JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 3, 2022, p.667-673
https://publishoa.com
ISSN: 1309-3452

Study on behaviour of beam column joint under cyclic load

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ABSTRACT
The results of cyclic loading on beam column (BC) joints employing PP+Steel fibre with variable volume fraction are compared to the results of standard T beam joints. The test examined the performance of the hysteresis load versus defection curve, displacement ductility, and energy absorption properties. Three external beam-column junctions were studied and **results were collated with traditional concrete specimen.**From the **experimental outcomes**, the conventional concrete and $(PP_{1/2}+Steel_{1/2})_{2.0}$ runs for four cycle and have the energy absorption of 514.06 kN-mm and 569.72 kN-mm. Also the maximum performance released by $(PP_{3/4}+Steel_{1/4})_{2.0}$ specimen runs for fifth cycle and absorbs the energy of 764.18 kN-mm.
Keywords: Beam column joint, T beam, cyclic load, hysteresis load versus defection curve, displacement ductility and energy absorption.

Introduction:

The experimental study carried out by (Ganesan et al 2007) reveals about the enhancement of strength, stiffness and ductility of beam column joints by including SFRHPC and also found to be more promising in minimizing transverse reinforcement congestion in beam column joints.The performance of the joint by focusing on bond and shear transfer for the seismic effects on various joints has been investigated (S.R. Uma and A. Meher Prasad).Shear strength enhancement is possible only upto a certain limit by adding transverse shear reinforcement and the failure in shear strength may occure when the addition is beyond the limit (RahmaniKadarningsihetal 2014).The study provides an overview of the proposed ideas relating to joint behaviour (Prakash Panjwani, S.K. Dubey 2015). The behaviour of reinforced concrete (RC) beam-column joints at the corner panel after a ground corner column loss is investigated in this work. A frame's ductility is determined by the ductility of its components, especially its joints (B. Abdelwahed 2019). The seismic performance of reinforced concrete (RC) beam-column joints strengthened using steel reinforced polymer (SRP) systems is investigated by the authors. The findings of cyclic tests on SRP strengthened joints are compared to the results of a prior experimental programme that included companion specimens that were not furnished with transverse beam stubs and were strengthened with carbon fiber-reinforced polymer (CFRP) systems (Alessandro De Vita etal 2017). Due to their larger load carrying capability, superior ductility and stiffness response, and reduced congestion in Beam Column Joints, the testing findings demonstrated that headed bars may be significantly substituted by conventional bars in earthquake-prone areas (PayalSachdevaetal 2021). HyFRC materials were developed in this study to provide cost-effective alternatives to Reinforced Concrete (RC) Knee Joint (KJ) structures in areas with low to moderate seismic risks (S. M. Iqbal etal 2021). The test results shows the formation of microcracks in the matrix and fibre interception prevents the crack propagation in the same direction. (Ganesan and Indira, 2000).

Experimental Programme:

Mix Proportions for concrete:

The concrete is made with an M40 mix ratio. The IS 10262–2009 requirements are followed to get the M40 concrete grade. With a constant water cement ratio of 0.4, the suggested and implemented mix percentage is 1:1.94:2.34.

Table.1 Mix Design for M_{40} Grade Concrete

Ingredients of concrete	Weight per Cum	Mix Ratio
Cement in kg/m^3	386	1
Fly ash in kg/m^3	43	0.1
Fine aggregate in kg/m^3	835	1.94
Coarse aggregate in kg/m^3	1024	2.34
Water content in lit/m^3	172	0.4
Super Plasticizer in lit/m^3	4.3	0.01

Specimen Details:

The cyclic load test was carried out on the T beam specimen. The reinforcement detail of the specimen is shown in Figure.1. Six numbers of 12 mm diameter HYSD bars (high yield strength) are used and two 12 mm diameter HYSD bars are used to reinforce the beam at the top and bottom. A two-legged stirrup with a 6 mm diameter HYSD bar put in the beam at 120 mm centre to centre, as a mould, a water-resistant ply wood sheet is employed. Figure 2. shows the location of PP and Steel fibers concentrations. Figure.3 and Figure.4 shows the mould and reinforcement placing in the mould.

