# Repair Systems for RC Beam-to-Column Joints with Carbon Fiber Reinforced Polymer under Cyclic Loadings

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## Introduction

The massive damages caused by the Loma Prieta Earthquake (63 deaths, approximately 6 to 13 billion dollars in damages) and the Northridge Earthquake (72 deaths, over $20 billion in damages) showed that there needed to be better structural design and retrofitting requirement. In the context of concrete beam-to-column joints, methods such as external steel plating, pressure epoxy injection and carbon fiber polymer reinforcing have been developed to address issues of reinforcing existing structures for a future earthquake event. Steel plating is to externally attach steel members to concrete beam-to-column joints. Even though external steel plating is a viable solution, it is difficult to manipulate on job site. Pressure epoxy injection also brought upon many concerns and drawbacks in its construction as mentioned in the 1985 FEMA-97 report, "NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings". Lastly, carbon fiber reinforced beam-to-column joints is considered as more effective in restoring the structural performance of repaired joints and will be the focus of this research.

## Materials & Test Specimens

The ultimate tensile strength of carbon fiber reinforced polymers (CFRP) is 550 ksi, which is ten times stronger than mild steel. CFRP is a very strong and light composite material. CFRP can also provide other benefits to reinforced concrete, such as allowing CFRP to perform similarly to steel ties as confining and shear resisting element. For the testing of the beam-to-column joints, two specimens were used which were half-scaled from the actual size (Fig.1). LVDTs were installed to measure the deflection of the specimens. The strain gauges were also attached to measure the strain of the rebar. There were 10 strain gauges installed per specimen. Four more strain gauges were installed in the repaired specimens, placed on top of the carbon fiber.

## Experimental Program

Two beam-column control joints were tested with the same type of loading sequence, denoted BCJ-1 (**B**eam-to-**C**olumn **J**oint No. **1**) and BCJ-2 (Photos 1 & 3). Both specimens were tested till they showed signs of failure such as; cracking and spalling of concrete, flexural and shear cracks in the beam element. The damaged specimens were subsequently repaired with CFRP and retested for structural integrity, BCJ-1R (**B**eam-to-**C**olumn **J**oint No. **1** with CFRP **R**epair) and BCJ-2R (Photos 2 & 4).

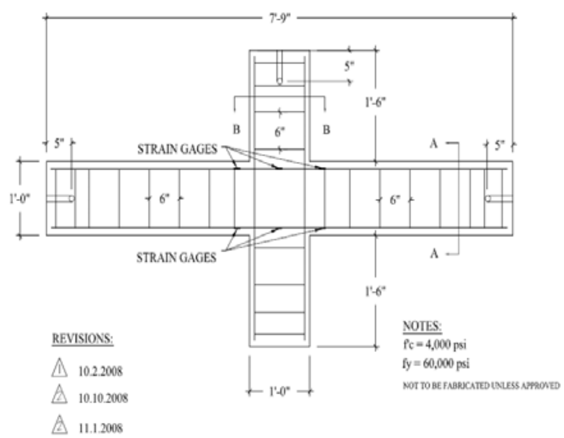



Fig. 1: Specimen configuration, rebar & gage locations


Photo 1 & 2: Beam-Column Joint 1 (BCJ-1 & BCJ-1R)


Photo 3 & 4: Beam-Column Joint 2 (BCJ-2 & BCJ-2R)

