Enhancement of Beam-Column Joint by RC Jacketing

Rajesh Prasad Dhakal (cdhakal@ntu.edu.sg)
Tso-Chien Pan (cpan@ntu.edu.sg)
Keh-Chyuan Tsai (kctsai@ce.ntu.edu.tw)

Introduction

In low to moderate seismicity regions, reinforced concrete buildings are designed to resist dead and live loads only. This results in joint cores with reinforcement detail that cannot fulfil seismic design criteria, thus making such building frames vulnerable to joint shear failure when subjected to lateral loading or ground excitation. Even in seismic regions, old buildings designed according to the then existing immature seismic design codes lack sufficient hoops inside the joint cores. The joint cores are the most critical components in such frames, and the ultimate failure of such frames under lateral loading would be due to the inadequate shear capacity of the joint core. Hence, such lightly reinforced joints need to be strengthened before exposing them to any form of lateral loading. Reinforced concrete (RC) jacketing is an effective method of retrofitting such connections. In this paper, the usefulness of RC jacketing technique to strengthen lightly reinforced beam-column joints is investigated experimentally.

Test details

As shown in Figure 1, a full-scale reinforced concrete sub-assembly with a 3.7 m high column and a 5.4 m long beam is subjected to quasi-static reversed cyclic loading. Due to the set-up details, the effective height of the column and the effective length of the beam given by the distances between the centrelines of the supports at the two extremes are 3.2 m and 6.0 m, respectively. An axial compression equal to 10-15% of the section capacity is applied at the column-top, and equal and opposite displacement cycles are applied at the two beam-tips. The amplitude of the cyclic displacement is increased gradually to induce up to 3% radian storey-drift. Thereafter, the first phase loading is terminated, and the specimen is retrofitted. The retrofitted specimen is again subjected to gradually increasing cyclic displacements in a similar fashion until 5% radian storey-drift is induced The geometrical dimensions and rebar details of the beam and column before and after retrofitting are shown in Figure 2. The 300×550 mm beam is reinforced with seven 32 mm diameter bars, five of them at the top and two at the bottom. Similarly, the 350×500 mm column in the original specimen is reinforced with eight 25 mm diameter bars. The stirrups in the beam comprise of four legs of 10 mm diameter bars spaced at 200 mm, and the ties in the column have two legs of 10 mm diameter bars with 150 mm spacing. The beam size is not changed after retrofitting, whereas the retrofitted column is 670×820 mm in cross-section. The RC jacket cast outside the central 2.7 m of the original column includes four 25 mm diameter longitudinal bars arranged symmetrically with 12 mm diameter ties spaced at 100 mm.

The details of the original specimen were taken from a typical RC building frame in a low seismicity region, and these details make the specimen of the undesirable strong-beam weak-column type. As the column ties of the original specimen are continued through the joint, the joint core has only three ties, which is not enough to satisfy seismic design requirements. Note that no additional stirrups are inserted in the joint core during retrofitting (see Figure 3b). Before casting the 160 mm thick RC jacket, the crushed concrete is cleaned and epoxy is injected into the small cracks in the joint panel. The compressive strength of the original concrete is 33.6 MPa whereas the concrete used in the RC jacket has a high compressive strength equal to 74.8 MPa. The yield strengths of the 32 mm, 25 mm, 12 mm and 10 mm diameter bars are 527 MPa, 527 MPa, 420 MPa and 356 MPa, respectively. LVDT transducers and load cells are used to measure the displacements and forces at the beam-tips and also at the column-top. In addition, a pair of diagonally arranged pi-gauges is used to monitor the shear deformation of the joint panel.

