Seismic Response of RC Beam-Column Joints Using Innovative Flat Coupler Technique

[1] K. Marimuthu, [2] S. Kothandaraman

[1] Ph.D Research Scholar, [2] Professor, Pondichery Engineering College

[1] marimuthu76@yahoo.com, [2] sk@pec.edu

Abstract— This paper presents the seismic behaviour of beam-column joints introducing with flate coupler reinforcement technique. A total of four beam-column joint specimens were cast; two of them consist of 'coupler moment resisting joint' (CMRJ) specimens and the remaining were of 'special moment resisting joint' (SMRJ) specimens. The CMRJ specimens were incorporated with a specially made flate coupler reinforcement whereas, the SMRJ specimens were designed and detailed according to IS 13920 – 1993. All the specimens were tested under displacement control method with increasing drift ratio and each drift consisted of three full-cycles. Test results of the proposed CMRJ technique show better response with respect to its load carrying capacity, stiffness and ductility, compared to the convensional SMRJ technique.

Index Terms— Beam-Column Joint, Coupler, stiffness, ductility.

I. INTRODUCTION

In general, the effective performance of the exterior joints depends on the strength and ductility. It can be achieved by providing adequate anchorage to the beam longitudinal bars and sufficient confinement in the core joint. Insufficient anchorage of beam longitudinal bar and lack of transverse reinforcement causes joint deterioration and anchorage breakdown in the joint [1]. 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 in the joint. Many researchers were suggested different joint reinforcement patterns and techniques such as headed bar technique [2], [3], inclined bar/diagonal cross bracing technique [4]-[7], square spiral reinforcement technique [8], providing beam stub [9], cage reinforcement technique [10], hair clip technique [11] and fibre reinforcement technique [12],[13] to improve the seismic behaviour of the joints. From the above techniques, it is observed that the anchorage of beam longitudinal bars and confinement of joint core details are the major issues in the joint region due to problem of steel congestion in the joint region which are directly affecting the joint behaviour. In order to overcome all the above difficulties a "joint coupler" has been introduced as an alternate option and the impact of couplers in the joint region is presented in this article. The experimental results showed that the proposed technique effectively reduces the reinforcement congestion in the joint region and improved ductility of the joint under reverse cyclic loading.

II. SPECIMEN DETAILS AND MIX PROPORTION

The experimental programme comprises of two categories of four half scaled specimens to represent a typical exterior joint of RC structure. The proposed first category of the specimen named as Coupler Moment Resisting Joint (CMRJ) and second category named as Special Moment Resisting Joint (SMRJ) and the SMRJ specimen was designed and detailed as per IS 13920-1993[14]. Each category consisted of two specimens and geometric characteristic of both categories of the specimen were same. The cross section of the column and beam was 175 mm x 125 mm. The length of the column and beam was 1500mm and 900mm respectively.

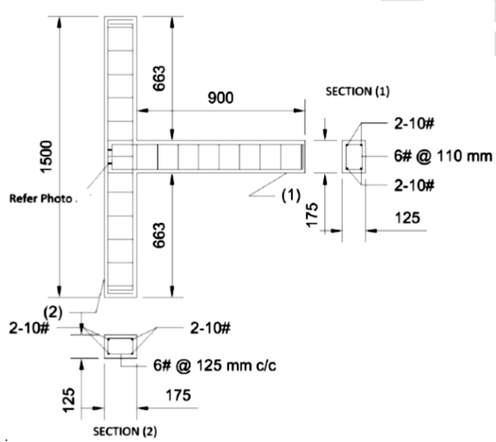
For category A, the column main reinforcement was 4Ø10 and shear reinforcement was 6Ø125mmc/c. The beam reinforcement was 2Ø10 at both top and bottom and shear reinforcement was 6Ø110 mm c/c (Refer fig.1).

For category B, the column main reinforcement was 4Ø10 and shear reinforcement was 6Ø75 mm c/c at a distance of 450mm and remaining portion was 100 mm c/c. The beam reinforcement was 2Ø10 at both top and bottom and shear reinforcement was 6Ø35mm c/c at a distance of 310 from the face of the column and remaining portion was 70mm c/c.

