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Effect of Wire Mesh Orientation on Strength of Exterior RC Beam-Column Joints Retrofitted Using Ferrocement Jackets

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ABSTRACT: In various parts of the world, the behavior of reinforced concrete moment resisting frame structure during recent earthquakes has highlighted the consequences of poor performance of reinforced concrete beam-column joints. Reinforced concrete beam-column joints in a reinforced concrete moment resisting frame are crucial zones for transfer of loads, effectively between the connecting beams and columns in the structure. Ferrocement retrofitting are mostly used for strengthening damaged structures due to easy availability and durability. In the present work, effect of wire mesh orientation on the strength parameters of stressed exterior beam-column joints retrofitted with ferrocement jackets have been presented. The beam-column joints were stressed to ultimate load and then retrofitted with ferrocement jackets with two different wire mesh orientations. The results show a significant increase in ultimate load carrying capacity of retrofitted beam-column joints using ferrocement jackets with two layers of wire mesh with orientation at L-shape and at 45 degree to the longitudinal axis of the joint, varies from 6.70 percent to 22.57 percent along with the increase in the yield load and stiffness of the joint. However, orientation at 45 degree shows the higher percentage increase in the stiffness and ultimate load carrying capacity followed by L-shape orientations to the joint.

Keywords: Ferrocement, wire mesh layers, orientation, retrofitting, beam-column joints, exterior

I. INTRODUCTION

The reinforced beam-column joints are known as the vulnerable and critical region of a reinforced concrete moment resisting structure subjected to seismic loads. The worldwide reaction of the structure is mainly governed by the behavior of the beam-column joints, during earthquakes. If beam-column joints behave in a brittle manner then the structure will display a brittle behavior and if beam-column joints behave in a ductile manner, the worldwide behavior of structures will be ductile. The RC beam-column joints are subjected to large shear stresses in the joint region under the action of seismic forces. The stresses produced due to moments and shear forces of converse signs on the member ends on either side of the joint core. High bond stresses are also forced on reinforcement bars in going into the joint. The diagonal cracking and crushing of concrete in the joint core are due to the axial compression and joint shear stresses effect in principal tension and compression stresses in the column. These difficulties are highlighted in past years by the damage observed during earthquakes in different countries [ACI-ASCE 352R-02]. Bansal *et al.* various efforts have been made to overcome such deficiencies of concrete by developing two phase composite materials wherein the presence of one phase improves the basic properties of the other phase and each phase is used to its best advantage. Bansal *et al.* studied the effect of wire mesh orientation for beams retrofitted with ferrocement jackets. A considerable increase in the load carrying capacity and energy absorption was observed for all orientations. However, orientation at 45^0 showed higher percentage increase in energy absorption followed by 60° and 0° respectively. After retrofitting, all the test specimens showed reduced crack widths, large deflection at the ultimate load and a significant increase in the ductility ratio. Sehgal *et al.* studied the behavior of simply supported ferrocement box girder subjected to UDL on the entire top flange and also on the half of the flange width. It was concluded that irrespective of the mode of load application, the first crack load was practically constant. Also the maximum deflection at the mid span at the first crack was same, demonstrating the large load distribution which the box section can bear. It was also concluded that serviceability for the box girder elements is governed by the maximum crack width and not the deflection.