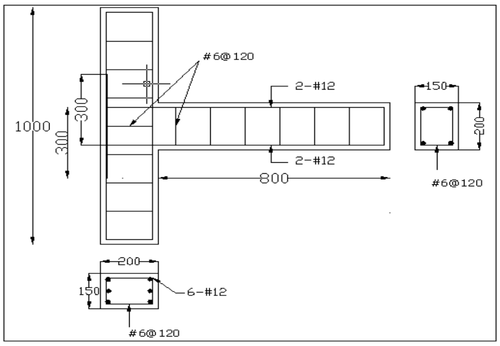

Figure.1 2D View of Beam Column JointReinforcement Detailing

Figure.3 Beam Column Joint - Mould

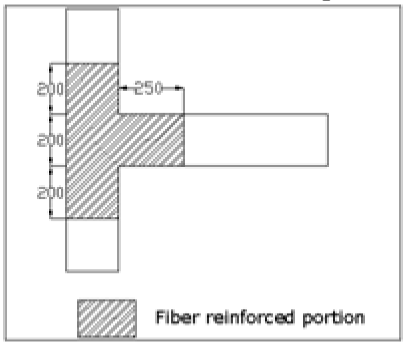

Figure.2 Fibre Location in Reinforced Concrete Beam Column Joint

Figure.4 Beam Column Joint- Reinforcement

Test Set up and Procedure:

The experimental trials were conducted using a loading frame with 100 tonne capacity at room temperature. To minimize the column axial force a steady load of 75KN is applied in the axial direction by maintaining the position as illustrated in figure 5.Measurement of deflection for the applied load is gauged using a Linear Variable Displacement Transducer (LVDT) by placing it in the opposite direction to the loading direction (Column's free end).The load at the free end is applied using a jack with an increment rate of 4 KN and load's intensity is measured using a proving ring with least count of 0.1 KN.The experimental findings supported for designing curve between load and deflection.

Figure.5 Beam Column Joint - Forward Loading

Results and Discussion:

Load-Deflection Behavior

Figure.6 shows the load-deflection behavior of conventional reinforced concrete beam-column joint in a hysteresis form. Three complete cyclic loads were applied on the conventional concrete joint and only one forward cycle, where the joint failed.

Figure.7 shows the load-deflection behaviour of $(PP_{1/2}+Steel_{1/2})_{2.0}$beam-column joint in a hysteresis form. Similar to conventional concrete joint, this joint was also subjected to complete three cyclic loads and only one forward cycle, where the joint failed. Figure.8 shows the load-deflection behaviour of $(PP_{3/4}+Steel_{1/4})_{2.0}$beam-column joint in a hysteresis form and except the last cycle. Four complete cyclic loads were applied on the $(PP_{3/4}+Steel_{1/4})_{2.0}$beam-column joint and only one forward cycle, where the joint failed. Compared with the all specimens of beam-column joint this one

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performs better under cyclic load due to better fiber bridging and stiffness.

