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SEISMIC STRENGTHENING OF EXTERIOR RC BEAM-COLUMN JOINTS BYADVANCED FERROCEMENT JACKETING

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ABSTRACT

In a RC framed structure, beam-column joints are highly vulnerable to failure when subjected to seismic loads. RC framed structures constructed in accordance to pre-seismic codes will have deficiencies at the beam-column region, resulting in poor performance of the same when subjected to large lateral loads. In this study, six scaled down models of the beam-column joint of a non-seismically designed structure was prepared. Retrofit in the form of ferrocement jackets were applied on the con-trol specimen. Two types of ferrocement jacketing schemes were used, first one is the conventional square jacketing and the second is the advanced jacketing scheme in which the beam and column corners were rounded prior to the application of jackets. All the specimens were subjected to quasi static reverse cyclic loading. The experimental re-sults showed that there is an improvement in ultimate load carrying capacity, ultimate deflection, energy dissipation capacity and ductility for jacketed specimens compared to that of control specimens. The advanced ferrocement jack-eting technique was found to have slightly better perfor-mance compared to the conventional square jacketing.

1. INTRODUCTION

The buildings designed in accordance to pre-seismic codes are capable of carrying vertical loads only and hence called gravity load designed (GLD) structures. These struc-tures exhibit a column hinging mechanism of failure when subjected to lateral loads and hence the failure is highly catastrophic. For a beam hinging mechanism to occur (so that the failure shall be localised in nature), the columns should be stronger than the beams in the framed structure. For providing such a property to the beam-column joints, a number of jacketing schemes have been adopted. The most common ones are RC jacketing, steel jacketing, fibre reinforced polymeric composite(FRPC) jacketing, ferroce-ment jacketing and shotcrete jacketing [1–3]. Among these RC jacketing is the most commonly used method, but the major disadvantage is that it increases the dead weight of the structure to a great extent, thereby altering the dynamic characteristics of the structure. FRPC jacketing is an attrac-tive option but the initial cost of the same is very high [4,5]. Considering the cost as well the performance factor, ferro-cement jacketing is an attractive option of jacketing.

In developing countries ferrocement jacketing can be an attractive option to repair and strengthen RC beam- column joints as its raw materials are cheap and readily available [6]. It has a number of improved engineering properties such as tensile and flexural strengths, tough-ness, fracture and crack control, fatigue resistance and im-pact resistance due to the unifom distribution of reinforce-ment. The major drawback of conventional square jacket-ing is that it provides confining pressure only at the cor-ners thereby resulting in stress concentration at corners. In square jacketing technique there is extreme stress con-centration at the corners unlike the jacketing of a circular column in which there is uniform distribution of confin-ing pressure [7]. Hence jacketing with rounded beam and column corners gives a certain degree of confinement by reducing stress concentration at corners. This type of jack-eting can be effective in improving strength of existing sub-standard beam-column joint and improving its load carry-ing capacity so that vertical extension of existing structure is made possible.

2. EXPERIMENTAL PROGRAMME

As the multistoreyed structure is assumed to be non-ductile in nature, a typical beam-column joint designed strictly in accordance to IS 456:2000 is considered for the experiment programme. The details of the scaled down model is shown in Fig. 1.

2.1 Material properties

Portland Pozzolana cement (PPC) was used for mak-ing both concrete as well as ferrocement mortars. Locally available crushed granite stone of maximum size 10mm with a specific gravity of 2.72 was used as coarse aggregate. M-sand with fineness modulus 2.74 and specific gravity 2.34 was used as fine aggregate. The concrete mix propor-tion arrived was 1:1.23:2.43 with 0.44 w/c ratio. The con-crete mix achieved a compressive strength of 39.73 N/mm^2 after 28 days. The mortar mix proportion was 1:2 with 0.35 w/c ratio. TMT steel rods of yield stress 363 N/mm^2 were used as reinforcement and the wire mesh used had square opening of size 5 x 5mm.

2.2 Casting of specimens

Control specimens The longitudinal as well as transverse reinforcement were prepared as per the dimen-sions and the reinforcement cage was placed in the steel mould after oiling the surface of the mould.

