Seismic Resistance of Exterior Beam Column Joint with Diagonal Collar Stirrups
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ABSTRACT
The performance of beam-column joints have long been recognized as a significant factor that affects the overall behaviour of reinforced concrete (RC) framed structures subjected to large lateral loads. The reversal of forces in beam-column joints during earthquakes may cause distress and often failure, when not designed and detailed properly. In the present study, four one third scaled exterior beam-column joint specimens were prepared with only one of them conforming to the guidelines of IS 13920: 1993 for seismic resistant design. Second one was detailed with additional diagonal collar stirrups at joints and beam reinforcements and the third one is cast without collar stirrups but having additional beam reinforcements. The fourth specimen was having same longitudinal reinforcements of the first specimen but with increased spacing of ties in the joint region. All the specimens were subjected to similar reverse cyclic loading to simulate earthquake loading in structures. The loading was applied by displacement control mode. Based on the experimental findings and subsequent analysis, it is found that, second specimen having additional beam reinforcements and diagonal collar stirrups at joints exhibits a better performance than the others.

Keywords: Beam-column joint, ductility, energy dissipation, reinforcement details, ultimate load

1. Introduction
The performance of beam-column joints have long been recognized as a significant factor that affects the overall behaviour of reinforced concrete (RC) framed structures subjected to large lateral loads. The beam-column joints that are not detailed and built in accordance with seismic codes present a serious hazard that can affect the overall ductility of a structure subjected to severe earthquake shocks.

The failure of reinforced concrete structures in recent earthquakes in several countries has caused concern about the performance of beam-column joints (Durrani and Wight 1985). Since past three decades extensive research has been carried out on studying the behaviour of joints under seismic conditions through experimental and analytical studies.

Various international codes have been going periodic revisions (Tsonos 2007). Among the Indian codes IS 13920:1993 deals with ductile detailing of reinforced concrete structures subjected to seismic forces. However, despite the significance of the joints in sustaining large deformations and forces during earthquakes, specific guidelines are not explicitly included in
Indian codes of practice (IS 456: 2000, IS 1893 : 2002, IS 13920: 1993, SP 34:1987). One of the basic assumption of the frame analysis is that the joints are strong enough to sustain the forces (moments, axial and shear forces) generated by the loading, and to transfer the forces from one structural element to another (beams to column, in most of the cases). Confinement of joint can be done to satisfy the above condition (Asha and Sundarrajan 2006, Bindhu et al. 2008, Bindhu et al. 2009a).

2. Present Study
The main objectives of the present study was to confine the R.C beam column joint by providing diagonal collar stirrups at joint region and to investigate the strength, ductility and energy dissipation capacity of beam-column joint specimens having various reinforcement arrangements and thereby to compare the behaviour of the specimens made of non-conventional confining reinforcement pattern with conventional reinforcement pattern as per IS 13920: 1993.

An eight storey building was modelled and analyzed using STAAD Pro. A typical exterior beam-column joint of the building was designed and detailed as per IS 13920:1993 and scaled to the laboratory conditions (Tsunos et al. 1992, Tsunos 2000, Murty et al. 2001, Murty et al. 2003, Jain and Murty 2005 a, Jain and Murty 2005 b, Ingle and Jain 2005, Bindhu et al. 2009b).

2.1 Details of Beam-Column Joint
The experimental program included four 1/3 scaled specimens (C1, C2, C3 & C4). The specimen C1 was conforming to IS 13920, C2 with additional beam reinforcements and diagonal collar stirrups over C1, C3 with additional beam reinforcements over C1 and C4 similar to C1 but with increased spacing of ties at joint. The size of the beam was 800 mm x 100 mm x 150 mm and column 1000 mm x 100 mm x 150 mm. The dimensions and reinforcement details of test assemblages are shown in Fig.1 and Fig.2.

3. Casting of Specimens
The cement used was Ordinary Portland Cement 43 grade conforming to IS 8112:1989. River sand passing through 4.75 mm IS sieve and having a fineness modulus of 3.16 was used as fine aggregate. Crushed granite stone of maximum size not exceeding 12.5 mm was used as coarse aggregate.

