The Rehabilitation of the Deficient RC Exterior Beam-Column Joints Using Cement Based Composites

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ABSTRACT :

The beam-column joints that are deficiently detailed and are not built in accordance with seismic codes present a serious hazard from view point of the overall ductility of a structure subjected to severe earthquake shocks. In order to prevent hazards associated with such deficiencies, many existing buildings have to be rehabilitated against severe earthquakes. Four half-scaled exterior beam-column joint specimens were prepared with only one of them conforming to the guidelines of ACI 318-02. The other three specimens were insufficient from view point of joint hoops and main reinforcements of beam and column. The two reinforced concrete (RC) exterior beam-column joints with these deficiencies were rehabilitated using cement based composites with alkali resistant (AR) Glass fabric and Saint Gobain Technical Fabric (SGTF) to improve an alternative and economical rehabilitation method. These rehabilitated RC joints were experimentally studied under the cyclic loads that simulate seismic excitation. In order to strengthen the deficient external beam-column joints, AR Glass and SGTF fabrics were laid out on the tension face of column and beam and then both column and beam were wrapped. Experimental results were compared against the sample designed in accordance to the ACI guidelines. The use of AR Glass and SGTF fabrics mounted by cement paste on the exterior surface of concrete was fairly effective on the ductility, absorbed total, dissipated and recovered energy in addition to ultimate displacement and load carrying capacity

KEYWORDS: Seismic, rehabilitation, beam-column joint, fabric, cement based composite

1. INTRODUCTION

The all reaction forces of columns and beams in RC structures subjected to strong ground motions concentrate in the joint, because of that beam-column joints are crucial regions of structures. After recent severe earthquakes such as Kocaeli (Turkey) 1999, Taiwan 1999, Bam (Iran) 2004 and Pakistan 2005 earthquakes, it was observed that some RC structures collapsed and had heavy damages due to deficient transverse reinforcements and poor anchorage of main reinforcements in the joint, weak column/strong beam design.

Many existing RC structures in Turkey have extremely concrete with low strength and were built before the development of current seismic codes, or without complying with current seismic codes. Such hazardous existing buildings have to be rehabilitated for safety of life and property. The amounts of scientific researches and innovations on developing economical and easily applicable strengthening methods continuously increase. The other main objectives of these researches are to prevent a brittle shear failure of joints and to shift the failure towards a beam flexural hinging mechanism. Corazao and Durrani 1989, Beres et al. 1992, Alcocer and Jirsa 1993, Ghoborah et al 1997 proposed several rehabilitation and strengthening techniques that increase shear resistance of beam-column joints by using concrete jackets, bolted steel plates and corrugated steel sheets. The rehabilitations methods of existing RC structures varied from the simple to the complex. Some of the important problems encountered in the rehabilitation of beam-column joints are to supply the materials needed for effective rehabilitation of beam-column joints and the adaptation of these materials used in strengthening to the existing materials, the cost and availability of materials.

The RC jacketing method is commonly applied for strengthening of RC columns in developing countries such as Turkey and Pakistan. This method can increase the capacities of axial load and bending moments of RC columns but does not have extensive contribution on the behavior of beam-column joints. The disadvantages of methods such as RC jacketing and RC shear wall adding to existing RC frames are complex their application details, heavy labor, long construction time, and difficulties in placing the concrete and reinforcements between existing structural elements and mold. In the rehabilitation of RC structures. The fiber reinforced polymers (FRP) which has some important advantages such as quick application, short construction time, corrosion resistance, not excessively increase the dimensions of the sections of structural elements but are extremely expensive. Gergely et al. 2000, Ghoborah and Said 2001, 2002, Anatonopoulos and Triantafillou 2003, Prota, A. et al. 2003 and 2004, Mukherjee and Joshi 2004, Ghobarah and El-Amoury 2005, Balsamo et al. 2005 investigated the effects of CFRP on the flexural and shear strength, ductility of beam-column joints. Besides, the cement based composites have been developed recently because their costs are fairly lower than CFRP's cost. Fabric reinforced cement-based composites (FRCC) can be used together with structural elements as overlay of floors, and walls, retrofit components of beams and columns. The tensile strength, toughness, and ductility of fiber cement-based composites increase as the fiber contents in mix increases. Peled and Mobasher 2003 studied tensile performances of the pultruded fabric cement based composites using a closed loop control direct tensile tests performed on a MTS testing machine. In this study, the effects of fabric reinforced cement based composites (FRCC) on performance and behavior of the rehabilitated reinforced concrete (RC) exterior beam-column joints were studied and strengthened exterior RC beam-column joints were subjected to cyclic loads to simulate seismic excitations.