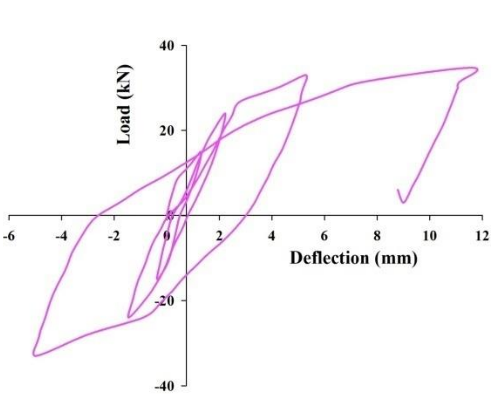

Figure.6 Load-Deflection behaviour of Conventional RC BC Joint

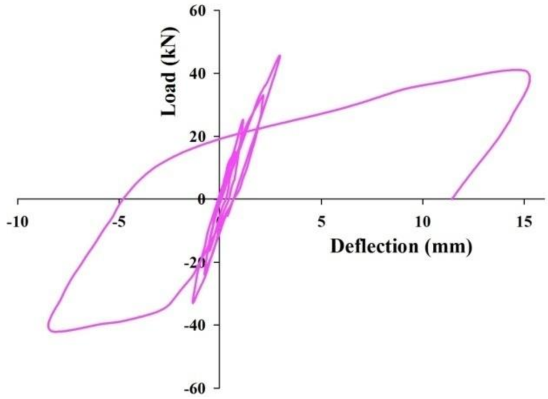

Figure.8 Load-Deflection behaviour of (PP3/4+Steel1/4)2.0 BC Joint

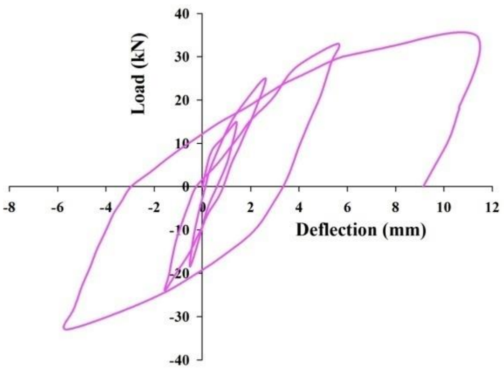

Figure.7 Load-Deflection behaviour of (PP1/2+Steel1/2)2.0 BC Joint

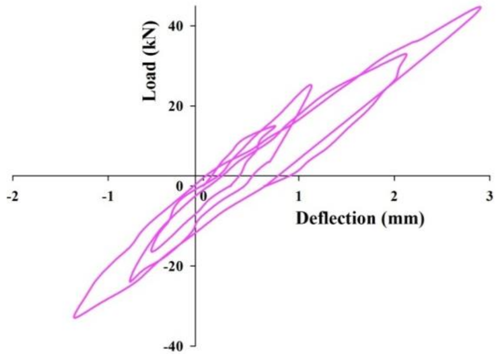

Figure.9 Load-Deflection Behaviour of (PP3/4+Steel1/4)2.0 BC Joint without Last Cycle

Figure.8, Figure.9 and Figure.10 shows the failure pattern of conventional concrete, $(PP_{1/2}+Steel_{1/2})_{2.0}$ and $(PP_{3/4}+Steel_{1/4})_{2.0}$ beam-column joints respectively. Figure.11 shows the maximum load-deflection enveloping from the each cycle hysteresis loop in the conventional concrete beam-column joint. Maximum load taken by the joint is 34.75 kN and 11.38 is the corresponding deflection. Figure.12 and Figure.13 show the maximum load-deflection enveloping from each cycle hysteresis loop in the $(PP_{1/2}+Steel_{1/2})_{2.0}$ and $(PP_{3/4}+Steel_{1/4})_{2.0}$beam-column joints respectively. The maximum load taken by the $(PP_{3/4}+Steel_{1/4})_{2.0}$beam-column joint, which exhibits 40.7 kN under cyclic load with 15.09 mm displacement at the maximum load. $(PP_{1/2}+Steel_{1/2})_{2.0}$ joint exhibits a maximum load of 38 kN and deflection at the maximum load is 11.59 mm.

Figure.8 Failure Pattern of Conventional Concrete BC Joint

Figure.9 Failure Pattern of (PP1/2+Steel1/2)2.0 BC Joint

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Figure.10 Failure Pattern of (PP3/4+Steel1/4)2.0 BC Joint

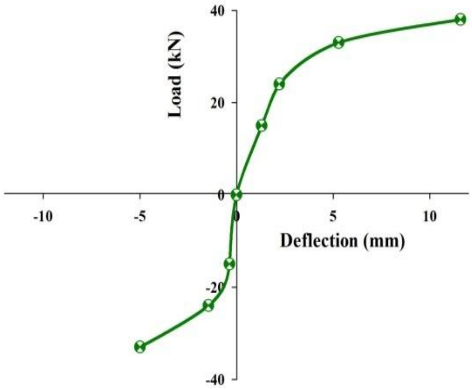

Figure.12 (PP1/2+Steel1/2)2.0 BC Joint Load-Deflection Response Envelopes of Hysteresis Curves

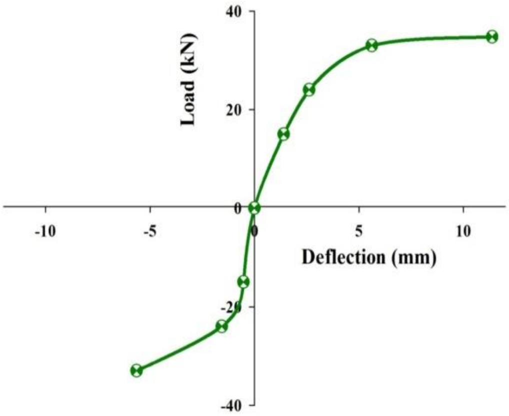

Figure.11 Conventional RC BC Joint Load-Deflection Response Envelopes of Hysteresis Curves

