PERFORMANCE OF CORNER RC BEAM-COLUMN JOINTS UP-GRADED WITH CFRP COMPOSITES UNDER SEISMIC LOADING

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Corner beam-column joints, FRP, Rehabilitation, Strengthening, Seismic, Shear strength.

1 INTRODUCTION

A concrete frame structure's bearing capacity and ability to exhibit ductile behavior are highly dependent on the reinforcement detailing of the joint connections between its independent members, such as beams and columns. Accordingly, to obtain a sound structural behavior, the joints must be constructed to be at least as strong as the structural members connected to them and show ductile behavior in the ultimate limit state. In a moment resisting reinforced concrete framed buildings, these joints are of three types: interior, exterior and corner. Interior and exterior joints are found at bottom and intermediate levels, and corner joints at the roof level. A substantial work is reported on interior and exterior joints (for example, [1-8]) but work on corner joints are very limited.

The corner joints, if designed only for gravity loads and are based on pre-seismic codes, may suffer substantial damage during earthquakes particularly under opening cycles, i.e. those causing flexural tension on the inside of the joint. Several techniques of repair and strengthening of reinforced concrete joints, damaged by earthquakes, have been reported in earthquake prone countries such as Japan, Mexico, and Peru. Of the various repair techniques used, the most common involved were RC or steel jackets. Plain or corrugated steel plates have also been tried. These techniques cause various difficulties in practical implementation at the joint, namely intensive labor, artful detailing, increased dimensions, corrosion protection and special attachments. To overcome the difficulties associated with these techniques recent research efforts have focused on the use of epoxy-bonded Fiber Reinforced Polymer (FRP) sheets or strips with fibers oriented properly so as to carry tension forces due to shear.

In the present paper a practical technique for the seismic rehabilitation of poorly detailed beam-column corner joints using FRP composite sheets has been proposed. A full scale corner beam-column sub-assemblage was constructed with inadequate joint shear strength and no transverse reinforcement in the joint; representing pre-seismic code design construction practices of joints and encompassing the vast majority of existing joints. The corner joint specimen was tested under reversed cyclic lateral load histories so as to provide the equivalent of severe earthquake damage. The damaged specimen was repaired using suggested scheme and then subjected to the similar cyclic lateral load history. Response histories of the specimen before and after repair were then compared through hysteretic loops, load-displacement envelopes and ductility. The test results indicated that the suggested repair scheme is very effective in upgrading the shear capacity and ductility of the joint. The results also show that, with the proposed FRP scheme of repair, the repaired specimen achieves a substantially higher load carrying capacity and slower stiffness degradation.

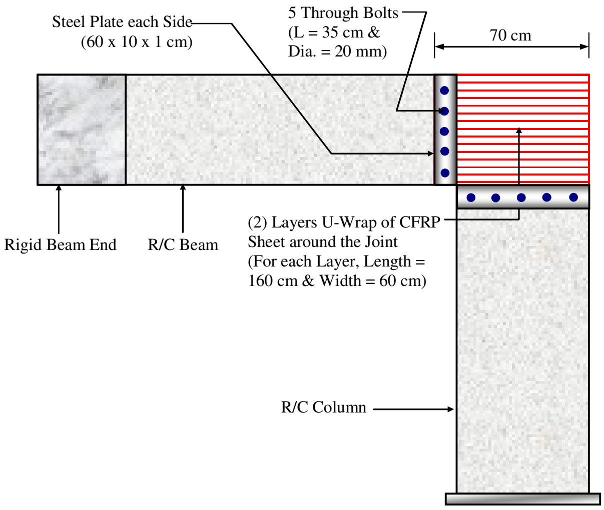
2 EXPERIMENTAL PROGRAM

2.1 Test Specimens

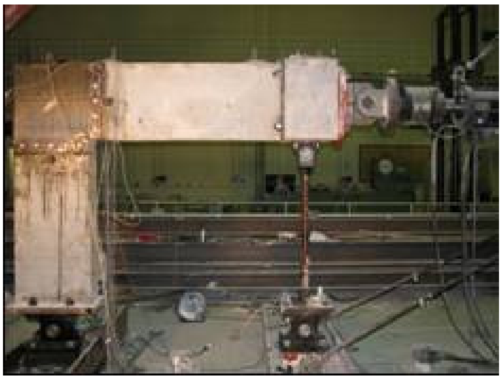
In finding out the size of corner joint specimen, first a prototype member size was chosen and then a crude analysis was carried out to come up with the most reasonable scale for the test specimen that comply with the available testing facility and equipment. A full-scale beam-column joint was found to be the most convenient. The specimen was constructed with no transverse reinforcement, representing pre-seismic code design construction practice of joints and encompassing the vast majority of existing beam-column connections.