2. *Research Significance*

The objective of this research was to develop an economic and easily applicable rehabilitation method reduced intensive labors for seismic rehabilitation of existing RC beam-column joints using cement based composites with fabric. The three of four external beam-column joint specimens were insufficient from view point of joint hoops and main reinforcements of beam and column so that the buildings designed before 1970s could be modeled. The forth beam-column joint specimen was produced in accordance with the requirements of ACI 318-02. Two different fabric types were used to study the effects of fabric types on strengthening of beam-column joints. The effects of these rehabilitation techniques on the cyclic load carrying capacity and the behavior of RC beam-column joints were investigated by comparing the test results of all specimens from view point of ductility, and total dissipated energy.

3. Materials and Preparation of Test Specimens

The concrete used in constructing the specimens was tested under the uni-axial compression loads and had compressive strength of 30 MPa. The steel used for longitudinal reinforcements was Grade 60 with average yield stress of 525 MPa. Stirrups were Grade 40 with average yield stress of 290 MPa. The AR Glass used in this study is bounded fabric. In this fabric, a perpendicular set of yarns (warp and weft) are glued together at the juntion points and is coated with epoxy during fabric production. The bounded fabric was made from multiflament AR with 4 yarns per cm in both directions of the fabric. The number of filaments in a bundle of fabric is 400 and bundle diameter is 0.27 mm. The AR Glass Fabric was manufactured by NEG Glass using yarns of filament diameter of 13.5 microns, tensile strength of 1270-2450 MPa, and modulus of elasticity of 78,000 MPa. The other fabric used was provided by Saint Gobain Technical Fabrics (SGTF). Both of fabric types are shown in *Figure 1*. This fabric has 2 rovings per linear inch width or 78.74 rovings per linear meter. There are approximately 1579 filaments per roving where average diameter of a filament is 19 microns. The young's modulus of AR glass is given to be around 72 GPa. The machine direction strands go over the cross machine direction strands. Therefore, cross machine direction strands are straight and machine direction strands have a slight curvature.

Four half scaled exterior RC beam-column joints were constructed. One of the RC exterior joints was designed in accordance with ACI 318-02 and was called as RCACI318. Other three specimens were designed to represent existing RC structures built before 1970 code provisions from view point of transverse reinforcement details in the joint. While one (RCNH1) of three specimens was tested under the reversed cyclic loads as control specimen, other two specimens were strengthened by using cement based composites made from AR Glass fabric with 6 layers and SGFT with 4 layers. In the joint, the total bending moment capacity of columns is two times higher than that of beam for all specimens. The length of the beam and the column represent the distance to the points of contra-flexure in frame. The dimensions of cross-sections of the column and the beam were 125×200 mm and 125×300 mm respectively. The all main reinforcements of beam were anchored 200 mm inside the joint zone. The reinforcement details and geometry of the beam-column joint specimens are presented in *Figure 2*.

Fabric “L” shaped and wrapping cement based composite segments were used in strengthening of two joint specimens. “L” shaped segments were laid out on the top and bottom of beam section for tensile surfaces of beam varied with respect to the direction of cyclic loads. AR Glass fabric had six layers “L” shaped segments while “L” shaped segment made from SGFT was four layers. The specimen strengthened by FRCC made from AR Glass fabric is shown in *Figure 3*. The “L” shaped segments were completely wrapped by transverse cement based composites.

4. Experimental Set Up and Program

The four storied RC school building was analyzed according to the time-history of Bolu-Duzce Earthquake 1999 and an exterior beam-column joint at the first floor of this building was chose as a specimen model. The length of the columns and the beam of exterior beam-column joint specimens represent the distance to the points of contra-flexure in frame. In the experimental set up, the test specimens were placed to the loading frame such that the columns were horizontal and the beams were vertical position (*see Figure 4*). The displacement history of this joint was based on the reversed cyclic loads applied at the beam tip. This experimental study was done at Arizona State University; Structure Laboratory of Civil Engineering Department. The loading history illustrated *in Figure 5* was slowly applied to eliminate any dynamic effects by MTS actuator with capacity of 250 kN. A constant axial load of 90 kN (0.13 A_g f_c) was applied to the columns of each specimen. The beam deflections at plastic hinge region were measured from three different points by using three spring-loaded LVDT with ranges of 5.08 mm, 3.175 mm and 25.4mm.