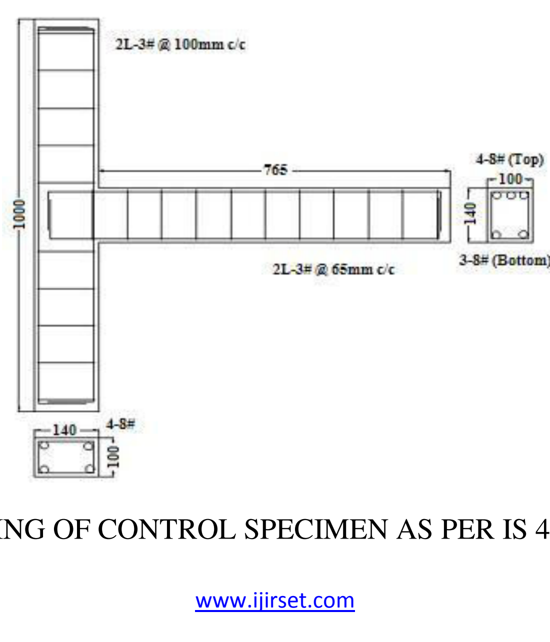

FIGURE 1. DETAILING OF CONTROL SPECIMEN AS PER IS 456:2000

A cover of 10 mm was provided. Concrete was poured into the mould and thoroughly vibrated so that complete compaction was achieved. A total of six specimens were cast, out of which four were retrofitted. Specimens were demoulded after 24 hours and then cured in water tanks for 28 days after which the jacketing was done.

Retrofitted specimens The ferrocement jackets were prepared using a single layer of wire mesh and cov-ered with cement mortar. Before applying the ferrocement jackets, the surfaces of all specimens were roughened us-ing sand paper and coated with a thin layer of cement grout to ensure proper bond between concrete surface and ap-plied mortar layer. A single layer of wire mesh was tightly wound around the specimens and tied using steel wires. For advanced ferrocement jacketing, the corners of the beams as well as columns were rounded to approximately 20 mm radius in the jacketed portion of the assemblage and then wrapped with a single layer of wire mesh. The mortar was applied on top of the wire mesh layer so that the final thick-ness of the jacket was approximately 15 mm. Square jack-eted specimens are denoted by FJ-1 and advanced jacketed by FJ-2. Proper curing was done for 28 days.

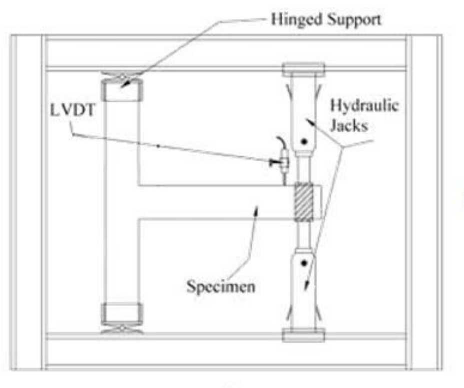

FIGURE 2. EXPERIMENTAL SETUP

2.3 Test setup

The control specimens as well as retrofitted specimens were subjected to quasi static reverse cyclic loading condi-tions. The specimens were tested in an upright position and loading was applied at the end of the beam. A schematic drawing of the setup is shown in Fig. 2. Cyclic load was applied at 50 mm from the free end of the beam with the help of two hydraulic jacks. The test was load controlled. The load increment chosen was 2 kN/cycle. To record loads precisely, load cells with least count 1 kN were used. The specimens were instrumented with Linear Variable Differ-ential Transformer (LVDT) having least count 0.1 mm to measure the deflection at the loading point.

3. RESULTS AND DISCUSSIONS

The test results of control specimens as well as jack-eted specimens are presented and compared in terms of load-displacement hysteretic curves, load displacement en-velope, energy dissipation capacity and cracking patterns. Table 1 summarises the results of the tested specimens.