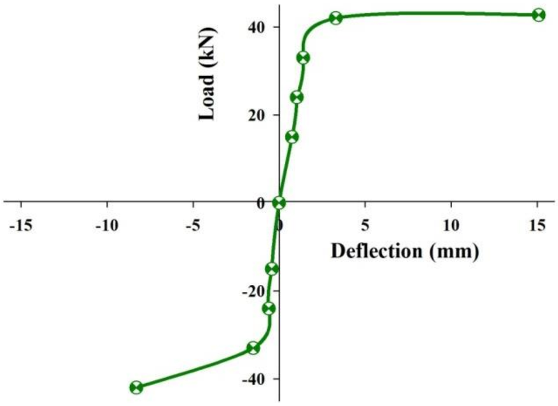

Figure.13 Load-Deflection Response Envelopes of Hysteresis Curves from (PP3/4+Steel1/4)2.0 BC Joint

Energy Absorption of Beam-Column Joints

Table.2 Cumulative Energy Absorption of Convention Concrete Joint

Cycle	Energy Absorption in Forward Cycle (kN mm)	Energy Absorption in Reverse Cycle (kN mm)	Energy Absorption in each Cycle (kN mm)	Cumulative Energy Absorption (kN mm)
First Cycle	7.5	4.08	11.58	**11.58**
Second Cycle	10.92	16.26	27.18	**38.76**
Third Cycle	76.365	133.44	209.81	**248.57**
Fourth Cycle	265.50	--	265.50	**514.06**

Table.3 Cumulative Energy Absorption of $(PP_{1/2}+Steel_{1/2})_{2.0}$**Joint**

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Cycle	Energy Absorption in Forward Cycle (kN mm)	Energy Absorption in Reverse Cycle (kN mm)	Energy Absorption in each Cycle (kN mm)	Cumulative Energy Absorption (kN mm)
First Cycle	8.85	4.35	13.20	**13.20**
Second Cycle	17.165	17.1	34.27	**47.47**
Third Cycle	73.16	152.2	225.36	**272.83**
Fourth Cycle	296.89	--	296.89	**569.72**

Table.4 Cumulative Energy Absorption of $(PP_{3/4}+Steel_{1/4})_{2.0}$ **Joint**

Cycle	Energy Absorption in Forward Cycle (kN mm)	Energy Absorption in Reverse Cycle (kN mm)	Energy Absorption in each Cycle (kN mm)	Cumulative Energy Absorption (kN mm)
First Cycle	3.33	3.36	6.69	**6.69**
Second Cycle	6.69	6.39	13.08	**19.77**
Third Cycle	19.005	15.615	34.62	**54.39**
Fourth Cycle	20.27	220.395	240.66	**295.05**
Fifth Cycle	469.13	--	469.127	**764.18**

For specimen with $(PP_{3/4}+Steel_{1/4})_{2.0}$ mix energy absorption started from 6.69 kN mm in the first cycle, 13.08 kN mm, 34.62 kN, 240.66 kN mm mm and 469.127 kN mm for second, third, fourth and fifth cycles respectively. Cumulative energy absorption of the beam-column joint is 764.18 kN mm. For $PVA_{2.0}$ mix the energy absorption is 13.20 kN mm, 34.27 kN mm, 225.36 kN mm and 296.89 kN mm first, second, third and fourth cycles respectively.

In the same way, for conventional concrete the energy absorption is 11.58 kN mm in the first cycle, 27.18 kN mm, 209.81 kN mm and 265.50 kN mm for second third and fourth cycles respectively. Figure.14 shows the energy absorption of the beam-column joint for each cycle. $(PP_{3/4}+Steel_{1/4})_{2.0}$ joint performs better than the other mixes in both load and displacement, this is may be due to the impact of fiber hybridation which leads to increase in the crack arresting and fiber bridging as mentioned in the earlier chapter.

Table.2, Table.3 and Table.4 show the cumulative energy absorption of conventional concrete, $(PP_{1/2}+Steel_{1/2})_{2.0}$ and $(PP_{3/4}+Steel_{1/4})_{2.0}$ joints respectively. These tables give details of the energy absorption for each cycle in forward and backward directions of applied load.