The mix was designed in proportion of 1:1.33:2.47 by weight respectively and the water-cement ratio was kept as 0.45. The 28 day average compressive strength from 150 mm cube test was 34.55 N/mm². The reinforcement cages used for different specimens are shown in Fig.3. The specimens were cast in horizontal position inside wooden moulds and were demoulded after 24 hours and then cured in water tank.
Figure 1: Reinforcement details for Specimens C1 and C2
Figure 2: Reinforcement Details for Specimens C3 and C4
Figure 3: Reinforcement Cages Prepared for Different Specimens
3.1 Experimental Setup

The test set up in the laboratory is shown in Fig. 4. The specimens were tested in an up right position and static reverse cyclic loading was applied. Both ends of the column were hinged properly within the self straining test frame. A deflection control test was conducted in which the specimen was subjected to an increasing deflection with increments not exceeding 2.5 mm up to the failure. The specimens were instrumented with hydraulic jacks, LVDTs, dial gauges and strain gauges to monitor the behavior during testing. Lateral loading, at deflection increments of 2.5 mm was applied in a cyclic manner by means of hydraulic jacks having a capacity of 100 kN and 200 kN for downward and upward loading respectively. It was applied at a distance of 100 mm from the free end of the beam until failure of the specimens. One dial gauge was placed at the loading point of beam to control deflection at the point of application of load. Electrical resistance strain gauges were pasted on the reinforcement in order to measure strains. The specimens were evaluated in terms of ultimate load carrying capacity, load displacement relationship, and energy dissipation characteristics.

Figure 4: Test Setup in the Laboratory

3.2 Crack Pattern and Failure Mode

The crack patterns in different specimens are shown in Fig. 5. For specimen C1 and C2, the initial diagonal and column beam interface hairline cracks occurred in the third cycle of loading in positive direction and fifth cycle of loading in negative direction. For specimen C2, further cracks were developed at the column beam interface only after sixth cycle in both positive and negative direction. However, in specimen C3, the cracks in the joint at diagonal direction started after third cycle of loading in positive direction and fifth cycle of loading in negative direction. The specimen C2 failed due to the advancement of crack width at the interface between column and beam. Among the specimens, C2 specimen which was additionally detailed with collar stirrups and beam reinforcements exhibited the best performance. For this specimen, no major cracks were noticed at the joint and the joint
remained intact throughout the test. Hence the failure was dominated by tensile failure than the joint failure. The improvement of performance by developing further cracks away from the joint face to the beam region can be noticed for the specimen with collar stirrups. The crack width is also less for this specimen compared to other specimens. The specimen C3 and C4 without collar stirrups have diagonal cracks at the beam-column joint region. This may be due to the higher flexural capacity of beam compared to the column.

![Figure 5: Crack Patterns of Different Specimens](image)

### 3.3 Ultimate Load Carrying Capacity of Specimens

The ultimate load carrying capacities of all the specimens were observed and Fig.6 shows the comparison of the same. For the specimen C1 detailed as per IS 13920: 1993, the ultimate load is 38 kN. But for the specimen C2 detailed as per IS 13920: 1993 with collar stirrups and additional beam reinforcements, the ultimate load is 72 kN. Incase of the specimen C3
detailed without collar stirrups at joint but with additional beam reinforcements, the ultimate load reached is 65 kN.

![Graph showing comparison of ultimate load carrying capacity of different specimens.](image)

**Figure 6:** Comparison of Ultimate Load Carrying Capacity of Different Specimens

Similarly for the specimen C4 which is similar to C1 but with increased spacing of ties in joints, ultimate load reached is 35 kN. These results show the effectiveness of the diagonal collar stirrups with additional beam reinforcement in the enhancement of ultimate load carrying capacity.

### 3.4 Hysteretic Loops

The hysteretic loops of the load displacement relationship for the four specimens tested in the laboratory are shown in Fig. 7 through Fig.10. It is observed that the specimen C2 with
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Figure 7: Load-Displacement Hysteresis Loop for Specimen C1

Figure 8: Load-Displacement Hysteresis Loop for Specimen C2
additional beam reinforcement and diagonal collar stirrups developed better hysteretic loops with higher curve area compared with other specimens. The performance of the specimen C2 over the specimen C3 shows the enhanced strength and behaviour of joints with diagonal collar stirrups.

