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Research paper

Experimental Study on Fibre-Reinforced Concrete Beam-Column Joint with Ductile Detailing Under Reverse Cyclic Loading

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Abstract

The behaviour of a beam-column (BC) joint in a moment resisting framed structure is the key criteria when the structure is subjected to seismic loading. In the past many research have been carried out to grasp the mechanism of failure of beam-column joint and methods to enhance the performance of beam-column joint have been developed. The provision of ductile detailing as prescribed in IS-13920: 1993 has been followed. Improvement of the performance of joint region has been studied by using additional reinforcement with different fibres. In the present study the performance of the BC joint is studied in terms of load vs. displacement curve, stiffness degradation vs. drift angle curve and energy dissipation by the BC joint using different types of fibres in the specimen. The laboratory testing of the concrete cubes and cylinders reinforced with different percentages of fibre volume have been implemented. Based on the test results, the selection of the optimum quantity of fibre that can be used in beam-column joint for each type of fibre has been done. The testing of the specimens of BC joints is carried out in cyclic actuator of capacity 100 kN. The fibres which have been used in the present study are carbon fibre, steel fibre and glass fibre. Percentages of the fibres that had been added to the specimen are carbon fibre (0.75%), steel fibre (0.75%) and glass fibre (0.50%) respectively and the control specimen made from ordinary concrete made of M25 mix concrete. The performance of the specimens reinforced with different type of fibres is then compared and the specimen showing desirable performance under cyclic loading is found out. It has been observed that the application of carbon fibres could improve the strength and ductility of BC joints appreciably.

Keywords: *beam-column joint; performance; fibre; load; displacement.*

1. Introduction

Beam–column joints are most vulnerable when the structure is subjected to seismic excitation [1]. In RC moment resisting frames, BC joints are the most important elements for transfer of forces and moments [2]. Owing to reversal of moment over BC joints when subjected to the seismic excitation, larger joint horizontal and vertical shear forces are produced in the joints [4]. The formation of plastic hinge must be avoided since it is harmful for the entire structure. Thus, BC joints are intended to have adequate strength and stability to ensure the structural safety [5]. Structural Strength and ductility will be based on proper detailing of the reinforcement in the joints. So the joint region is to be detailed properly as per the provisions of IS-13920: 1993.

Fibre-Reinforced Polymer (FRP) has numerous precious qualities, for example, high elasticity, high durability, light weight and imperviousness to cater for severe natural conditions [6]. FRP has some remarkable preferences in view of its lightweight, high quality, cracking resistance and simplicity to application. Concrete structures are intended to play out their capacities proficiently over an outline benefit life [7]. Despite that, as a result of human blunders (e.g. plan blunder, change of utilization, and absence of maintenance), material imperfection or change in environmental conditions, some structures need repairs and retrofitting over their outline benefit life [8]. To enhance the seismic behavior of reinforced concrete structures, analysts have been searching for various alternative materials, for example, basalt, glass, polypropylene, carbon, steel, fiber composite (FRP) [9]. Two sorts of fiber that regularly utilized as a part of the concrete are steel fiber and polypropylene fiber.

A hopeful answer for enhancing the strength and ductility of RC BC joint is to utilize steel fibre-reinforced concrete [10]. The steel fibres have high modulus and stiffness so they can enhance compressive strength and durability of concrete [11]. Then again, the polypropylene and carbon fibres have great qualities so they can limit the propagation of cracks [12]. Hybrid fibres have proven to be alternative materials for enhancement of strength and ductility of RC beam-column joint [13-18]. Normal concrete performs in a inferior way forming multiple cracks when subjected to seismic excitations. However fibre reinforced concrete has the great qualities to arrest the cracking of concrete for more cycles of loading applied on it.

In RC frame structures, problems of diagonal cracking and failure of concrete in the joint region can be solved by two mean, namely providing larger column sizes and providing confinement reinforcement around column bars in the joint region. However the above solution for strengthening of the joint region is limited to few cycles of load, afterwards it may follow the cracking and crushing of the concrete near the joint. So in this study, an attempt has been made for further strengthening of the joint region by using the above mentioned ductile detailing along with the replacement of normal concrete with fibre reinforced concrete.

