SEISMIC STRENGTHENING OF EXTERIOR RC BEAM-COLUMN JOINTS BY ADVANCED 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 control 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 results 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 jacketing technique was found to have slightly better performance 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 structures 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, ferrocement 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 attractive 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, toughness, fracture and crack control, fatigue resistance and impact resistance due to the uniform distribution of reinforcement. The major drawback of conventional square jacketing is that it provides confining pressure only at the corners thereby resulting in stress concentration at corners. In square jacketing technique there is extreme stress concentration at the corners unlike the jacketing of a circular column in which there is uniform distribution of confining 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 jacketing can be effective in improving strength of existing sub-standard beam-column joint and improving its load carrying 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 making 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 proportion arrived was 1:1.23:2.43 with 0.44 w/c ratio. The concrete mix achieved a compressive strength of 39.73 N/mm² after 28 days. The mortar mix proportion was 1:2 with 0.35 w/c ratio. TMT steel rods of yield stress 363 N/mm² 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 dimensions and the reinforcement cage was placed in the steel mould after oiling the surface of the mould.

   \[ \text{FIGURE 1. DETAILING OF CONTROL SPECIMEN AS PER IS 456:2000} \]
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 covered with cement mortar. Before applying the ferrocement jackets, the surfaces of all specimens were roughened using sand paper and coated with a thin layer of cement grout to ensure proper bond between concrete surface and applied 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 thickness of the jacket was approximately 15 mm. Square jacketed specimens are denoted by FJ-1 and advanced jacketed by FJ-2. Proper curing was done for 28 days.

![FIGURE 2. EXPERIMENTAL SETUP](image)

2.3 Test setup

The control specimens as well as retrofitted specimens were subjected to quasi static reverse cyclic loading conditions. 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 Differential 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 jacketed specimens are presented and compared in terms of load-displacement hysteretic curves, load displacement envelope, energy dissipation capacity and cracking patterns. Table 1 summarises the results of the tested specimens.

3.1 Hysteretic curves

The force-displacement hysteretic loops for the specimens are shown in Fig. 3. Hysteretic loops show
the performance of beam column joint under cyclic loading. The wider the loops, the larger will be the energy dissipation capacity. From the hysteresis curves it can be clearly seen that the area enclosed by the hysteresis curve of control specimens are very small compared to that of the jacketed specimens. So both the jacketing schemes improved the seismic 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 jacketed specimens FJ-1 and FJ-2 have better load carrying capacity 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 capacity over conventional square jacketing scheme.

3.3 Ultimate deflection response

From the hysteresis curves it can be seen that the jacketed specimens FJ-1 and FJ-2 have higher deflections at ultimate 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 specimens have better ductility compared to control specimens. Provision of additional layers of wire mesh could have improved the ductility of the jacketed specimens further. It can be seen that the ultimate deflection of the FJ-2 specimens 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 enabling 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.

![Load-displacement envelope](image-url)

FIGURE 3. HYSTERESIS CURVES OF TESTED SPECIMENS
TABLE 1. TEST RESULTS OF CONTROL AND JACKETED SPECIMENS

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Ultimate load (kN)</th>
<th>% Increase</th>
<th>Ultimate deflection (mm)</th>
<th>% Increase</th>
<th>Energy dissipation capacity (kNmm)</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>8</td>
<td>-</td>
<td>7.1</td>
<td>-</td>
<td>44.1</td>
<td>-</td>
</tr>
<tr>
<td>FJ-1</td>
<td>12</td>
<td>33.33</td>
<td>13.5</td>
<td>90.1</td>
<td>198.6</td>
<td>350.3</td>
</tr>
<tr>
<td>FJ-2</td>
<td>12</td>
<td>33.33</td>
<td>17.2</td>
<td>140.8</td>
<td>265.1</td>
<td>501.1</td>
</tr>
</tbody>
</table>

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 specimens. The load deflection envelope also signifies the superiority of the FJ-2 jacketing scheme over the FJ-1 jacketing scheme.

3.5 Energy dissipation capacity

As a measure of the dissipated energy of the specimens, the area under the full load displacement envelope was computed and defined as the energy that could be dissipated 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 structures this can result in brittle joint shear failures which are highly catastrophic in nature. In the case of FJ-1 specimens, 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 propagated to the column region without affecting the joint by a significant magnitude and hence a ductile
mode of failure was observed in these 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 following 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 than that of FJ-1 scheme.
4. FJ-2 specimens exhibited perfect beam hinging mechanism of failure, which is highly desirable when it comes to seismic performance of a framed structure.

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REFERENCES