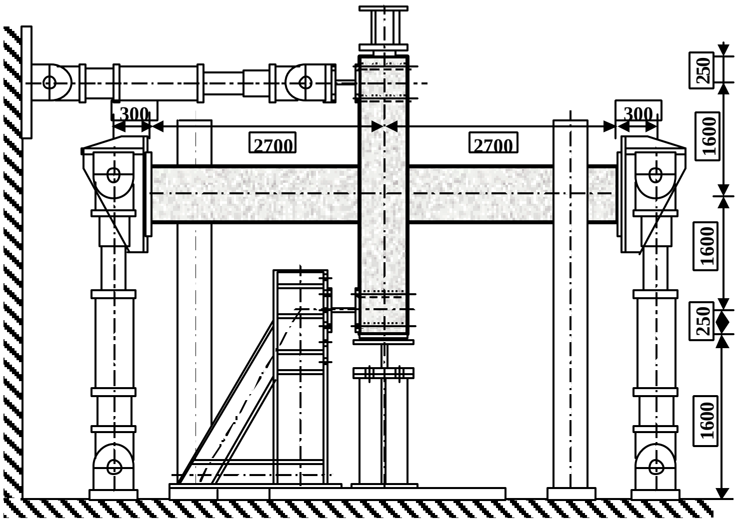

Figure 1. Test set-up

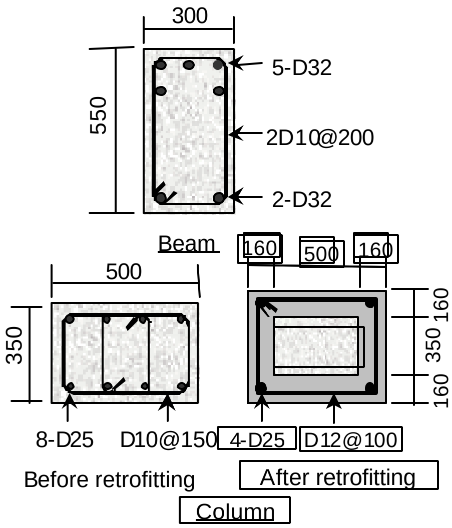

Figure 2. Specimen details

Results and discussions

A pair of orthogonal diagonal cracks in the joint panel of the original specimen was visible when the storey-drift reached 0.5% radian. During the higher displacement cycles, these diagonal cracks widened and some more hairline cracks emerged in the joint panel. Spalling of concrete from the joint panel started during the 1.5% radian storey-drift cycle. The loading of the original specimen was terminated after the joint panel was damaged severely (see Figure 3a) after the 3% radian storey-drift cycles had been applied. Note that the damage is mostly concentrated in the joint panel and very few cracks could be seen in the beam or the column. In the retrofitted specimen, cracks first emerged in the beam during the 0.5% radian storey-drift cycles. The column began to crack when the storey-drift reached 0.75% radian, and diagonal cracks emerged in the joint panel when the 1.0% radian storey-drift cycles were applied At 1.75% radian storey-drift, concrete at the beam-column interface started crashing and an opening appeared at the corner of the interface, which widened during further loading cycles. On further loading, more cracks appeared throughout the specimen. The test was finally terminated after applying the 5% radian storey-drift cycles, when visibly significant damage occurred on the specimen (see Figure 3c). Significant damage could be observed in the beam and the column, and the diagonal cracks in the joint panel were not as wide as those in the original specimen.

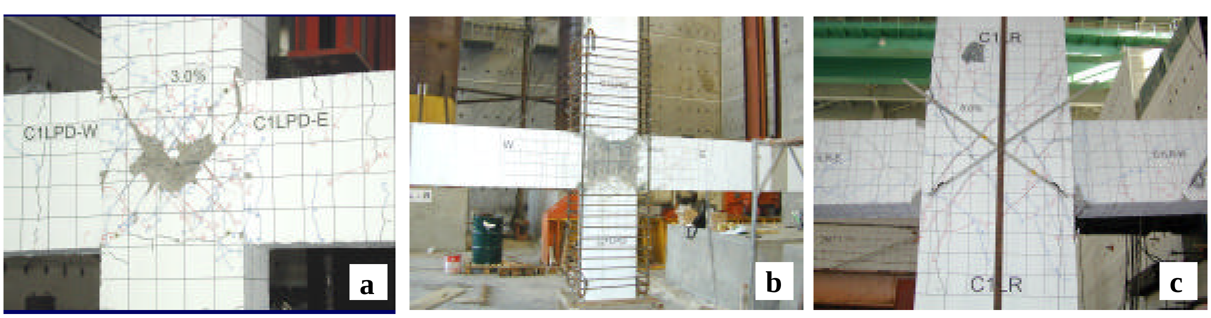

Figure 3. Specimen at the end of first loading, during retrofitting and at the end of final loading