5. Evaluations of Test Results

5.1. Behavior of the specimens

The beam tip displacement-reversed cyclic load hysteretic loops for all joint specimens are presented in *Figure 6a-d*. The envelopes of cyclic load-beam tip displacement of joint specimens were obtained from the peak values of each cycle of cyclic load-displacement curves for each specimen and are shown in *Figure 7*. When the cyclic load-beam tip displacement envelopes of the strengthened exterior beam-column joint specimens are compared with those of RCACI318 and RCNH1 from viewpoint of the cyclic load carrying capacity and beam tip displacement capability, it is seen that all of the strengthened specimens have higher displacement-cyclic load responses than RCACI318 and RCNH1. The hysteretic loops of beam-column joint specimens which dominate shear damages in the joint are pinched toward origin. The last three cycles of RCNH1 and the strengthened specimens which diagonal shear cracks were observed in the joint were pinched toward origin (see in Fig. 6b, c and d). Although X shear cracks dominated in the joints of these two specimens, these beam-column joint specimens failed due to the widening of flexural cracks at the column face of beam. Any diagonal shear crack in the joints of RCACI318 and RCCFRP2 didn't occur during reversed cyclic loadings. RCACI318 joint specimen failed due to widening the flexural crack at the column face of beam. The failure section of RCCFRP2 was moved from column face to beam mid-span unlike other specimens. Whereas, for RCCFRP2, the bending moment at the failure section of beam was half level of bending moment at the column face. However L segments were not wrapped over the distance of 0.38m from column face and widening of flexural crack at this region of beam was caused to failure of RCCFRP2. Although any process was not done to strengthen the joint, any diagonal shear crack was not occurred in the joint of RCCFRP2 and also the loosening of the steel angel beam pieces at the corner of beam and column were not appeared at the end of test. Because of that, it can be assumed that these steel angle beam pieces help to the load carrying capacity of the joint as an additional strengthening element and are effective on that behavior of the RCCFRP2 specimen. This failure mode is remarkable for improvement of behavior of strengthened beam-column joints subjected to reversed cyclic loads such as earthquake motions. So, it might be yielded that the main objective of strengthening the beam-column joints was achieved. CFRP sheets did not separate from concrete surface and did not bulge at the corner of beam and column at the end of test. The damages of all test specimens are shown in *Figure 9 a-c*. It was observed that the connection manners of the steel angle beam pieces at the corner of beam-column joint were effective on the former results.

5.2. Absorbed Total Energy Amounts

The total energy capacities of joint specimens were calculated to determine the effects of the strengthening techniques on the behavior of exterior beam-column joints subjected to reversed cyclic loads such as earthquake attacks. Because, these energy amounts absorbed by beam-column joints directly depend on strength and ductility of joints under reversed cyclic loads.

The total energy amount of joint is accumulation of the areas under the curves of force-displacement hysteretic loop up to peak loads in cases of both pushing and pulling of cyclic loads and is a cumulative value. The total energy amounts of each specimen are shown in Figure 8. The beam-column joint specimens strengthened using CFRP have more higher total energy amounts than those of RCACI318 and RCNH1. It can be denoted that RCCFRP2 specimen is stronger and more ductile than other specimens because this specimen absorbed the highest total energy amount. Moreover, the test results indicate that the strengthening technique used CFRP sheets improve the behavior of beam-column joints over deficient beam-column joint and the joint built according to seismic codes such as ACI 318-02 from view point of strength and ductility. Variations of initial stiffness-max deflection at each loop are presented in Figure 5a and b. These figure indicate that the initial stiffness of concrete beams strengthened by AR Glass fabric with cement paste are nearly ten times higher than that of the strengthened concrete beams using PE fabrics with cement paste up to the first maximum load of specimens.