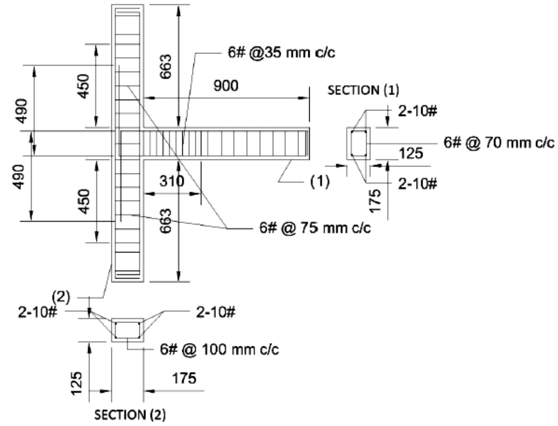
All the specimens have been cast with M20 grade concrete and Fe500 grade steel. Locally available river sand has been used as fine aggregate passing through 4.75mm IS sieve and crushed granite aggregate has been used as coarse aggregate passing through 12.5mm and retained on 4.75mm.The fineness modulus of fine aggregate and coarse aggregate are 2.61 and 6.83 respectively.

III. TEST SETUP AND LOADING PROCEDURE

All the four specimens were tested with the column member was in vertical position and beam member was in a horizontal position. The proper boundary condition was provided at the end of the column. All the specimens were subjected to a constant axial load 40 kN to the column by means of 500 kN capacity hydraulic jack. Push pull jack of 30 kN capacity was used to apply reverse cyclic load at the end of the beam. Each specimen was instrumented with LVDTs and strain gauges to monitor the behaviour of the specimen. The experiment was performed under displacement control method with predetermined drift ratio. The reverse cyclic load was applied at the beam tip in terms of drift ratio. Three fully reversed cycles were applied at each drift ratio. 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) (Drift ratio (%) = $\Delta l/l_b$).



(a) Category A: CMRJ specimen



(b) Category B: SMRJ specimen

Fig. 1 Reinforcement details of specimens

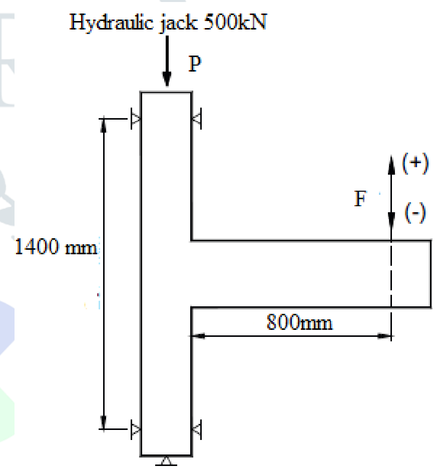


Fig. 2 Load setup

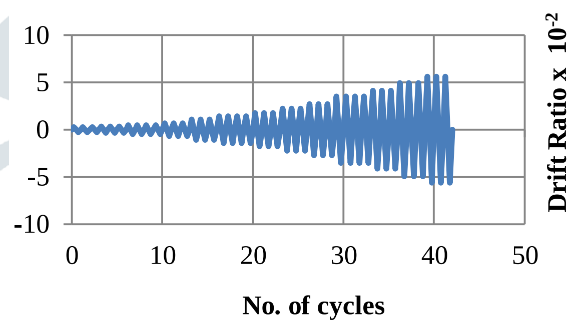


Fig. 3 Reverse cyclic loading history.

IV.RESULTS AND DISCUSSION

A. Load Carrying Capacity

The ultimate load carrying capacity of CMRJ specimen was found to be 18.41kN in push direction and 18.36 kN in pull direction. For the specimen SMRJ, the average ultimate load was found to be 19.46kN in push direction and 19.60 kN in pull direction. The average ultimate load carrying capacity of CMRJ specimen was 18.38kN and SMRJ specimen was

19.53kN. From the above result, it is observed that the load carrying capacity of SMRJ specimen was 12% higher than the CMRJ specimen and performed better in resisting the load. The load carrying capacity of the specimens listed in table (see Table 1).