Improvement of the performance of joint region has been studied by using additional reinforcement with different fibres. In the present study the performance of the beam-column joint is studied in terms of load vs. displacement curve, stiffness degradation vs. drift angle curve and energy dissipation by the BC joint using different types of fibres in the specimen. The laboratory testing of the concrete cubes and cylinders reinforced with different percentages of fibre volume have been implemented. Based on the test results, the selection of the optimum quantity of fibre that can be used in beam-column joint for each type of fibre has been done. The testing of the specimens of BC joints is carried out in cyclic actuator of capacity 100 kN. The fibres which have been used in the present study are carbon fibre, steel fibre and glass fibre. Percentages of the fibres that had been added to the specimen are carbon fibre (0.75%), steel fibre (0.75%) and glass fibre (0.50%) respectively and the control specimen made from ordinary concrete made of M25 mix concrete. The performance of the specimens reinforced with different type of fibres is then compared and the specimen showing desirable performance under cyclic loading is found out. It has been observed that the application of carbon fibres could improve the strength and ductility of beam-column joints appreciably.

2. Experimental Programme

In RC buildings, beam-column joints are more vulnerable when it is subjected to seismic exicitation. Force come from both horizontal and vertical direction during earth quakes, resulting severe damage of joints. So damage must be avoided as it is very difficult to repair those damage. Critical joints should be designed as per IS-13920:1993. It is important in earthquake resistant design, to assure the ductility in the structure , that the structure would be able to deform inelastically and dissipate energy without causing collapse. The maximum shear force, bending moment occurs at the joint region in a structure. So those joints are the most critical zone in a structure. Generally the exterior joint is more critical than interior joint during the occurrence of earthquake. After the study of literatures on fibres, it has been seen that carbon fibres, steel fibres, glass fibres has lot of tensile strength and ductile property. These fibres have the ability to resist propagation of micro cracks also. In the present work, four beam-column joints are casted in one third scale and detailing is done in accordance with provisions made in IS-13920: 1993. The beams casted are control specimen, 0.75% carbon fibre specimen, 0.75% steel fibre specimen and 0.50 % glass fibre specimen. The specimens are tested using cyclic load conducted using servo controlled hydraulic actuator of 100 kN capacity.

2.1 Details of Specimens

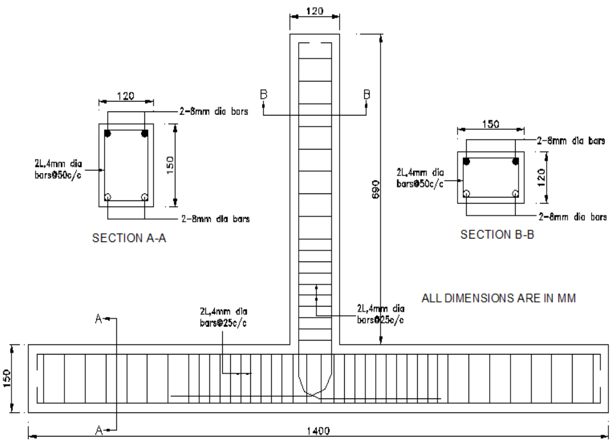

Fig. 1: Details of specimen used

Table 1: Details of Reinforcement used

Specimen	Beams			Column		
	Effective Span (mm)	Cross Section (*mm*)	Long. Steel	Effective Span (mm)	Cross Section (*mm*)	Long. Steel
CS	615	120×150	4#8ø	1300	120×150	4#8ø
CFRC	615	120×150	4#8ø	1300	120×150	4#8ø
SFRC	615	120×150	4#8ø	1300	120×150	4#8ø
GFRC	615	120×150	4#8ø	1300	120×150	4#8ø

Table 2: Details of Specimens used

Sl. No.	Designation of Specimens	Volume fraction of fibre (%)		
		Carbon	Steel	Glass
1	CS	0	0	0
2	CFRC	0.75	0	0
3	SFRC	0	0.75	0
6	GFRC	0	0	0.50