The recommended value of the maximum crack width was 0.1mm. Singh and Kaushik ferrocement composite columns are used for prefabrication, repair/retrofitting and for in-situ construction. Encasement of column end zone can be used to produce hinges for seismic retrofitting of columns. The presence of mesh reinforcement in encased columns exerts a confining pressure on the core concrete and consequently enhances its strength and ductility. B Ganesh, studied the behavior of ferrocement ribbon roofs for long spans. Singh V et al. examined the behavior of RC exterior beam-column joints. It was concluded that the ultimate load carrying capacity (7 to 12 percent) of the retrofitted beams, when compared to the control beams along with an increase of 15 percent in yield load for each of such exterior beam- column joints. Stiffness up to the first crack load was 17.36 percent and 26.94 percent more for stress level-2 and stress level-3 as compared to stress level-1. D.D'Ayala *et al.* conducted tests on different layouts of FRP fabric and sheets bonded to R.C. beam-column joints, and found that the strengthening procedure increases the stiffness and ductility, while increases in shear and flexural strength and in energy dissipation are highly dependent on proper confinement of concrete and anchorage of the wrapping. Mukherjee and Joshi, examined the performance of FRP in up progression of RC joints with adequate and deficient reinforcements with rehabilitation of damaged joints. All the specimens were strengthened by using carbon and glass FRP materials. The control specimens were used after testing to evaluate the rehabilitation of joints with FRP known as rehabbed specimens. It was observed ductile specimens showed higher load at yield in the FRP reinforced specimens than the control specimen and for the same tip load, the tensile force in steel was lower in the CFRP retrofitted specimen than in the GFRP specimens. The displacement at yield was much lesser than the load due to FRP retrofitting. All the FRP retrofitting specimens showed higher peak loads than the control specimen and FRP retrofitting specimens also showed a total loss of stiffness at a higher displacement level than the control specimen. The energy dissipation of the FRP retrofitted specimens was closes that of the control specimen. The FRP retrofitting increased the ultimate deformation of the structure up to a large extent. The load versus displacement curves for the retrofitted specimens showed that the use of FRP's not only restored the original capacity of damaged specimen, but also upgraded the ultimate load capacity by 55% with 30 % increase in displacement at ultimate load. Also 48% increase in initial was observed. Nassif and Najm the addition of a thin layer of ferrocement to a concrete beam also enhances its ductility and cracking strength. The composite beams reinforced with square mesh exhibit better overall performance as compared to composite beams reinforced with hexagonal mesh. An increase in the number of layers leads to improvement in the cracking stiffness of the composite beams for both the cases. According to Anugeetha and Sheela the ultimate load carrying capacity of beams retrofitted with ferrocement having one, two and three layers of wire mesh increased by 6.25%, 50%, and 81.25 % and that of GFRP retrofitted beams with one, two and three layers increased by 50%, 68.75%, and 81.25 %, respectively. The beams retrofitted with one layer of GFRP in the flexural zone showed a higher strength-to-cost ratio.

II. EXPERIMENTAL INVESTIGATION

In the experimental investigation, four exterior reinforced concrete beam-column joints were cast using M-20 grade of concrete and Fe-415 steel grade as shown in Fig.1, with 1:1.45:2.95 having water cement ratio of 0.47 and tested in the lab under point loading conditions as shown in Figure-2. The cross-section of column was 225 mm x 125 mm with length of 1000 mm. The cantilever cross- section was 125 mmx225 mm with a length of 500mm were used in the joints. 4-10Φ was used as longitudinal reinforcement in the columns, 6Φ lateral ties with spacing of 100mmc/c was provided in the columns. 2-10Φ used as tension reinforcement and 2- 8Φ was used in compression reinforcement (Singh *et al.*). All the four specimens were stressed up to ultimate load. The average of ultimate load of all the four joint specimens was taken as an ultimate stress level. These cracked beam-column joints then retrofitted using ferrocement jackets with two layers of wire mesh in L-shape and at 45 degree to the longitudinal axis of the joints as shown in Fig. 3 and Fig. 4. The retrofitted beam-column joints again tested and recorded the results in the form of load and deflection and crack patterns.

A. Material Properties

Portland Pozzolana Cement (PPC), Zone-II fine aggregate and crushed coarse aggregates of used 20mm and 10mm as per Indian standards were used in the investigation. The properties of different materials used in the investigation are reported in Tables 1 to 4.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Table 1: Physical Properties of Portland Pozzolana Cement.

Sr. No.	**Characteristics**	**Test Values**	**Value specified by IS :1489 (Part 1) - 1991**
1.	Standard Consistency (%)	33	---
2.	Fineness of cement as retained on 90 micron sieve (%)	0.67	Maximum 10%
3.	Setting times (minutes) Initial Final	 115 295	 Minimum 30 Maximum 600
4.	Specific gravity	3.13	-
5.	Compressive Strength (MPa) 7 days 28 days	24.5 35.5	Minimum 22.0 Minimum 33.0

Table 2: Physical Properties of Coarse Aggregate.

S. No.	Characteristics	Values	
		CA-I	***CA-II***
1.	Type	Crushed	Crushed
2.	Maximum Nominal Size (mm)	20	10
3.	Specific gravity	2.55	2.60
4.	Total water absorption (%)	1.70	1.75
5.	Fineness modulus	6.70	6.30

Table 3: Physical Properties of Fine Aggregate.