6. Conclusions

The deficient RC exterior beam-column joints in terms of seismic details were strengthened by carbon-fiber-reinforced polymer (CFRP) fabric. The test results of the strengthened beam-column joints under the reversed cyclic loads are evaluated from viewpoint of load carrying capacity, total energy amounts, and ductility. These results are compared with the test results of both RC exterior beam-column joint built in accordance with the requirements of ACI 318-02 and RC exterior beam-column joint disregarded the transverse requirements at ACI 318-02. According to these evaluations and comparisons;

1. CFRP sheets mounted onto the concrete surfaces of beam and column by using epoxy resins increase the load carrying capacity, the ultimate beam tip displacements, the absorbed total energy amounts over RCACI318.
2. It is seen that the RC exterior beam-column joint strengthened by two layers L CFRP sheets has the highest reversed cyclic load carrying capacity and the total absorbed energy amounts among other beam-column joint specimens.
3. at the tension surfaces of beam and column can prevent the. that have no transverse reinforcement and can move the failure section from the column face of beam to the mid-span, if these CFRP sheets are conveniently attached and wrapped to concrete surfaces and the sagging of them are prevented at the corners of joints.
4. When the steel angle pieces used at the corner of joints are fixed to the concrete by means of anchorage bolts and wrapped by CFRP sheets with the width of 0.15 m, it is observed that X shear cracks in the joints can be prevented. In addition to this result, it was also seen that failure sections at RC beam-column joints using two layers “L shaped” CFRP was moved from column face toward mid-span.

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AR Glass Fabric

Saint Gobain Technical Fabric (SGTF)

Figure 1: The fabric types used in strengthening of the exterior beam-column joint specimens