3.5 Ductility

The displacement ductility factor is the ratio of the maximum deformation that an element can undergo without significant loss of initial yield resistance to the initial yield deformation (Park and Paulay 1975). Fig. 11 through Fig.14 shows the lateral load displacement envelope.
curves of all the specimens. Table 1 gives the experimental results of ductility factor. It can be seen that the specimen C2 detailed with diagonal collar stirrups at joint and additional beam reinforcements had more ductility than that detailed without collar stirrups.

![Load Displacement Envelope for C1](image)

**Figure 11**: Load Displacement Envelope for C1

![Load-Displacement Envelope for C2](image)

**Figure 12**: Load-Displacement Envelope for C2
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Figure 13: Load-Displacement Envelope for C3
Figure 14: Load-Displacement Envelope for C4

Table 1: Displacement Ductility of Test Specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Displacement in mm</th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield + direction</td>
<td>- direction</td>
<td>Ultimate + direction</td>
<td>- direction</td>
<td></td>
</tr>
<tr>
<td><strong>C1</strong></td>
<td>7.50</td>
<td>5.00</td>
<td>17.50</td>
<td>17.50</td>
<td>2.33</td>
</tr>
<tr>
<td><strong>C2</strong></td>
<td>5.00</td>
<td>5.00</td>
<td>22.5</td>
<td>22.5</td>
<td>4.50</td>
</tr>
<tr>
<td><strong>C3</strong></td>
<td>7.50</td>
<td>7.50</td>
<td>22.5</td>
<td>17.50</td>
<td>3.00</td>
</tr>
<tr>
<td><strong>C4</strong></td>
<td>5.00</td>
<td>5.00</td>
<td>15.00</td>
<td>17.50</td>
<td>3.00</td>
</tr>
</tbody>
</table>

4. Energy Dissipation Capacity

Structures with high energy dissipation characteristics are able to withstand stronger shaking and better seismic response. The amount of energy dissipated during a particular loading cycle is calculated as the area enclosed by the corresponding load versus displacement hysteretic loop (Paulay et al. 1978). The cumulative energy dissipated is given in Table 2.

Table 2: Cumulative Energy Dissipation for Various Specimens

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Specimen designation</th>
<th>Energy dissipation (kN-mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>C1</strong></td>
<td>922.16</td>
</tr>
<tr>
<td>2</td>
<td><strong>C2</strong></td>
<td>1187.73</td>
</tr>
<tr>
<td>3</td>
<td><strong>C3</strong></td>
<td>974.43</td>
</tr>
<tr>
<td>4</td>
<td><strong>C4</strong></td>
<td>864.25</td>
</tr>
</tbody>
</table>

Fig. 15 shows the energy dissipation capacity versus number of cycles. It can be seen that, in the first four cycles, the specimens do not have greater energy dissipation. However, in the final cycles, the specimens have greater dissipated energy. The reason is that higher lateral load produces greater area (dissipated energy) bounded by the load displacement curve. It is clearly observed that the specimen detailed with diagonal collar stirrups and additional beam reinforcements had more energy dissipation capacity than the others.
5. Conclusions

Seismic performance of reinforced concrete moment resisting framed structures mainly depends upon the inelastic behaviour of joints. Based on the experimental investigation conducted on exterior beam-column joint under static reverse cyclic loading, the following conclusions are drawn.

- The load carrying capacity of the specimen additionally reinforced with beam and diagonal collar stirrups (C2) is nearly 98% higher than the specimen detailed as per IS 13920(C1) and 10% more than the specimen with additional beam reinforcements (C3). Also the specimen detailed with increased spacing of ties at joints gave unfavorable results; i.e., a reduction of 10% with regard to load carrying capacity (C4).

- Ductility of the specimen additionally detailed with diagonal collar stirrups and beam reinforcements is compared and found that it is 54% higher than that of the specimen detailed as per IS 13920: 1993 without collar stirrups, and 5% higher than specimen detailed as per IS 13920, but having additional beam reinforcement.

- Energy dissipation capacity of the specimen detailed additionally with diagonal collar stirrups and beam reinforcements is observed to be 22.36% higher than that of the specimen detailed as per IS: 13920: 1993.

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6. References