Sr. No.	Characteristics	Test Value
1.	Specific gravity (oven dry basis)	2.64
2.	Bulk density loose (kg/litre)	1.31
3.	Fineness modulus	2.25
4.	Water absorption (%)	2.25
5.	Grading Zone (Based on percentage passing 600 µm sieve) as per IS: 383-1970	II

Table 4: Physical Properties of Steel Bars and Steel Wire Mesh.

S. No.	Diameter of bars/ wire mesh (mm)	Yield strength (MPa)	Ultimate Strength (MPa)	Elongation (%)
1.	10	554.00	670.00	20.5
2.	8	557.00	676.23	25.8
3.	6	442.42	612.70	32.7
4.	0.5	665.00	950.00	18.2

B. Testing Arrangement

All the four beam-column joint samples after and before retrofitting were tested using servo controlled hydraulic jack as shown in Figure-2. The joint samples were fixed and point load was applied on free end of the beam. The data collected in the form of load and deflection values through LVDT's.

C. Retrofitting Process

Stressed BC joint samples were retrofitted with the detail procedure of retrofitting. Two samples were wrapped with two layers of wire mesh on the joint in L-shape and other two samples were wrapped at 45 degree to the longitudinal axis of the joint in 25mm thick cement mortar layer as shown in Fig. 3. Retrofitted joint samples cured for ten days before testing and tested by same methods.

III. RESULTS AND DISCUSSION

All the four prototype beam- column joint specimens were stressed upto ultimate load. Out of these four beam- column joints two specimens R1 and R2, were wrapped by Type-A technique of retrofitting. In this retrofitting technique two layers of L-shape wire mesh with appropriate were wrapped on the lower and upper faces of the beam at the joint then cement mortar 1: 2 of 25mm thick with water cement ratio of 0.40 was applied as a bonding material on the wire mesh as shown in Figure-5. In Type- B retrofitting technique again two specimens R3 and R4, were wrapped with two layers of two L- shapes of appropriate size of wire mesh on the lower and upper faces of the beam- column joints with extra mesh of appropriate size was wrapped diagonally at 45 degree to the joint with 25mm thick cement mortar on wire mesh as shown in Fig. 6 (Singh *et al.*).

It was observed from experimental data and corresponding graph of Type-A retrofitted specimen (R1), that retrofitting leads to a significant increase in ultimate load carrying capacity from 22.68kN to 24.60kN, whereas the deflection corresponding to ultimate load of 24.60kN was 20.50mm as compared to 23.24 mm for control specimen at 22.68kN. For Type-A retrofitted sample (R2), exactly similar trend was observed. The Increase in load is also of almost of same order i.e. 22.68kN (control specimen) to 23.80kN (retrofitted specimen) with deflection of 18.68mm compared to 23.24 mm for control specimen at 22.68kN. Thus an average Type- A retrofitted beam-column joint specimens showed 6.70 percent increase in ultimate load carrying capacity with 15.70 percent decreases in deflection as compared to control beam-column joint specimens.

In case of Type- B retrofitted specimen (R3), it was observed from experimental data and corresponding graph that retrofitting leads to a significant increase in ultimate load carrying capacity from 22.68kN to 27.60kN, whereas the deflection corresponding to ultimate load of 27.60kN was 14.72mm as compared to 23.24 mm for control specimen at 22.68kN. Also there was a considerable increase in the yield load from 22kN (control specimen) to 24kN (retrofitted specimen). For Type- B retrofitted specimen (R4) exactly similar trend was observed. The increase in load is also of almost of same order i.e. 22.68kN (control specimen) to 28.00kN (retrofitted specimen) with deflection 10.26mm compared to 23.24mm for control specimen at 22.68kN. Also there was a considerable increase in the yield load from 22kN (control specimen) to 24kN (retrofitted specimen). Thus an average Type- B retrofitted beam-column joint specimens showed 22.57 percent increase in ultimate load carrying capacity with 46.25 percent decreases in deflection as compared to control beam-column joint specimens. The results are shown in Table 5 and 6.

From a comparative point of view it was observed from Figure- 7, that the beam- column joints with different wrapping technique showed different behavior. Specimens with Type-B retrofitting scheme show maximum improvement in their ultimate load carrying capacity from 22.68kN (control specimen) to 27.80N with decrease in deflection from 23.24mm to 12.49mm followed by Type –A retrofitting. However, the ductility ratio and energy absorption decreases with higher stiffness in beam- column joints retrofitted wire mesh with Type-B retrofitting. The average less spacing and less number of cracks were observed in retrofitted beam- column joints indicating better distribution of stress after retrofitting.