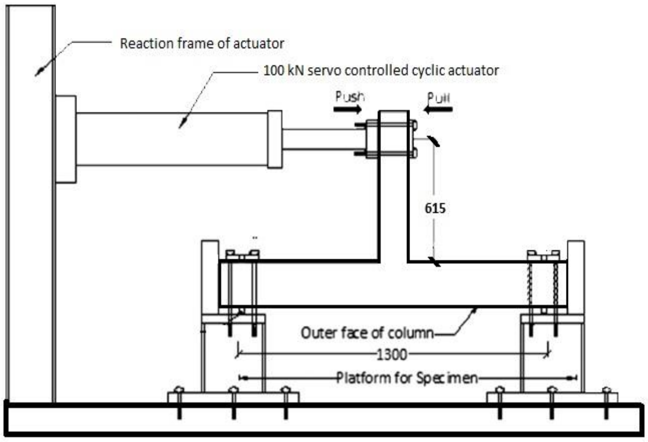

Fig. 2: Cyclic Actuator Set-Up

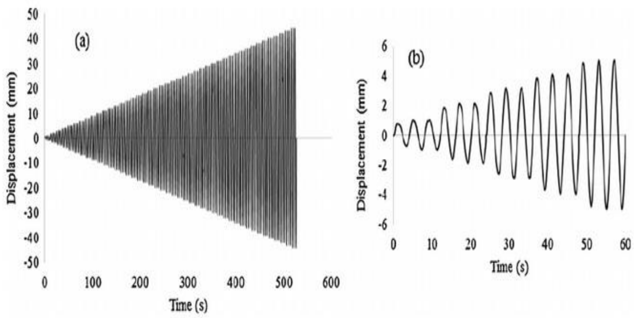

Fig. 3: Loading History Applied on the Specimen

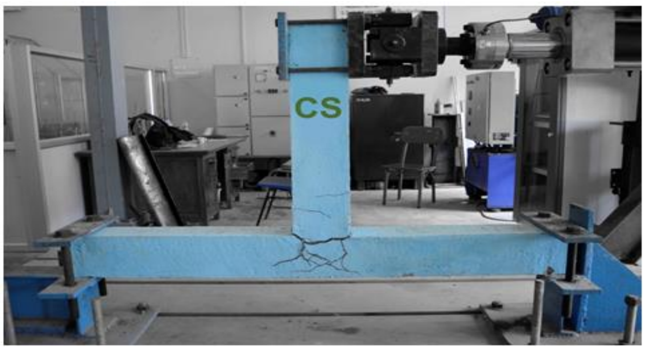

Fig. 4: Control Specimen (CS) Crack Pattern

Fig. 5: CFRC specimen crack pattern

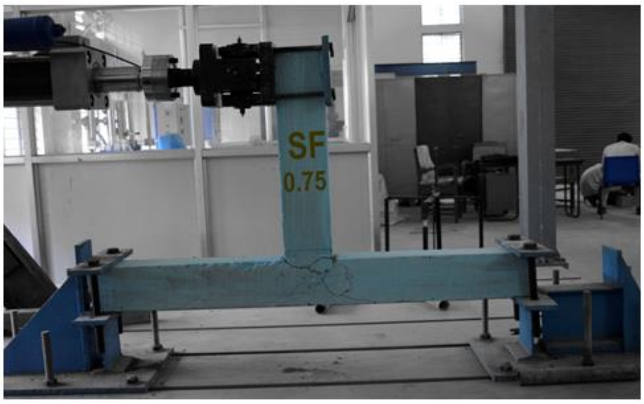

Fig. 6: SFRC specimen crack pattern

Fig. 7: GFRC specimen crack pattern

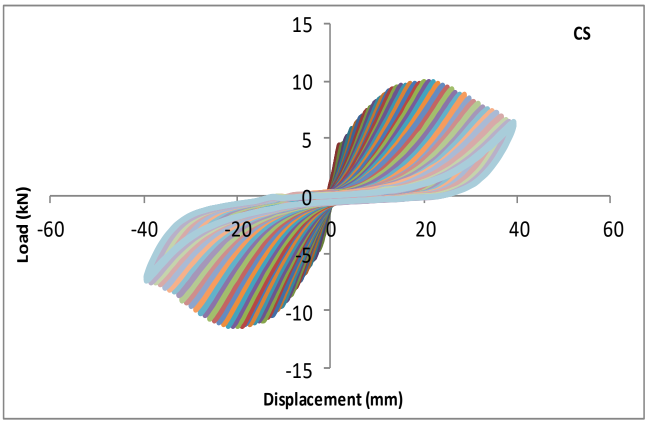

Fig. 8: Hysteresis Curve of CS

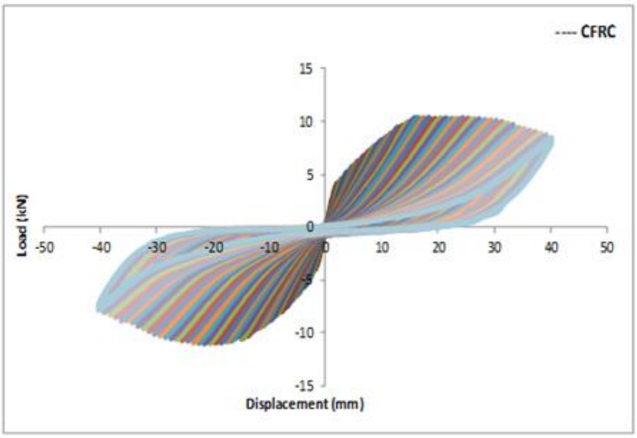

Fig. 9: Hysteresis curve for CFRC specimen

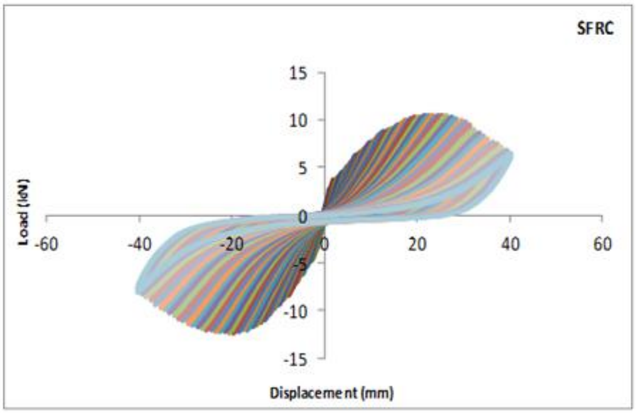

Fig. 10: Hysteresis curve for SFRC specimen

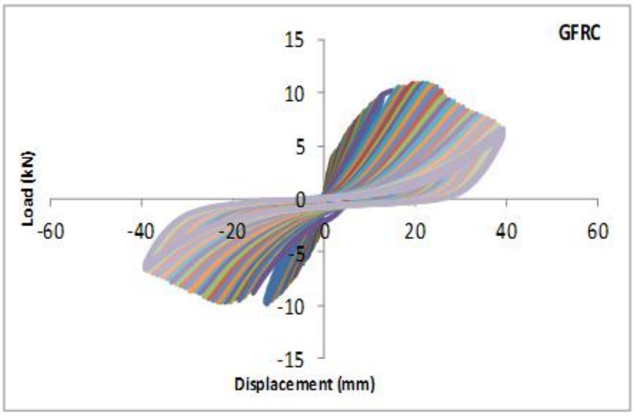

Fig. 11: Hysteresis loop for GFRC specimen

Table 3: Test Results

Designation of specimen	First crack load (kN)	Ultimate load (kN)		Deflection at ultimate load (*mm*)	
		Forward cycle	Reverse cycle	Forward cycle	Reverse cycle
CS	3.18	10.90	9.70	22	14
CFRC	4.70	10.45	11.07	16	21
SFRC	3.73	10.46	12.35	23	20
GFRC	4.08	10.91	9.80	21	12

Table 4: Energy absorption capacity and displacement ductility

Designation of specimen	Energy absorption capacity (kN-mm)	δ_y (*mm*)	δ_u (*mm*)	Displacement ductility factor, ψ	
				Absolute	Relative
CS	6852.39	7.82	33.92	4.33	1.00
CFRC	11048.53	7.89	45.54	5.77	1.31
SFRC	8200.34	8.22	36.45	4.43	1.01
GFRC	7796.17	7.01	34.19	4.87	1.10

2.2 Comparison of Load vs. Deformation Envelope Curve

From the combined graph drawn for all type of specimens tested, it can be drawn to our knowledge that in the forward cycle the Beam-Column joint specimen containing 0.5% glass fibre has been subjected to maximum peak load of 10.91 kN and in the reverse cycle the beam-column joint containing 0.75% steel fibre has experienced the maximum load of 12.35 kN. Further it has been observed that maximum average peak load is experienced by 0.75% SFRC beam-column joint specimen. This result shows that optimum amount of steel fibre when added to a structure can improve its load carrying capacity.