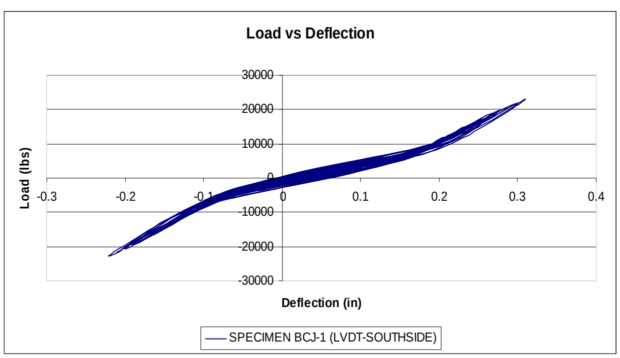
## Test Results

*Results from Specimen BCJ-1 & BCJ-1R*

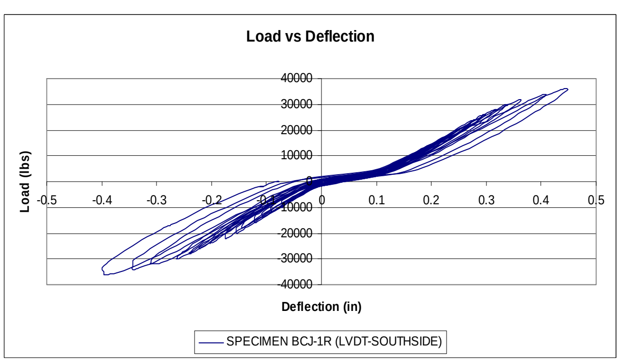
Specimen BCJ-1 was tested in a load controlled regime. At 18 kips it was found necessary to stop the loading to evaluate the extent of cracks and stresses. It was observed that steel reinforcement was still in the elastic region. Testing was resumed and column loading increase to 23 kips. Repaired specimen BCJ-1R was tested until actuator had reached 36 kips. Visual observation was carefully monitored during the loading process. Due to the CFRP confinement no cracks was able to be observed during the testing. However at near maximum load of the testing cycle, shear cracks appeared on the specimen and therefore the testing was quickly stopped. Results of testing are plotted on load vs. deflection as shown in Graphs 1 & 2.

*Results from Specimen BCJ-2 & BCJ-2R*

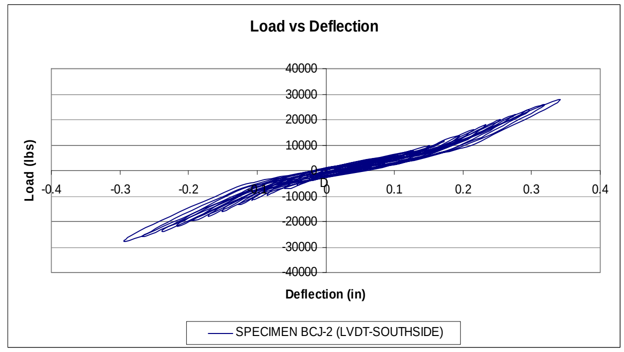
Specimen BCJ-2 was tested with the idea to stress horizontal rebars to the inelastic range. The test specimen was proceeded with the objective to load it to a maximum of 30 kips of cyclic loading. At the load of 28 kips shear cracks were observed at location throughout the beam portion of the specimen. The testing was stopped to preserve the specimen for the following repair scenario. Repaired specimen BCJ-2R was targeted to reach the loading of 40 kips. During the loading process new flexural cracks was observed at the top of specimen at the load of 18 kips. Shear cracks were observed at the loading of 28 kips. Results of testing are plotted on load vs. deflection as shown in Graphs 3 & 4.



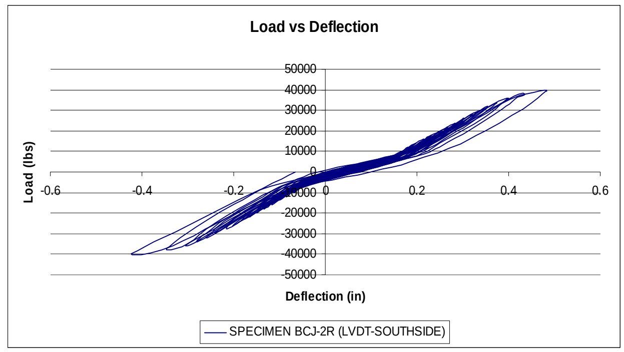

Graph 1: Concrete Beam-Column Joint 1 (BCJ-1)




Graph 2: Repaired Beam-Column Joint 1 (BCJ-1R)




Graph 3: Concrete Beam-Column Joint 2 (BCJ-2)




Graph 4: Repaired Beam-Column Joint 2 (BCJ-2R)

## Conclusions

1. The repairing of the joint was simple, quick and easy, thus the combination of speed and workability makes CFRP effective process on construction job sites.
2. Specimens BCJ-1 & 2 initially carried maximum load of 23 kips & 28 kips with corresponding displacement of 0.332 inch & 0.341 inch. After the repair, the specimens were able to sustain maximum load of 36 kips & 39 kips with corresponding displacement of 0.457 inch & 0.483 inch. This indicates that CFRP is able to restore the load carrying capacity of the joint, actually 39% increase.
3. In specimen BCJ-1, displacement at 23k was 0.332 inch at the same load displacement of the repair specimen (BCJ-1R) was 0.253 inch. Displacement of repair specimen was 76% of specimen BCJ-1. In specimen BCJ-2, displacement of repair specimen was 87% of specimen BCJ-2.

## References

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