Table 1. Observed load carrying capacity of the specimens

Specimen ID	Ultimate load (kN)		Average Ultimate Load (kN)	Ultimate Displacement (mm)		Yield Displacement (mm)	
	Push	Pull		Push	Pull	Push	Pull
CMRJ	18.41	18.36	18.38	48	48	3.20	2.40
SMRJ	19.46	19.60	19.53	48	50	11.60	6.40

B. Ductility Factor

Ductility is an important parameter to maintain the flexural capacity of beams in RC framed structure. The term ductility refers the ability of a structure to undergo large deformation in the inelastic range without a substantial reduction in strength [15]. In general, large deformation can be expressed in terms of ductility factor (μ). It is defined as the ratio of ultimate deformation (Δ_{max}) to corresponding deformation when yielding(Δ_y) occurs. i.e. $\mu = (\Delta_{max} / \Delta_y)$.

The yield and max deformation of different types of joint were calculated by using load-displacement envelope curve and the evaluated ductility factor is shown in Table 2. It is observed that the ductility factor of CMRJ specimen is 17.5 which is three times higher than SMRJ specimen. Hence the CMRJ specimen is a more ductile specimen as compared with the other specimen.

Table 2 Observed ductility and stiffness of test specimens

Specimen ID	Displacement ductility factor		Average Displacement ductility factor	Initial stiffness (kN/mm)		Average stiffness	Energy absorption capacity (kN mm)
	Push	Pull		Push	Pull		
CMRJ	15.00	20.00	17.50	5.44	7.23	6.3	1100
SMRJ	4.13	7.81	5.97	1.675	3.06	2.37	975

C. Energy Absorption Capacity

Energy Absorption Capacity (EAC) is one of the fundamental parameters in lateral loading and which is determined by the area enclosed by lateral load-displacement loops. The hysteresis loop describes the Energy Absorption Capacity (EAC) and stiffness degradation of the tested specimens. The EAC is measured as 1100kNmm for CMRJ specimen and 975kNmm for SMRJ specimen [refer Table 2]. It is observed that the energy absorption capacity of CMRJ specimen is 12% higher than SMRJ specimen due to less pinching effect in the hysteresis loop which reduces the stiffness degradation rate. Hence it is concluded that the performance of the CMRJ specimen is found better than the other specimen.

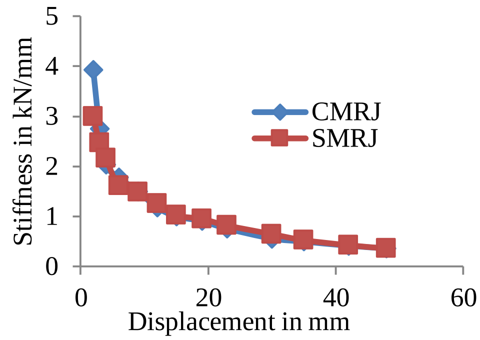


Fig. 4 Stiffness degradation curve.

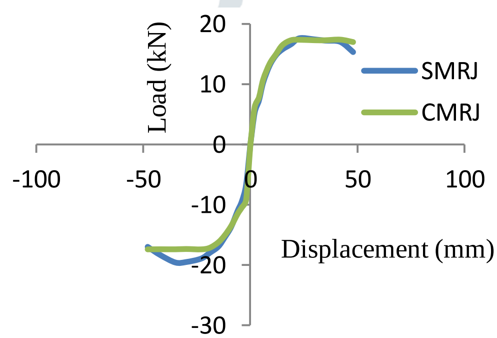


Fig. 5 Load-Displacement Curve

D. Stiffness

Stiffness is defined as required load for the unit deformation of the joint and the secant stiffness is a qualitative measure of stiffness degradation. During the reversal loading, micro cracks are being initiated inside the joint that will increase the deformation which may consequently reduce the stiffness. Hence, it is necessary to evaluate the stiffness degradation in the beam-column joint.