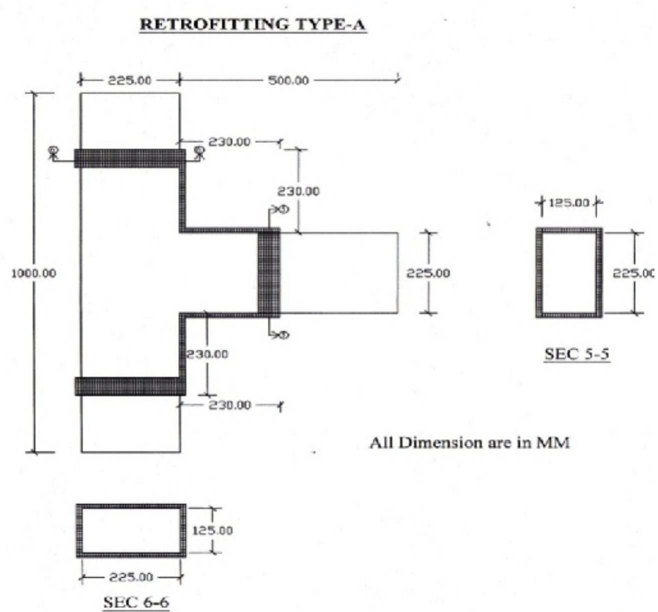

Fig. 5.

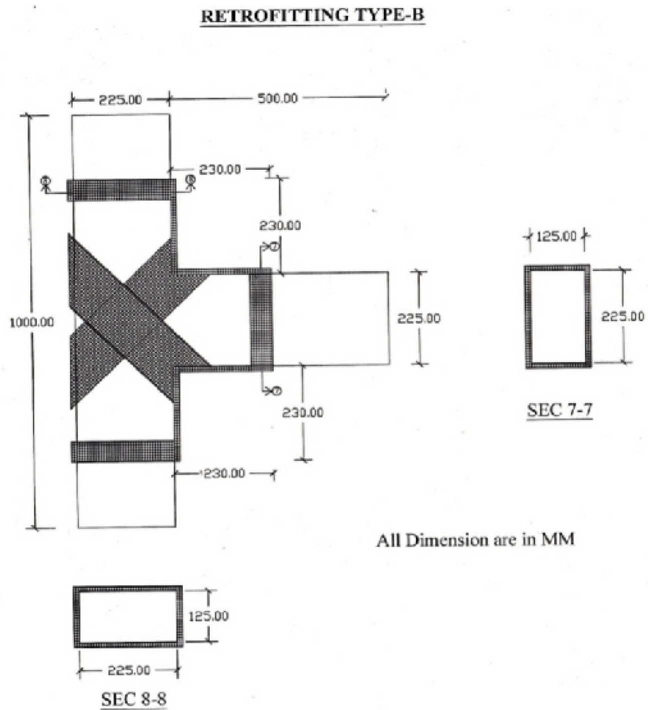

Fig. 6.

Table 5: Load vs Deflection Data for Control Beam- Column Joints and Beam- Column Joints Retrofitted with Ferrocement Jackets Using Type - A Retrofitting.

S.No.	Average Control Beam-Column Joint (CS)		Type-A Retrofitted Beam- Column Joint (R1)		Type-A Retrofitted Beam- Column Joint (R2)		Average = (R1+R2)/2	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	2.00	0.38	2.00	0.46	2.00	0.44	2.00	0.45
3	4.00	0.76	4.00	0.87	4.00	0.90	4.00	0.88
4	6.00	1.52	6.00	1.63	6.00	2.16	6.00	1.89
5	8.00	2.48	8.00	2.89	8.00	3.52	8.00	3.21
6	10.00	3.05	10.00	3.24	10.00	4.07	10.00	3.65
7	12.00	4.77	12.00	3.86	12.00	4.79	12.00	4.32
8	14.00	5.62	14.00	4.88	14.00	6.41	14.00	5.65
9	16.00	6.10	16.00	5.46	16.00	6.87	16.00	6.17
10	18.00	7.05	18.00	5.96	18.00	8.00	18.00	6.98
11	20.00	8.38	20.00	6.83	20.00	9.46	20.00	8.14
12	22.00	19.43	22.00	15.90	22.00	14.64	22.00	15.27
13	22.68	23.24	24.60	20.50	23.80	18.68	24.20	19.59

Table 6: Load vs Deflection Data for Control Beam-Column Joints and Beam-Column Joints Retrofitted with Ferrocement Jackets Using Type- B Retrofitting.

