# PERFORMANCE OF EXTERIOR RC BEAM-COLUMN JOINTS UPGRADED WITH CFRP COMPOSITES UNDER SEISMIC LOADING

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**Keywords**

Beam-column joints, Fiber-reinforced polymers, Rehabilitation, Strengthening, Seismic, Shear strength.

## 1 INTRODUCTION

There are many existing structures that were designed before the development of current seismic design codes or to earlier codes before ductile reinforcement detailing was required. The frames of these structures were designed to resist only gravity loads or gravity and moderate wind loads (which is the case for most structures in many countries). Such gravity load designed reinforced concrete structures usually have little or no transverse reinforcement within the beam-column joint. In most earthquakes occurred around the world, beam-column connections in RC buildings were the main cause for structural failure under earthquake loading. In general, several repair/strengthening techniques are currently available to upgrade the infrastructure components. It seems, however, that upgrading using FRP composite materials may be the best candidate for such conditions. They are strong, economic, lead to no changes in the existing structures, have excellent adaptability to the existing geometry, thin and light. Repair and/or strengthening the existing structures using FRP composite materials will increase the strength and rigidities of the structure without adding extra load, unwanted property during earthquake.

In the last four decades several research papers have been published on the effect of seismic loads on poorly detailed reinforced concrete beam-column joints, typical of pre-seismic code designed moment resisting frames [1-5]. A detailed review of literature shows that systematic studies to determine the behavior of the FRP repaired/upgraded members under cyclic loading are still limited. Moreover, the behavior of seismically excited FRP repaired beam-column joints is not well established at various stages of response e.g. before and after yielding of reinforcements, crushing of concrete, fiber fracture or debonding. The present paper is also an effort in the same direction. In this paper, efficiency and effectiveness of Carbon fiber reinforced polymers (CFRP) in upgrading the shear strength and ductility of seismically deficient exterior beam-column joint has been studied. For this purpose, a reinforced concrete exterior beam-column sub-assemblage was constructed with non-optimal design parameters (inadequate joint shear strength with no transverse reinforcement) representing pre-seismic code design construction practice of joints and encompassing the vast majority of existing beam-column connections. The specimen was subjected to cyclic lateral load histories so as to provide the equivalent of severe earthquake damage. The damaged specimen was then repaired using CFRP sheets. This repaired specimen was subjected to the similar cyclic lateral load history and its response history was obtained. Response histories of the specimen before and after repair were then compared. The results were compared through hysteretic loops, peak loads and ductility.

## 2 EXPERIMENTAL PROGRAM

### 2.1 Test Specimens

In finding out the size of exterior 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. Half-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 (Fig. 1). 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, as shown in Fig. 2.