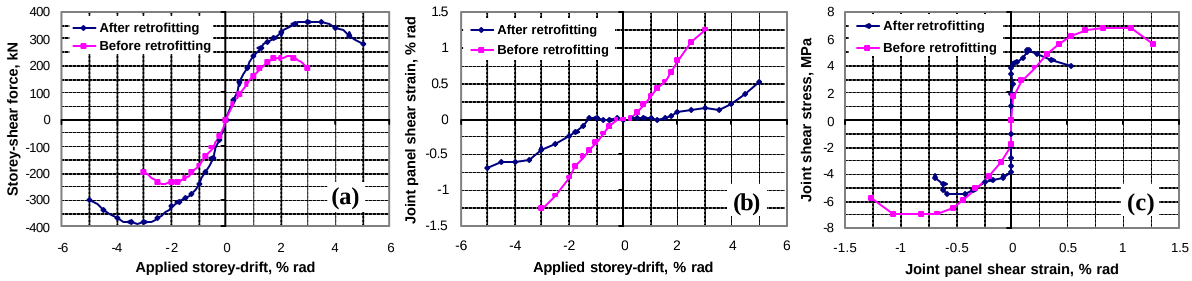

Figure 4. Behaviour of the original and the retrofitted specimen

Figure 4a shows the envelopes of the storey-shear force versus storey-drift loops recorded during the two loading phases. Here, the storey-shear force is the reading from the load cell at the column-top, and the storey-drift is the rotation of the line joining the beam-tips from the original beam axis; i.e. summation of the displacements of the two loading points divided by the effective beam length. A gradual reduction of the shear stiffness in the pre-peak region followed by a gradual degradation of the storey-shear force in the post-peak region can be noticed in both curves. As the weakest component of the original specimen was the joint and it was strengthened by RC jacketing, the shear capacity of the sub-assembly understandably increased after retrofitting. Surprisingly, the deformability of the specimen also increased after retrofitting. The RC jacket makes the joint and the column more rigid, and the deformations of these components should reduce after retrofitting. For further scrutiny, joint shear deformation is plotted against the applied storey-drift in Figure 4b. As expected, the joint shear deformation is significantly less in the retrofitted specimen than that in the original specimen. It indicates that unlike the original specimen that was about to undergo joint shear failure, the joint may not be responsible for the peak load and eventual failure of the retrofitted specimen. For confirmation, joint shear stress computed assuming perfect bond is plotted against the joint shear strain in Figure 4c. In spite of the high strength concrete used for RC jacketing which certainly enhances the joint shear strength, the maximum joint shear stress induced in the retrofitted specimen (5.5 MPa) is substantially less than that induced in the original specimen (7 MPa). This corroborates that the maximum storey-shear force corresponds to the capacity of the beam, because the column capacity was also improved by RC jacketing. Consequently, the increased deformability of the retrofitted specimen must have come mainly from the plastic flexural deformation of the beam. In spite of the undesirable strong-beam weak-column status of the original specimen, the retrofitted specimen behaved as the favourable strong-column weak-beam type.

Conclusion

A full-scale lightly reinforced concrete beam-column sub-assembly was strengthened by casting an RC jacket outside the column and the joint, and the improvement brought over by the retrofitting technique in the cyclic response of the specimen was verified experimentally. The joint of the original specimen was not adequately reinforced to fulfil seismic design requirements, and it was the weakest component of the sub-assembly. When subjected to cyclic lateral loading, the joint panel hence experienced severe damage due to excessive shear deformation while the beam and column remained virtually undamaged. The original specimen was vulnerable to joint shear failure. On the other hand, the retrofitted specimen failed after the formation of a plastic hinge in the beam, and the joint was no longer the weakest component of the sub-assembly. Apart from the increase in the capacity and deformability, the shear deformation of the joint panel reduced significantly after retrofitting. It is concluded that the RC jacketing method is effective in strengthening non-seismic RC frames with inadequately reinforced joints.