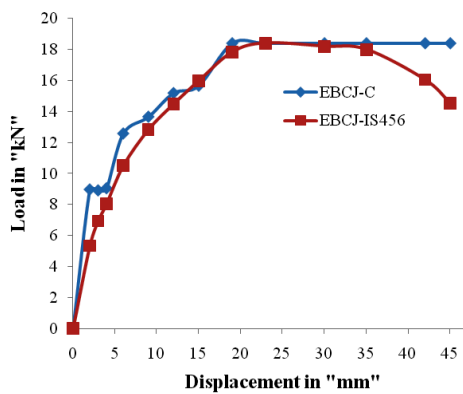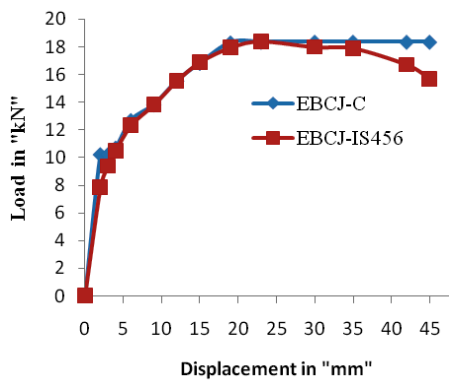
Fig. 4: Stiffness degradation curve for control (EBCJ-IS456) and proposed joint (EBCJ-C) specimen.

(a) Postive direction

(b) Negative direction

Fig. 5: (a) & (b) Load-Displacement Curve for Coupler joint (EBCJ-C) and Proposed joint (EBCJ-IS456) specimen.
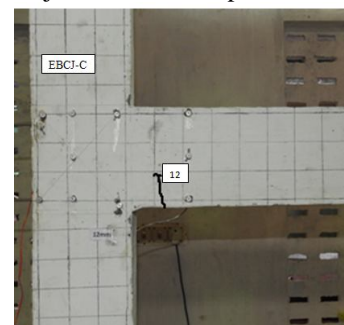
D. Energy Absorption Capacity

The Energy Absorption Capacity (EAC) is one of the fundamental parameters in the lateral load resisting system and the capacity structure mainly depends upon on its absorb and release the energy input by the earthquake force. The cumulative energy dissipation of the tested specimen was calculated by summing up the energy absorbed in consecutive hysteresis loops throughout the test. The energy absorption capacity is calculated by the area encloses in the corresponding beam tip load-displacement curve. The cumulative absorption capacity was found to be 1100kNmm for proposed joint specimen (EBCJ-C) and 860kNmm for control specimen (EBCJ-IS456). The energy absorption capacity of the proposed joint specimen (EBCJ-C) is 22% higher than that of the control specimen (EBCJ-IS456). This may be due to less pinching effect was observed in the hysteresis loop of the proposed joint (EBCJ-C) which reduces the stiffness degradation rate. Hence it is concluded that the performance of the proposed joint specimen (EBCJ-C) exhibits better performance in terms of energy dissipation capacity than the other specimen.

E. Failure Mode

The Fig. 6 (a) to (d) shows the initial and failure pattern of the proposed joint (EBCJ-C) and the control joint specimens (EBCJ-IS456). The crack which occurs at the peak of each load cycle has been observed and noted manually by marking the cracks. There are two types of cracks have been formed on the tested specimens. Those are flexural, i.e. perpendicular to the axis of the column and the beam and shear cracks, i.e., inclined cracks occur on the beam, column and joints.

Initially, the same kind of behavior has been exhibited in all the specimens, i.e. the first flexural crack appeared in the beam portion. The first flexural crack was observed in beam front face at 12mm displacement cycle in the proposed joint specimen (EBCJ-C) and 6mm displacement cycle in the control specimen (EBCJ-IS456). For the proposed joint specimen (EBCJ-C), the first diagonal shear cracks started within the joint at 35mm displacement cycle and Fig. 6 (b) shows the formation of shear cracks within the joint region. Similarly, Fig. 6 (d) shows the formation of the first diagonal shear cracks in the control specimen (EBCJ-IS456) and it was started within the joint at 12mm displacement cycle.

(a) Coupler joint specimen (EBCJ-C) First crack

(b) Coupler joint specimen (EBCJ-C) Ultimate crack

(c) Control specimen (EBCJ-IS456) First crack

(d) Control specimen (EBCJ-IS456) Ultimate crack

Fig.6: First crack & Failure modes of Coupler joint (EBCJ-C) and Control joint (EBCJ-IS456) specimens.

From the above observation,   it is found that the first crack and shear cracks formation in the beam, column and joint area have been delayed in the proposed joint specimen (EBCJ-C). Also, it is observed that less joint damage is observed in the proposed joint specimen (EBCJ-C). Further, no pullout failure, no plastic hinges and no cleavage fracture have been found   inside the joint region of the proposed joint specimen (EBCJ-C). From these observations, it can be concluded that the performance of proposed coupler joint specimen (EBCJ-C) is very effective in term of controlling the cracks and damages in the joint and it can be used for low to medium seismic zone.

V. SUMMARY AND CONCLUSIONS

In this study, to check the reliability and the efficiency of proposed coupler joint (EBCJ-C), totally four half scaled exterior joints, i.e. (EBCJ-C and EBCJ-IS456) have been cast and tested under reverse cyclic loading condition.

Based on the findings from the experimental study the following conclusions are drawn below.

1. The first crack load of the proposed coupler joint specimen was increased about 200% i.e. the first crack was delayed.

2. The Ultimate load carrying capacity of both the proposed coupler joint specimens (EBCJ-C) & control specimen (EBCJ-IS456) was found to be same

3. The ductility of the proposed coupler fitted specimen was increased tremendously. The displacement ductility of the proposed coupler fitted specimen (EBCJ-C) is approximately 300% higher than the control specimen (EBCJ-IS456). Hence, the proposed method can be more beneficial in low to medium seismic zone areas.

4. The initial stiffness of the proposed coupler joint specimen (EBCJ-C) was 6.3 which is about 3.5 times higher than that of the control specimen (EBCJ-IS456). Therefore, it is concluded that the proposed joint is stiffer against joint distortion.

5. The energy dissipation of the coupler joint specimen ((EBCJ-C) was increased considerably in the proposed coupler joint specimen. It is about 22% higher than the control specimen (EBCJ-C).

6. In addition that, the coupler plays important role in delaying and propagating of cracks in the joint region. Also, the proposed coupler joint technique eliminates the pullout and cleavage failure in the joints. Hence, the proposed coupler joint specimen (EBCJ-C) is more effective in controlling the damages in the joint region.

7. Also, the proposed coupler joint specimen (EBCJ-C) can be an alternate solution to reduce the conventional difficulties such as fabrication of reinforcement, placing of reinforcement, casting and compaction of concrete.

8. The main advantages of the proposed coupler joint (EBCJ-C) are reducing the congestion, ease of fixing and faster construction at the site.

ACKNOWLEDGEMENTS

NOTATION

BIS	Bureau of Indian Standard.
Displ.	Displacement
EAC	Energy Absorption Capacity
EBCJ-C	Exterior Beam-Column Joint with Coupler
EBCJ-IS456	Exterior Beam-Column Joint design and detailed by IS456-2000
Fig.	Figure
Pos.	Positive
RC	Reinforced concrete
LVDT	Linear Varying Differential Transducer
Neg.	Negative
μ	Ductility factor
Δ_{max}	Ultimate deformation
Δ_y	Yield deformation
Δl	Applied displacement
l_b	Length of beam

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