3.1 Hysteresis curves

The force-displacement hysteresis loops for the speci- mens are shown in Fig. 3. Hysteretic loops show the per-formance of beam column joint under cyclic loading. The wider the loops, the larger will be the energy dissipation ca-pacity. From the hysteresis curves it can be clearly seen that the area enclosed by the hysteresis curve of control speci-mens are very small compared to that of the jacketed spec-imens. So both the jacketing schemes improved the seis-mic behavior of the non-ductile control specimen. Among the two jacketing schemes FJ-1 and FJ-2, wider hysteresis loop was shown by FJ-2 as the confinement in this case is improved by rounding the beam and column corners.

3.2 Ultimate load response

From the hysteresis curves it can be seen that the jack-eted specimens FJ-1 and FJ-2 have better load carrying ca-pacity compared to the non-ductile control specimen. This can be attributed to the provision of ferrocement jackets which strengthens the joint region thereby improving the load carrying capacity. It can also be seen that provision of the improved ferrocement jacketing scheme does not show any significant improvement in ultimate load carrying ca-pacity over conventional square jacketing scheme.

3.3 Ultimate deflection response

From the hysteresis curves it can be seen that the jack-eted specimens FJ-1 and FJ-2 have higher deflections at ul-timate load compared to the non-ductile control specimen. This can be attributed to the provision wire mesh in ferro-cement jackets which enables the joint region to undergo large deformations before failure. So the jacketed speci-mens have better ductility compared to control specimens. Provision of additional layers of wire mesh could have im-proved the ductility of the jacketed specimens further. It can be seen that the ultimate deflection of the FJ-2 speci-mens are 27.2% higher compared to that of FJ-1 specimens. This can be attributed to the rounding of the beam as well as column corners in FJ-2 which increased the confinement and reduced the stress concentration at corners thereby en-abling the specimens to undergo large deformations before failure when compared to the conventional square jacketed specimens. So the newly proposed advanced ferrocement jacketing is effective in improving the ductility compared to the conventional method.

3.4 Load-displacement envelope

The maximum loads and displacements obtained in each half cycle were used for plotting the load displacement envelopes for the tested specimens. The envelope shown in Fig. 4 enables the comparison of relative performance of the different specimens.

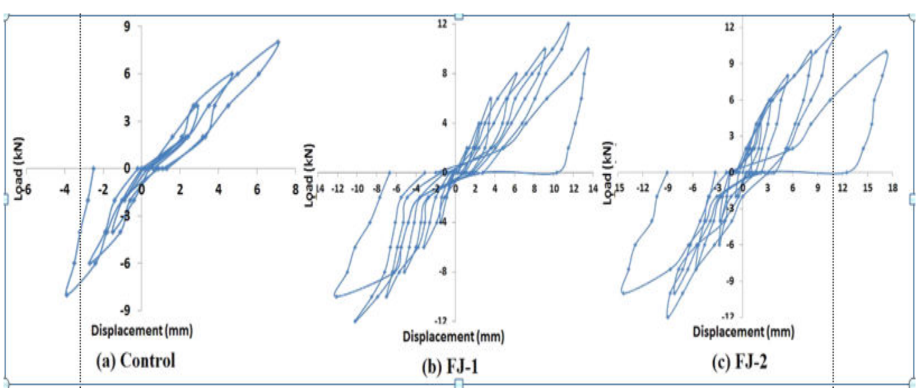

FIGURE 3. HYSTERESIS CURVES OF TESTED SPECIMENS

TABLE 1. TEST RESULTS OF CONTROL AND JACKETED SPECIMENS

Specimen	Ultimate load		Ultimate deflection		Energy dissipation capacity	
	(kN)	% Increase	(mm)	% Increase	(kNmm)	% Increase
Control	8	-	7.1	-	44.1	-
FJ-1	12	33.33	13.5	90.1	198.6	350.3
FJ-2	12	33.33	17.2	140.8	265.1	501.1

The large area enclosed by the wider load displacements envelopes of FJ-1 and FJ-2 specimens signifies that their energy dissipation capacity is much larger than that of the non-ductile control speci-mens. The load deflection envelope also signifies the supe-riority of the FJ-2 jacketing scheme over the FJ-1 jacketing scheme.