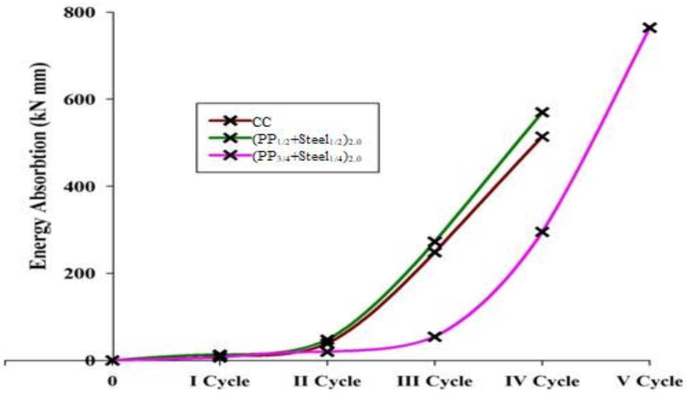

Figure.14 Energy Absorption of all the Beam-Column Joints

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Stiffness Degradation of Beam-Column Joints

For beam-column joint made with $(PP_{3/4}+Steel_{1/4})_{2.0}$ at the junction, stiffness degradation is 20.87 kN/mm, 20.0kN/mm, 15.56kN/mm, 14.33 kN/mm and 2.42 kN/mm for first, second, third, fourth and fifth cycles respectively. In case of reverse cycle the degradation in first, second, third and fourth cycles is 20.1 kN/mm, 18.29 kN/mm, 16.5 kN/mm and 4.69 kN/mm respectively. Stiffness degradation of conventional concrete joint at forward cycle is 10.71 kN/mm, 9.6 kN/mm, 5.61 kN/mm and 2.42 kN/mm for first, second, third and fourth cycles respectively. In the case of reverse cycle the degradation in first, second, and third cycles is 13.39 kN/mm, 9.92 kN/mm and 3.67 kN/mm respectively. Similarly for $(PP_{1/2}+Steel_{1/2})_{2.0}$ mix, the degradation is 11.53 kN/mm, 9.83 kN/mm, 6.2 kN/mm and 2.67 kN/mm for first, second, third and fourth cycles respectively. In case of reverse cycle the degradation in first, second, and third cycle is 17.44 kN/mm, 10.67 kN/mm and 4.13 kN/mm respectively. Figure.15 shows the stiffness degradation of all the beam-column joints under forward and reverse cycles. Joint with $(PP_{3/4}+Steel_{1/4})_{2.0}$ is seen to perform better than the other mixes.

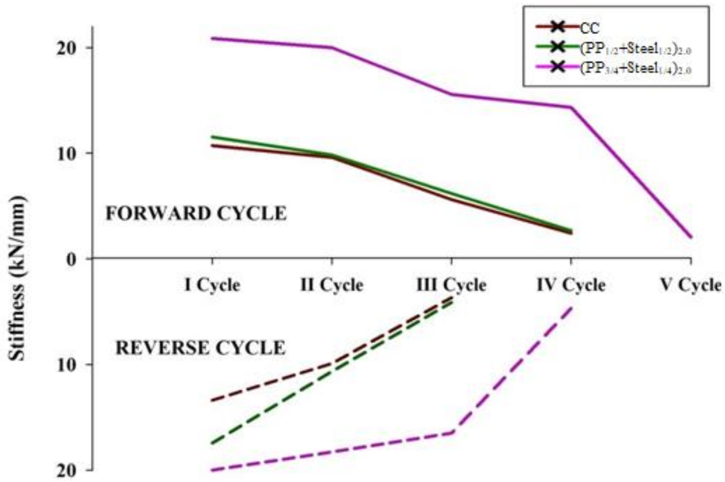

Figure.15 Stiffness Degradation of all the Beam-Column Joints under Forward and Reverse Cycles

Conclusion

The concluding remarks of the current study which involves flexural testing of beam column joints subjected under cyclic loading is detailed.

From the cyclic load test on beam column joint, $(PP_{3/4}+Steel_{1/4})_{2.0}$**s**pecimens were performed well.

- The $(PP_{3/4}+Steel_{1/4})_{2.0}$**s**pecimen reached fifth cycle, then after attains the failure
- The cumulative energy absorption of Conventional specimen attains the value of 514.06 kN-mm, $(PP_{1/2}+Steel_{1/2})_{2.0}$ specimen attains the value of 569.72 kN-mm and $(PP_{3/4}+Steel_{1/4})_{2.0}$ specimen attains the value of 764.18 kN-mm.
- The energy absorption value of $(PP_{3/4}+Steel_{1/4})_{2.0}$ specimen is 48% higher than the conventional specimen and 34.13% higher than the$(PP_{1/2}+Steel_{1/2})_{2.0}$ specimen.

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