Having decided the size of the test specimen, a reinforced concrete joint specimen was cast. The specimen was then subjected to cyclic lateral load histories so as to provide the equivalent of severe earthquake damage. The damaged specimen was then repaired through injecting epoxy into the cracks and externally bonding the specimens with CFRP sheets. The sheets were epoxy-bonded to joint region only and also effectively prevented against any possible debonding through mechanical anchorages as shown in Fig. 1(a). The sheets used for repair were unidirectional CFRP sheets with fracture strain = 1.2% and elastic modulus = 61.5 × 103 MPa.

The specimens were tested using the testing apparatus designed and installed in the Structural Test Hall, Department of Civil Engineering, King Saud University, Saudi Arabia. To apply the simulated seismic type cyclic load on the specimen, a 500-kN servo-controlled hydraulic actuator was connected to a reaction steel frame as shown in Fig. 1(b).



(a)



(b)

Fig. 1 (a) Schematic representation of FRP scheme and (b) test setup for testing of specimens.

To test the specimens horizontal-loading regime was used. The said loading was based on the conventional guidelines of quasi-static type testing as followed by most researchers in simulating seismic forces to test reinforced concrete structures. The loading cycles were controlled by the peak displacement until failure. For each displacement level, three fully reversed cycles were completed. It is important to note that the frequency of applied load (or induced displacement) was maintained constant throughout the test program; it was picked up to be around one cycle per minute, which corresponds to a frequency of 0.0167 hertz. All cycles were started with the pull direction first then went into the push direction.

3 DISCUSSION OF TEST RESULTS

3.1 Hysteretic Behavior

The hysteretic behavior of corner joint, before and after the repair, is shown as hysteretic curves in Figs. 2 and 3. Fig. 2 shows that the ultimate load for repaired specimen is substantially higher than its corresponding original (before repair) specimen (Figs. 2 and 3). This is primarily due to the increased confinement of joint resulting from externally bonded CFRP sheets. A further comparison of deformation capacity of repaired specimens with the original (i.e. before repair) specimen illustrates that the use of CFRP increases the deformation capacity of repaired specimens considerably. It is to be also noted that hysteretic curves are considerably different in push and pull directions (positive hysteretic plots show push values whereas negative region curves indicate pull values). This is due to asymmetric geometry of corner joint and substantially different stiffness in push and pulls directions. Push direction is stiffer than pull direction and therefore in order to have same displacement in two directions (as loading is displacement controlled) actuator has to apply significantly higher force in the push direction than pull direction.

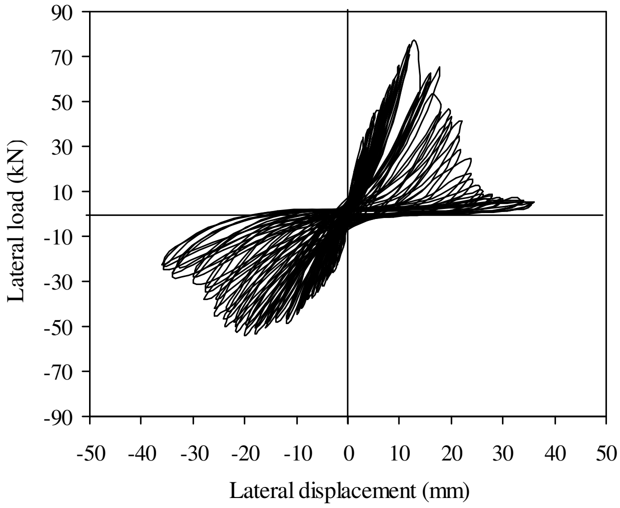


Fig. 2 Hysteretic plots for before repair specimen.