S.No.	Average Control Beam-Column Joint (CS)		Type-B Retrofitted Beam- Column joint (R3)		Type-B Retrofitted Beam-Column Joint (R4)		Average = (R3+R4)/2	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	2.00	0.38	2.00	0.89	2.00	0.55	2.00	0.72
3.00	4.00	0.76	4.00	1.57	4.00	1.70	4.00	1.64
4.00	6.00	1.52	6.00	1.99	6.00	2.53	6.00	2.26
5.00	8.00	2.48	8.00	2.54	8.00	3.61	8.00	3.08
6.00	10.00	3.05	10.00	3.25	10.00	4.55	10.00	3.90
7.00	12.00	4.77	12.00	4.29	12.00	5.97	12.00	5.13
8.00	14.00	5.62	14.00	5.25	14.00	6.24	14.00	5.74
9.00	16.00	6.10	16.00	5.90	16.00	6.21	16.00	6.05
10.00	18.00	7.05	18.00	7.09	18.00	6.65	18.00	6.87
11.00	20.00	8.38	20.00	8.40	20.00	6.99	20.00	7.69
12.00	22.00	19.43	22.00	9.77	22.00	7.25	22.00	8.51
13.00	22.68	23.24	24.00	10.10	24.00	8.89	24.00	9.50
			26.00	12.25	26.00	9.75	26.00	11.00
			27.60	14.72	28.00	10.26	27.80	12.49

Table 7: Test Results of Beam- Column Joints Using Ferrocement Jacket with Different Type of Retrofitting.

S.NO.	Beam Type	Pmax (kN)	Deflection (mm)	Ductility Ratio* ($\Delta U/\Delta Y$)	Stiffness P_u / Δ_U kN/mm	Energy Absorption** (kN-mm)
1	ACS	22.68	23.24	2.77	0.976	412.70
2	Avg. Type-A	24.20	19.59	2.40	1.23	377.65
3	Avg. Type-B	27.80	12.49	1.62	2.22	250.34

**Ductility Ratio of beam -column joints is defined as ratio of deflection at ultimate load to the yield load calculated from idealized trilinear load deflection curve. ** Area under the load deflection curve upto ultimate load*
ACS = Control / un-retrofitted beam -column joints
Avg. Type-A, RS= Retrofitted beam -column joints (Type- A retrofitting)
Avg. Type-B, RS = Retrofitted beam -column joints (Type-B retrofitting).

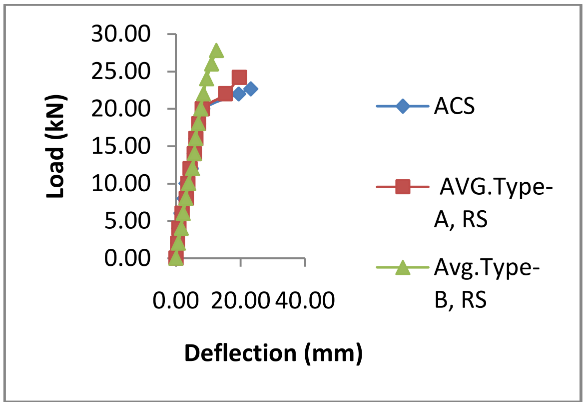

Fig. 7. Load vs Deflection Curves for Different Types of Retrofitting.

IV. CONCLUSIONS

Based upon the discussion and analysis of test results of the study undertaken, the following conclusions were drawn.

(i) The load carrying capacity of retrofitted beam-column joints for both types of retrofitting techniques increases significantly as compared to control beam-column joints.

(ii) Type-B retrofitted specimens i.e. diagonally wrapped beam-column joint specimens showed more improvement in their ultimate load carrying capacity and Stiffness as compared to Type-A retrofitted specimens as well as control beam specimens.

(iii) The Ferrocement jacketed beam-column joints with wire mesh at different orientations do not showed any debonding when loaded to failure.

(iv) The Ferrocement jacketed beam-column joints showed reduced spacing of cracks, less deflection at higher ultimate loads, as compared to control specimens, shows better distribution of stresses.

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