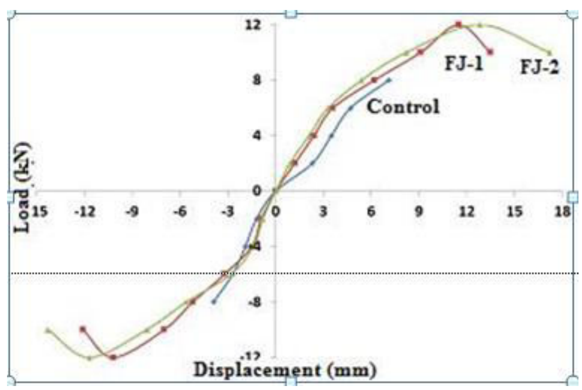

FIGURE 4. LOAD DISPLACEMENT ENVELOPE

3.5 Energy dissipation capacity

As a measure of the dissipated energy of the speci-mens, the area under the full load displacement envelope was computed and defined as the energy that could be dis-sipated by the specimens. It can be seen that the energy dissipation capacity of the jacketed specimens is 5-6 times that of the control specimens. A performance improvement of 33.5% was found for FJ-2 when compared to the energy dissipation capacity of FJ-1.

3.6 Cracking pattern and failure modes

The cracking patterns of the test specimens are shown in Fig. 5. For the control specimens a major diagonal crack was developed at the beam-column interface which is a clear significance of brittle nature of failure. In actual struc-tures this can result in brittle joint shear failures which are highly catastrophic in nature. In the case of FJ-1 speci-mens, diagonal cracks at joint region were absent. First hairline cracks occurred in these specimens during the third loading cycle. The cracks originating from the beam prop-agated to the column region without affecting the joint by a significant magnitude and hence a ductile mode of failure was observed in these specimens.

FIGURE 5. FAILURE PATTERN OF TESTED SPECIMENS

When it comes to FJ-2 specimens, the first hairline cracking occurred in the fourth cycle of loading. Diagonal cracks were completely absent in these specimens and also only a very few cracks were found on the column region. A perfect beam hinging mechanism was observed in these specimens and hence the failure is perfectly ductile in manner.

4. CONCLUSIONS

Based on the test results of this investigation the fol-lowing conclusions were drawn:

1. A 33.33% increase in ultimate load carrying capacity was observed for both FJ-1 and FJ-2 jacketing schemes compared to control specimens.
2. FJ-2 schemes showed a 27.2% increase in ultimate deflection compared to FJ-1 scheme signifying better ductile nature of the former.
3. The energy dissipation capacity of the FJ-2 scheme was also found to be better thatn that of FJ-1 scheme.

4. FJ-2 specimens exhibited perfect beam hinging mecha-nism of failure, which is higly desirable when it comes to seismic performance of a framed structure.

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REFERENCES

[1] Y. Geng, Z. J., Chajes, M. J., Chou, T. W., & Pan, D. C., 1998. “The retrofitting of reinforced concrete column-to-beam connections”. Composites science and technology, 58(8), pp. 1297-1305.
[2] Ha, G. J., & Cho, C. G., 2008. “Strengthening of reinforced high-strength concrete beam-column joints using advanced reinforcement details”. Magazine of concrete research, 60(7), pp. 487-497.
[3] Tsonos, A. G., 2010. “Performance enhancement of R/C building columns and beam-column joints through shotcrete jacketing”. Engineering Structures, 32(3), pp. 726-740. Mukherjee, A., & Joshi, M., 2005.
[4] “FRPC reinforced concrete beam- column joints under cyclic excitation”. Composite structures, 70(2), pp. 185-199.
[5] Tsonos, A. G., 2008. “Effectiveness of CFRP-jackets and RC-jackets in post-earthquake and pre-earthquake retrofitting of beam-column subassem-blages”. Engineering Structures, 30(3), pp. 777-793.
[6] Mourad, S. M., & Shannag, M. J. 2012. “Repair and strengthening of reinforced concrete square columns using ferrocement jackets”. Cement and Concrete Composites, 34(2), pp. 288-294. Kaish, A. B. M. A., Alam, M. R., Jamil, M., Zain, M.
[7] F. M., & Wahed, M. A., 2012. “Improved ferrocement jacketing for restrengthening of square RC short col-umn”. Construction and Building Materials, 36, pp. 228-237.