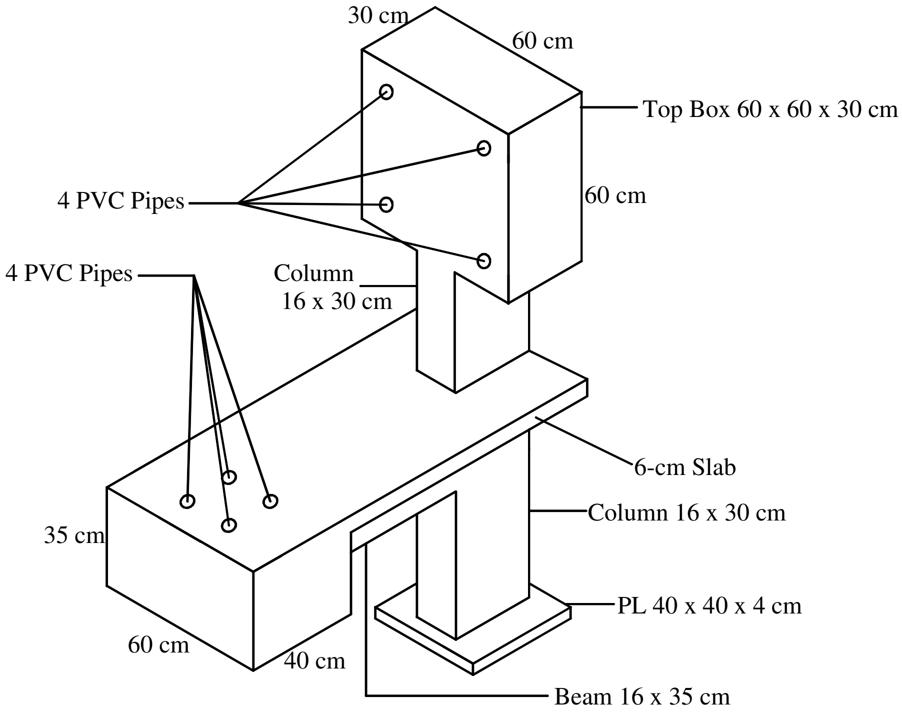


**Fig. 1** Schematic diagram of exterior joint specimen.

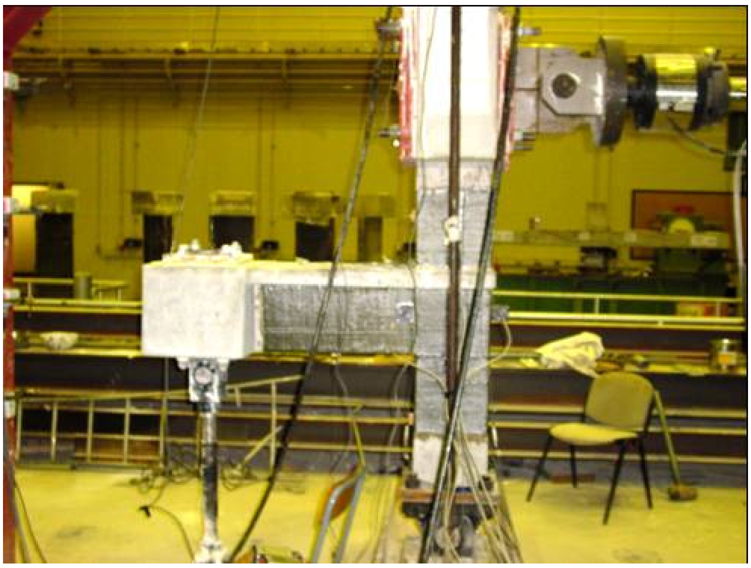

**Fig. 2** Picture showing FRP repaired specimen.

## 3 DISCUSSION OF TEST RESULTS

In the present section, through various experimental results, the effectiveness of CFRP in improving the as-built joint shear strength and ductility has been studied.

### 3.1 Hysteretic Behavior

The hysteretic behavior of exterior joints was examined in terms of shear strength (measured in terms of ultimate load) and deformation capacity. The load-displacement relationships for specimens before and after the repair are shown as hysteretic curves in Figs. 3 and 4. Fig. 3 shows that the ultimate load for repaired specimen is substantially higher than its corresponding original (before repair) specimen (Figs. 3 and 4). 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.

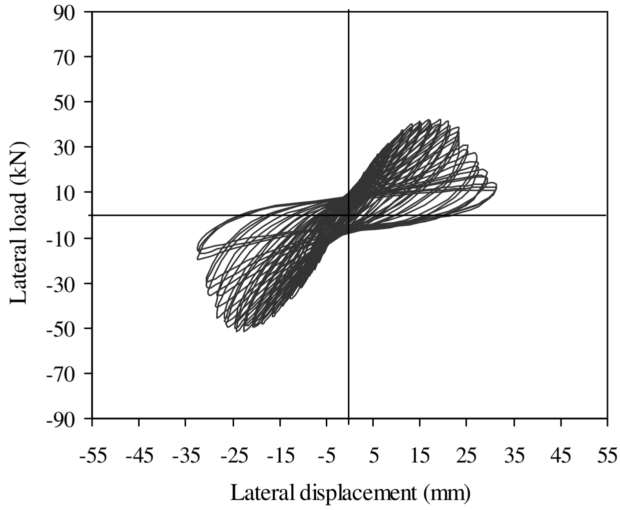


**Fig. 3** Load-displacement hysteretic plot for control specimen.

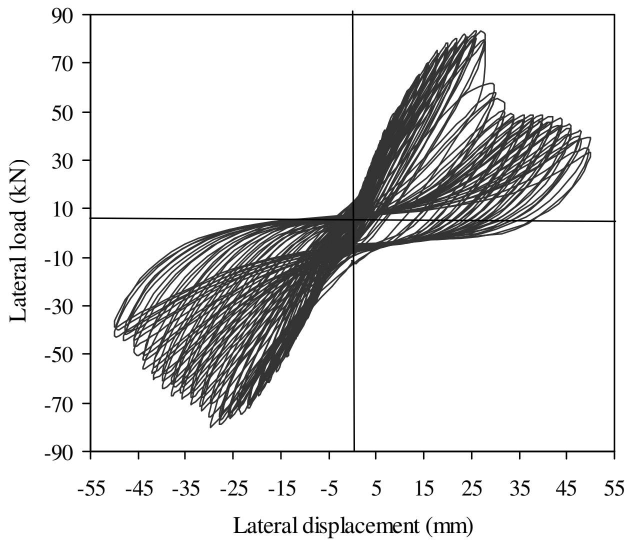


**Fig. 4** Load-displacement hysteretic plot for CFRP upgraded specimen.

### 3.2 Load-Displacement Behavior

In order to study load carrying capacity and ductility of original (before repair) and repaired exterior joint specimens, envelopes of load-displacement hysteretic curves for these two specimens were plotted and using these envelopes the peak load, ultimate displacements, and ductility for the specimens were 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 ductility clearly show that the application of CFRP sheets has improved the ductility of repaired specimen significantly. This increase in the ductility is up to 39% with respect to the before repaired specimen.

**Table 1:** Peak test load and maximum ductility

| Specimen | Average Peak load kN | Disp. At first yield of steel, $\Delta_y$ (mm) | Disp. at 20% drop of peak load, $\Delta_{20}$ (mm) | Ductility Factor $\Delta_{20} / \Delta_y$ |
|---|---|---|---|---|
| Before repair | 47.08 | 18.67 | 30.0 | 1.61 |
| After repair | 81.79 | 18.67* | 40.7 | 2.24 |

*Taken same as respective "before repair" value.

Table 1 illustrates that the increase in average peak load for repaired specimen is substantially higher than the original (before repair) as-built specimen by 74%. This is highly encouraging trend and may be attributed to excellent performance of CFRP sheets attached to the damaged specimen.

The 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. This table shows that the application of CFRP sheets has improved the ductility of repaired specimen significantly. Magnitude-wise the increase in ductility for repaired specimen is up to 39% with respect to its original (before repair) specimen.

## 4 CONCLUSIONS

The results of the experimental program, presented in this paper, establish the effectiveness of CFRP sheets in upgrading deficient exterior beam-column joints. The results of CFRP repaired specimen was compared with its corresponding before repair specimen and, in general, it was observed that CFRP sheets improve the shear resistance and ductility of the RC joint to a great extent.

## ACKNOWLEDGEMENTS

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