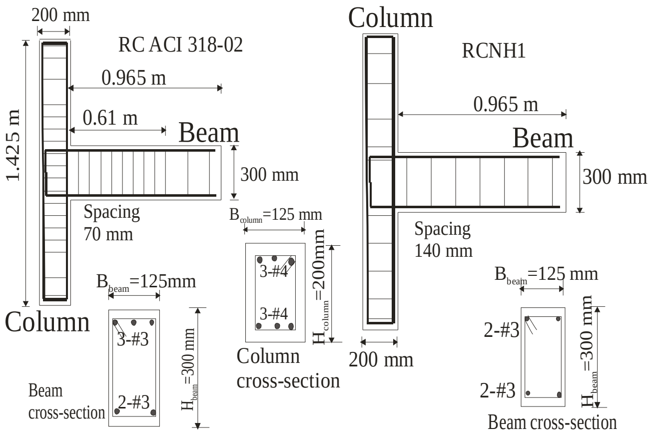


Figure 2: The reinforcement details of exterior beam-column joint specimens

Figure 3: The view of specimen strengthened by FRCC made from AR Glass fabric

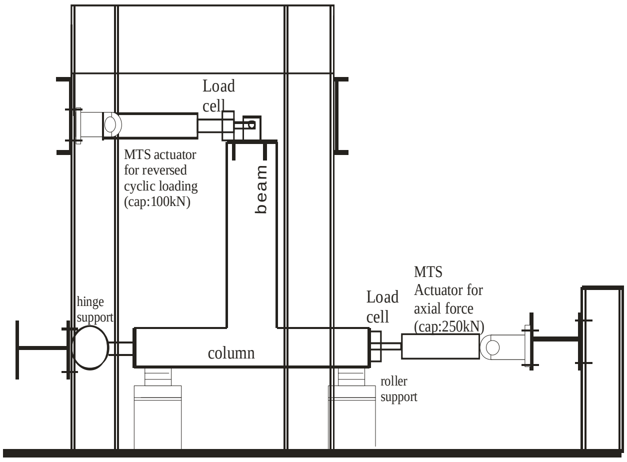


Figure 4: The positions of beam and column in the loading frame

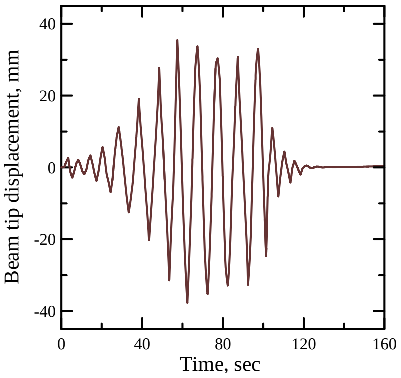
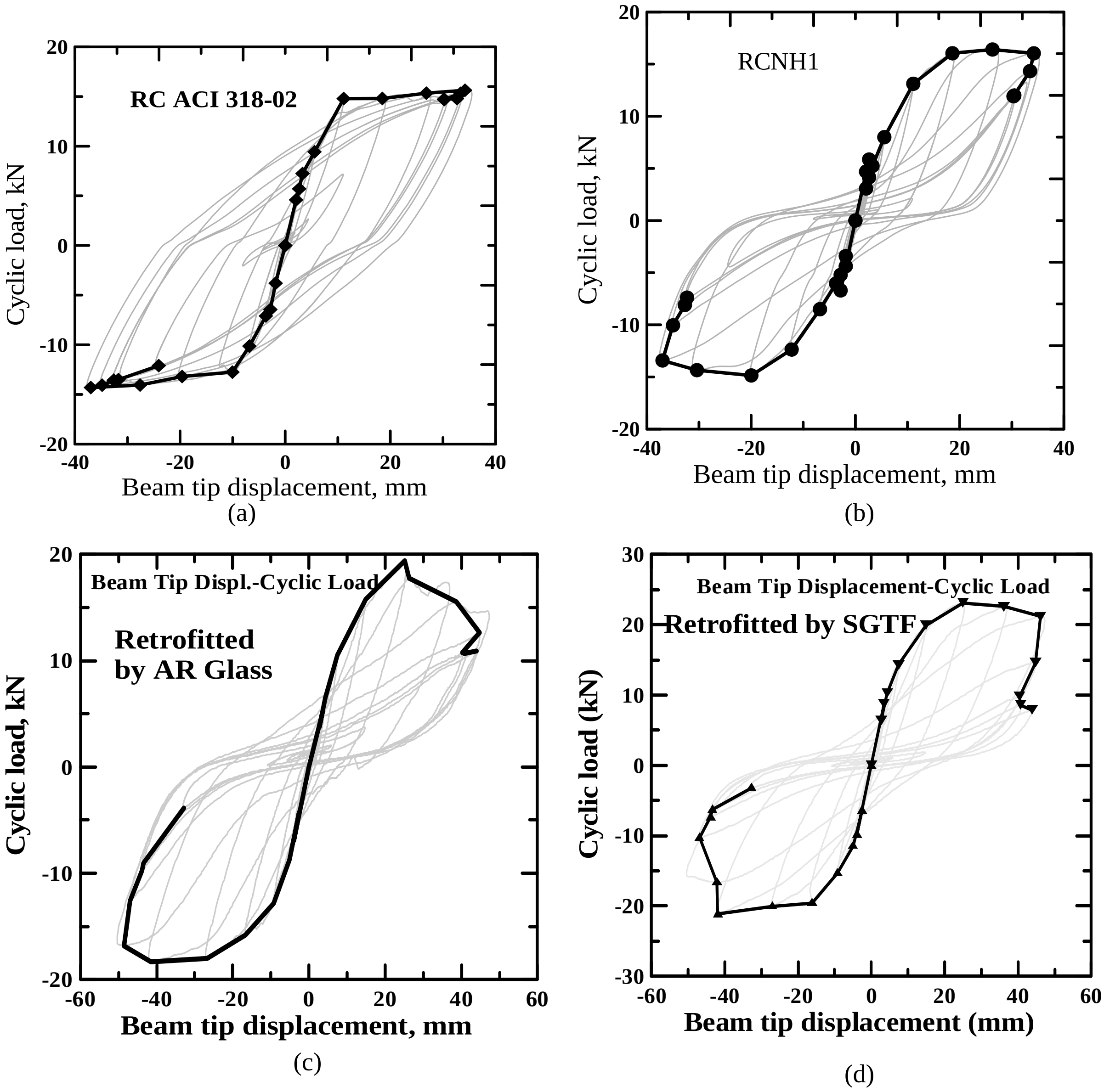


Figure 5: The beam tip displacement- time variation for reversed cyclic loading of beam-column joints



(a)

(b)

(c)

(d)

Figure 6a-d: The beam tip displacement-reversed cyclic load variations of beam-column joint specimens