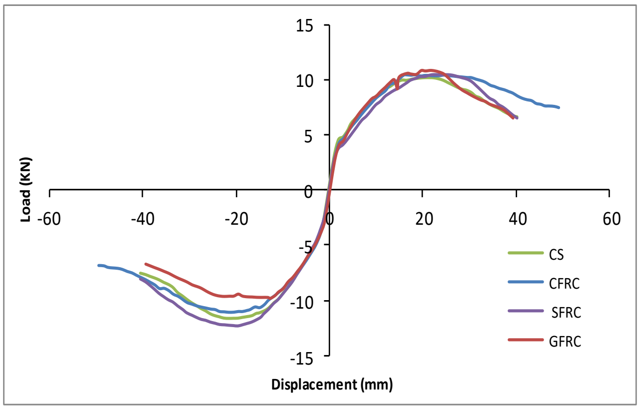

Fig. 12: Comparison of load vs. deflection between specimens

2.3 Comparison of Cumulative Energy vs Drift Angle (%)

The dissipation of cumulative energy of all the test specimens can be seen in the fig. 13. The Beam-column joint specimen with 0.75% carbon fibre has dissipated the maximum energy which is found to be 11048.53 kN-*mm*, which is 61.2% more than that of the control specimen. Further it also has the maximum drift angle out of all the test specimens which is 6.23%. This shows that specimen containing Carbon Fibre can highly improve the performance of the structure when subjected to higher excitation during seismic motion as it can dissipate more energy as compared to the other specimens. Steel fibre reinforced beam-column specimen dissipated an energy of 8200 kN-*mm* which is around 35% less than that of CFRC specimen and glass fibre reinforced specimen has dissipated an amount of energy 7796 kN-*mm* which is again 41% less than that of CFRC specimen. Hence it can be concluded from the above observation that carbon fibre has a better potential of dissipating high amount of energy.

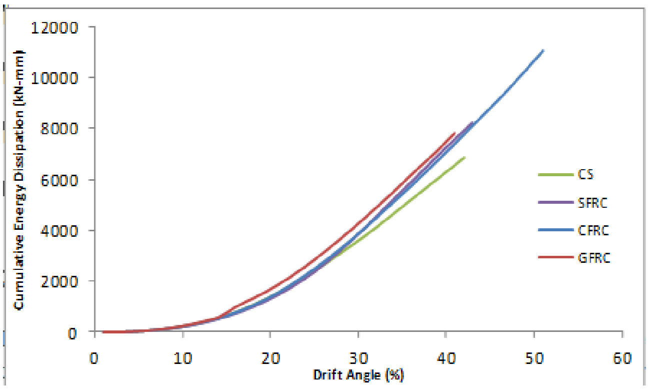

Fig. 13: Comparison of cumulative energy vs. drift angle between specimens

2.4 Comparison of Stiffness vs. Drift Angle (%) Curve

It has been observed from the fig. 14 that with the increase in the displacement value, the stiffness value of each specimen with or without fibre is decreasing. Initial decrement in the stiffness for almost all the specimens is quite steep , in the later stage the fall of stiffness is seem to be gradual. From the results it is seen that 0.5% glass fibre specimen is having the highest stiffness in the failure load which is 0.25 kN/*mm* and 0.75% Carbon fibre specimen has the lowest stiffness during the failure load which is 0.17 kN/*mm*. So it is seen that CFRC beam-column specimen has lost highest amount of stiffness and undergone the highest displacement with a displacement value of 38 mm in the failure load and also it has the maximum drift angle of 6.23% corresponding to the failure load.