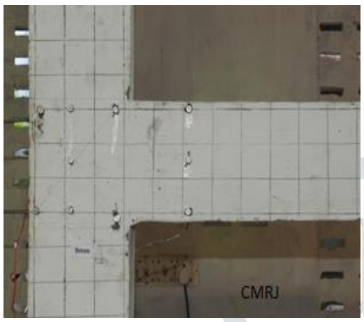
The measured load and corresponding displacement at the end of each cycle have been used to calculate the secant stiffness. To calculate stiffness, a tangent has been drawn at a load of 0.75 times of maximum load and then the slope of the tangent has been drawn for each cycle of the hysteresis loop.

Fig.4 shows the stiffness degradation curve of the CMRJ and SMRJ specimens. It is observed that the stiffness degradation rate is same for all the specimens and the initial stiffness is uniform due to transverse reinforcement and anchorage of beam longitudinal bars within the joint.

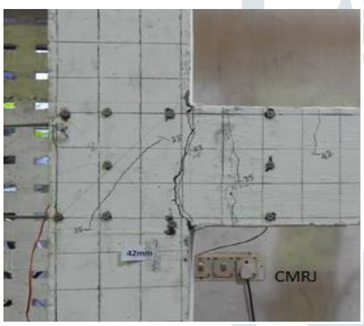
Providing sufficient confinement and proper beam longitudinal bar anchorage help to reduce the stiffness degradation rate and strength deterioration.

The stiffness values of the specimens are given in Table 2. The initial stiffness value of CMRJ specimen is 6.3 which is 63% higher than SMRJ specimen. The behaviour of SMRJ specimen is similar to the CMRJ specimen because of the usage of lateral ties in column, beam and joint regions and anchorage length within the joint region.

E. Failure Mode

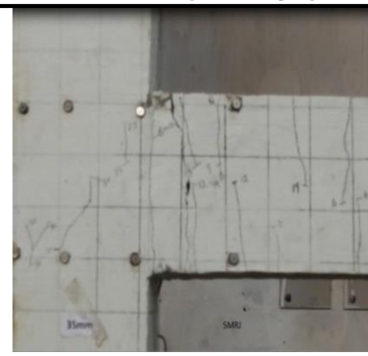


(a) CMRJ first-crack



(b) CMRJ ultimate crack

(c) SMRJ first-crack



(d) SMRJ ultimate crack

Fig.6 Failure modes of specimens

During seismic loading, the joints are subjected to large shear forces and moments. These shear forces will develop internal forces, i.e. tension and compression stresses within the joint which are transferred to concrete by bond stresses. Generally, if the stress reaches the tensile strength (f_{ct}) of the concrete, then it will develop cracks in the joint. Further, the repeated cycles of reversal loading and unloading will aggravate the situation. At the same time, the internal crack of the joint becomes worst, i.e. widening of the crack due to tension and compression loading. This widening consequently causes the stiffness reduction and pinching in the load-displacement loops. The crack which occurs at the peak of each load cycle has been observed and noted manually by marking the cracks.

The initial and ultimate crack pattern of all the specimens is shown in Fig.6. It is observed that two types of cracks have been formed on the specimens and 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, same kind of behaviour has been exhibited in all the specimens, i.e. the first flexural crack appeared in the beam at 12mm displacement cycle in CMRJ specimen, at 6mm displacement cycle in SMRJ and continued further towards the joint region. The diagonal shear cracks started within the joint at different displacement cycle in all the specimens, i.e. at the 35mm displacement cycle in CMRJ specimen, at 30mm displacement cycle in SMRJ specimen.

From the above observation, it is found that the first crack and shear crack formation in beam, column and joint area have been delayed and which results less joint damage in CMRJ specimen. Further, no pull out failure, no plastic hinges and no cleavage fracture have been found inside the joint in the CMRJ specimen. From these observations, it can be concluded that the performance of CMRJ specimen is more effective in controlling the damages in the joint than other specimen.

V. CONCLUSION

In this study, to check the integrity and the effectiveness of proposed joint (CMRJ) four half scaled exterior joint exterior joints i.e. SMRJ and CMRJ have been cast and tested under cyclic loading. Based on experimental study and the results, the following conclusions are presented below:

The ductility of the proposed joint coupler (CMRJ) specimen is three times higher than SMRJ specimen. The initial stiffness value of CMRJ specimen is 6.3 which is 63% higher than SMRJ specimen. The energy dissipation of the CMRJ is considerably high i.e. 12% higher than SMRJ. Hence, the proposed method can be more beneficial in low to medium seismic zone areas.