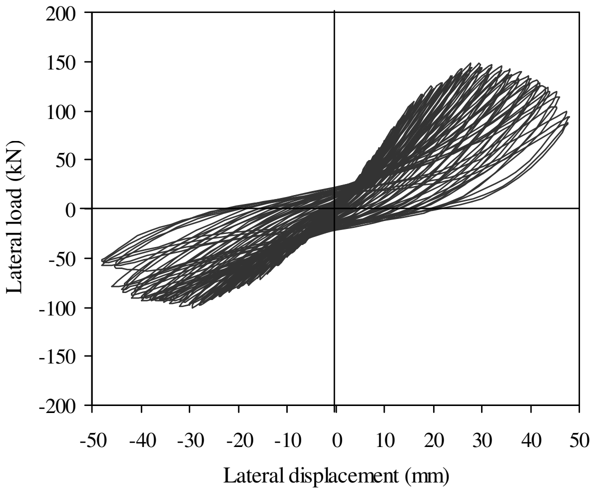


Fig. 3 Hysteretic plots for repaired specimen.

3.2 Load Displacement Envelopes

In order to study load carrying capacity and ductility of original (before repair) and repaired corner joint specimens, envelopes of load-displacement hysteretic curves for these two specimens are plotted and shown in Figure 4. Using these envelopes the peak load, ultimate displacements, and ductility for the specimens are obtained and listed in Table 1. The second column of Table 1 shows the average peak load (i.e. average of peak push and pull values) and third column shows the displacement corresponding to first yield of steel bars. This displacement is required to calculate ductility of the specimens. The estimated ductility, an important parameter for earthquake resistant construction, is shown in the last column of Table 1. The ductility is computed as the ratio of ultimate displacement to the displacement at first yield of internal steel. For computation, the ultimate displacement was set at a displacement corresponding to 20% drops of peak load. The values of average peak load and ductility clearly show that the application of CFRP sheets has improved the load carrying capacity and ductility of repaired specimen by 88% and 97% respectively. Such a high improvement in the load carrying capcity and ductility show excellent potential of CFRP sheets in structural rehabilitation.

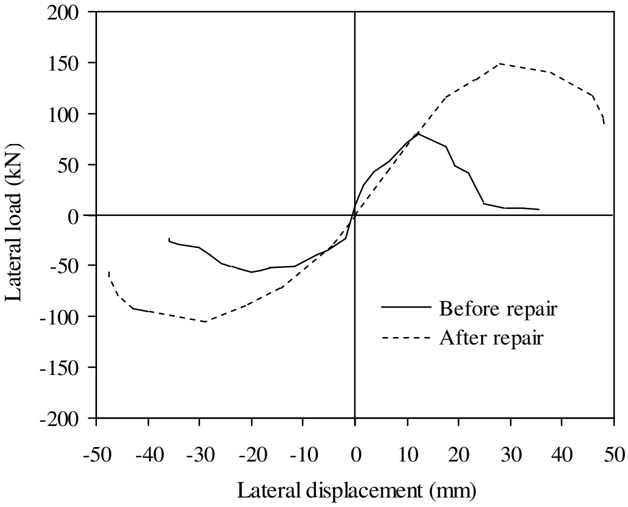


Fig. 4 Envelope of hysteretic loops.

Table 1 Peak test load and ductility.

Specimen	Average Peak load kN	Disp. At first yield of steel, Δ_y (mm)	Disp. at 20% drop of peak load, Δ_{20} (mm)	Ductility Factor Δ_{20}/Δ_y
Before repair	65.90	5.01	22.95	4.58
After repair	124.19	5.01*	45.19	9.02

*Taken same as "before repair" value.

4 CONCLUSIONS

In the present study effectiveness of CFRP sheets in improving the load carrying capacity and ductility of shear deficient corner joint was studied. It was observed that proposed method of repair can improve the load carrying capacity and ductility of joint by 88% and 97% respectively and can also decrease the rate of stiffness degradation significantly. The results thus show that the use of CFRP sheets in upgrading shear deficient joints is very promising.

ACKNOWLEDGEMENTS

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