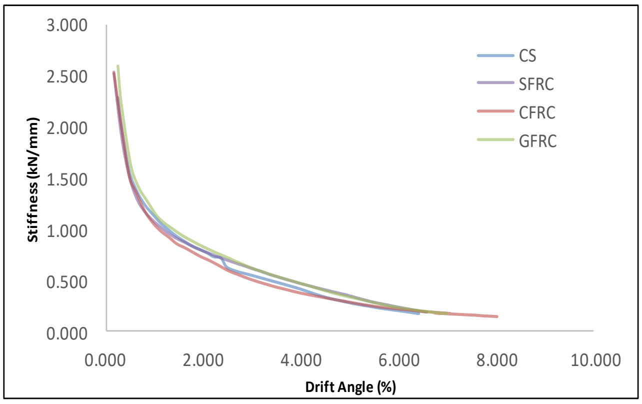

Fig. 14: Comparison of stiffness vs. drift between specimens

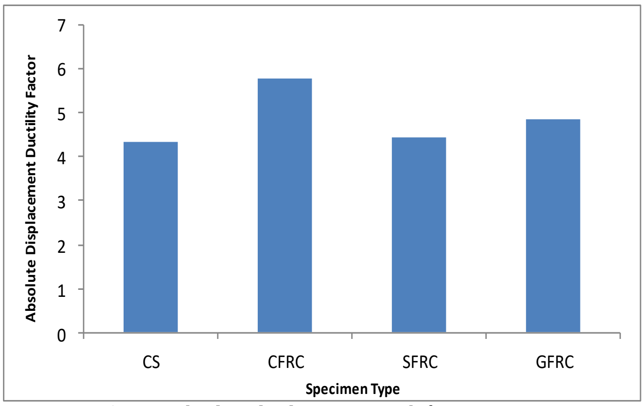

Fig. 15: Absolute displacement graph for specimens

3. Conclusions

In this study, behaviour of the entire beam-column joint with fibre reinforced concrete specimens with different types of fibres are studied under cyclic loading. The behaviour of these specimens was estimated on the basis of hysteretic behaviour, load-deflection curve, stiffness degradation, energy dissipated etc. The details of these performances and their interpretation are discussed in the following section.

1. In the control specimen, the first visible crack was seen at an applied displacement of 1*mm* and in all the other specimens, first visible crack started appearing after the application of 2 *mm* displacement. It was observed that diagonal cracks on the joint region of the fibre reinforced concrete specimens were comparatively less when compared with the control specimen.

2. It was observed from the test results that the ultimate load for all the specimens containing fibres is more when compared to the control specimen. Maximum peak load in the forward cycle was seen in specimen containing 0.5% glass fibre with a peak load of 10.91 kN. Maximum peak load in reverse cycle was seen in specimen containing 0.75% Steel Fibre with a peak load of 11.07 kN. Increase in the peak load of the specimen containing Glass Fibre and Steel Fibre can be attributed to the proper distribution of the fibres within the specimen and proper bridging of the fibres between the cracks that had delayed the crack propagation by certain amount.

3. All the test specimens failed with the development of the plastic hinge at the critical joint region.

4. Stiffness of all the fibres has decreased at almost same rate along with the increase in applied displacement. The initial stiffness of the specimen with fibres was more compared to the control specimen. In the initial stiffness it is observed that the specimen containing glass fibre is having a percentage stiffness gain of more than 18% over the control specimen. And in the stiffness corresponding to the failure load specimen containing glass fibre had a percentage stiffness gain of 13% over the control specimen. So from the results it can be drawn to our knowledge that specimen with glass fibre has a good stiffness property than ordinary concrete specimen.

5. It is seen from the obtained results that the maximum displacement of the specimens (containing fibre) has a higher value corresponding to the failure load than that of the control specimen except glass fibre specimen, which is almost same with the control specimen (CS). The maximal displacement corresponding to the failure load is obtained in the carbon fibre specimen which is 15% higher than that of the CS.

6. Cumulative energy dissipation of all the specimens was found out. It has been observed that the maximum strain energy was dissipated by the specimen with 0.75% carbon fibre, which showed a percentage gain of around 60% over control specimen. The reason behind this may be due to the high mechanical properties of the carbon fibre and adequate amount of fibre addition in the specimen with proper distribution within the concrete. All other fibre reinforced specimens also showed a significant increase in the energy dissipation than the control specimen, which further shows that fibres has a better potential in improving the extent of energy dissipation during seismic excitation.

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