The proposed technique eliminates the failures such as pull out failure and cleavage failure in the joints. Hence the CMRJ specimen is more effective in controlling the damages in the joint region.

Also the CMRJ can be an alternate solution to reduce the conventional difficulties such as fabrication of reinforcement, placing of reinforcement, casting and compaction of concrete. The main advantages of CMRJ are reducing the congestion in the joint, ease of fixing at any stage of the fabrication and faster construction at the site. Further, this method is cost effective, i.e. reduce material, manpower and time considerably.

REFERENCES

[1] Park R., and Paulay, T., "Behaviour of reinforced concrete external beam-column joints under cyclic loading", "Proceedings Fifth World Conference on Earthquake Engineering, Rome, Paper 88, pp.10, 1973.

[2] Kang, T.H.K., "Prediction of performance of exterior beam-column connection with headed bars subject to load reversal", Engineering Structure, Vol.41, pp.209-217, 2014.

[3] Chutarat, N., and Aboutaha, R.S., "Cyclic response of exterior reinforcement concrete beam column joints reinforcement with headed bars-experimental investigation", ACI Structural Journal, Vol. 100, pp.259-64, 2003.

[4] Tsonos, A.G., Tegos, I.A., and Penelis, G.G., (1992), "Seismic resistance of Type 2 Exterior beams column joints reinforcement with inclined bars", ACI Structural Journal, Vol. 89(1).

[5] Chalioris, C.E., Favvata, M.J., Karayannis, C.G., "Reinforced concrete beam-column joints with crossed inclined bars under cyclic deformations", Earthquake Engineering Struct. Dyn. Vol.37, pp.881-897, 2008.

[6] Kulkarni, S.M., and Patil , Y.D., "Cyclic Behaviour of Exterior Reinforced Beam-Column Joint with Cross-Inclined Column Bars", Vol. 11, Issue.4, Ver. III, 2014.

[7] Au, F.T.K., Huang, K., and Pam, H.J., " Diagonally-reinforced beam-column joints reinforced under cyclic loading", Vol. 158, Issue: SB1, pp.21-40, 2005.

[8] Asha, P., and Sundarajan, R., "Seismic behaviour of exterior beam column joints with square spiral confinement", Asian Journal of Civil Engineering (Building and Housing), Vol. 13, No. 4, pp.571-83, 2011.

[9] Chidambaram, K.R.S., and Thirugnanam, G.S., "Comparative Study on Behaviour of Reinforced Beam-Column Joints with Reference to Anchorage Detailing", Vol.2 (4), pp.12-17,2012

[10] Kaliluthin, A.K., and Kothandaraman. S., "Experimental investigation on behaviour of reinforced concrete beam-column joint", International Journal of Civil and Structural Engineering, Vol.4, No.3., ISSN 0976-4399, 2014.

[11] Murty, C.V.R., Rai, D.C., Bajpai, K.K., Jain, S.K., "Effectiveness of reinforcement details in exterior reinforced concrete beam-column joints for earthquake resistance", ACI Structural Journal, Vol.100, 149-56, 2003.

[12] Baysi, Z., and Gebman, M., "Reduction of Lateral Reinforcement in Seismic Beam-Column Connection via Application of Steel Fibers", ACI Structural Journal, Vol.99,2002,

[13] Ganesan, N., Indira, P.V., and Abraham, R., "Steel Fibre Reinforced High Performance Concrete Beam-Column Joints Subjected to Cyclic Loading", ISET Journal of Earthquake Technology, Vol. 44, No.3-4, pp.445-456, 2007.

[14] IS 13920 "Indian Standard Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces", Code of Practice, Bureau of Indian Standards, New Delhi, India, 1993.

[15] Park, R, "Evaluation of Ductility of Structures and Structural Assemblages from Laboratory Testing", Bulletin of the New Zealand National Society for Earthquake Engineering, Vol.22, No.3., 1989.