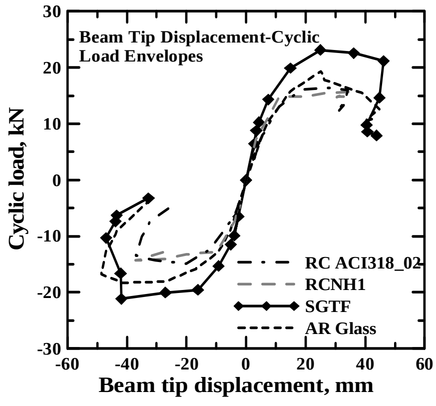


Figure 7: The envelopes of beam tip displacement

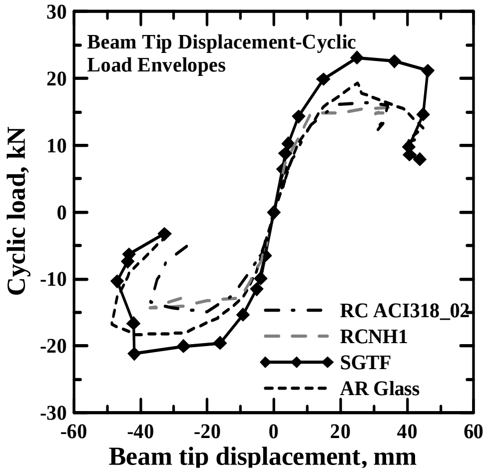
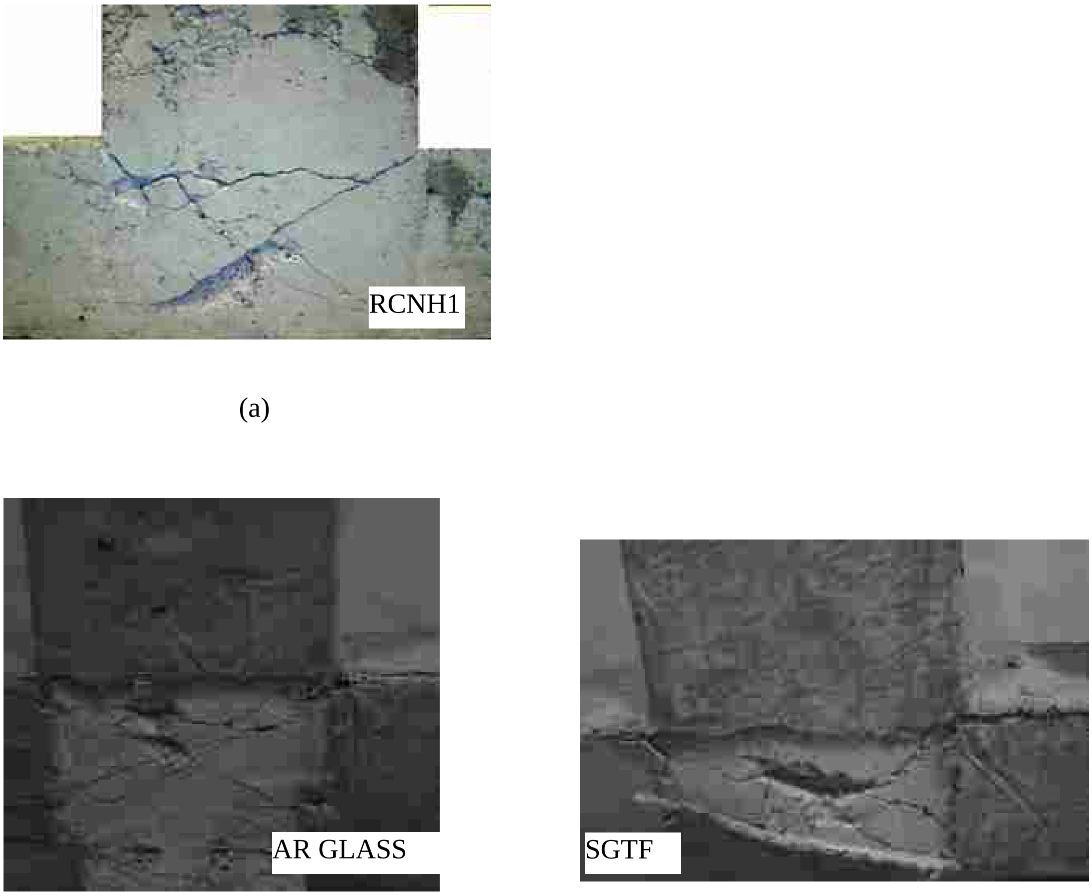


Figure 8: The envelopes of beam tip displacement-cyclic loads of beam-column joint specimens.



(a)

(b) (c)

Figure 9a-c: The damage views of the beam-column joiint specimens after tests for non-retrofit specimen (RCNH1) and retrofitted specimens by cement based composites respectively