Experimental Seismic Investigation of Composite RC - Diagonal Steel Prop Joints

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SUMMARY
Generally, resistance moment reinforced concrete frames should be controlled for story drifts due to lateral load. In recent years, different methods such as braced system used to design new RC frames as composite concrete-steel frame for transferring lateral load to braces and reducing the element dimensions, and also this system can be used for retrofitting of existing deficient RC frames with beams which their height were reduced during of construction process. This paper investigates the experiment behavior of external corner RC joints connected with steel prop and curb as a new composite concrete-steel element under cyclic loading, the system used for retrofitting of damaged joint and beam in RC frames against lateral loads and also for strengthening of RC frames with reduced height beams. Three half scale RC joint specimens were tested, including one reference designed based on design codes, one deficient reference with weaker beam, and third specimen as retrofitted RC joint with suggested method. Test results showed that rigidity degradation rates of retrofitted connections and damages in panel zone during cyclic loading were less than those in reference connections, so suggested system is effective for reducing strength and drift defects in existing weak damaged or undamaged beam-column joints.

Key words: composite concret-steel, reinforced concrete frame, retrofitting,beam-column joint, Steel prop&curb.

1. INTRODUCTION

It is required to rehabilitate the existing structures due to many reasons including the retrofitting of damaged structures under earthquakes or the need for strengthening or retrofitting undamaged structures designed based on old building codes, retrofitting due to mistakes in construction of structures. Having beams with height less than required height is one of design or construction mistakes in RC fames, causing reduction of bearing capacity and increasing vertical deflection of beams with increasing lateral deflection of frames. Therefore these damaged or undamaged frames need to be retrofitted. In recent years, different methods such as braced systems, shear wall, energy dissipation systems and dampers, fiber reinforced polymer, high performance fiber reinforced cementitious composites HPFRCC, used for retrofitting of deficient RC frames. Each of these mentioned methods can be used for upgrading and improving of linear and nonlinear behavior of RC frames such as rigidity, ultimate strength and ductility.

Externally bonded steel plates and FRP laminates have been extensively investigated by several researchers [El-Refaie, Ashour & Garrity, 1999; Yagi, Tanka & Otaguro, 1999]. The technique of retrofitting using externally bonded steel plates has gained widespread popularity, being fast, causing minimal site disruption and producing only small changes in section size. However, it suffers from a number of problems, including undesirable shear failures, difficulty in handling heavy steel plates, corrosion of the steel and the need for butt joint systems as a result of limited workable length [Jones, Swamy & Charif, 1988; Ziraba et al., 1994; Hussain et al., 1995]. FRP materials, on the other hand, have high strength to weight and stiffness to weight ratios and are chemically quite inert, offering significant potential for lightweight and durable retrofit [Nanni, 1995; Büyüköztürk & Hearing, 1998]. A major shortcoming of the FRP is its vulnerability to undesirable brittle failures due to large mismatch in the tensile strength and stiffness with concrete. Several studies undertaken in recent years at Cardiff University, to investigate the feasibility of using a high performance fibre-reinforced cementitious composite (HPFRCC) as a retrofitting material. [Karihaloo et al., 2000, 2002]. Yen and

Chien retrofitted several internal joints with bonding of steel plates to beams web by different methods in order to evaluate their cyclic behavior, they investigated both rehabilitation indexes of strength and ductility [Yen & Chien, 2010]. Retrofitting of structures by using of steel prop and curb that its results and performance is presented in this paper, can be effective considerably in increasing rigidity, strength and energy absorption by confining of concrete at erection place of steel curb and transferring force between RC structure and steel prop. In this research, two reference corner RC joints, one with standard beam as standard reference joint and another one with weak beam (reduced beam height) as weak reference joint, were initially designed, casted and tested under lateral cyclic load up to their ultimate damage states, after that both damaged beams were strengthened with steel prop and curb method. Global and local behavior of these four joints were investigated and those dominated parameters such as bearing capacity, rigidity degradation and energy absorption are evaluated.

2. EXPERIMENTAL PROGRAM

2.1. Specimens Details

Two half-scale specimens named as SC1 & SC2 used as control specimens as shown in Figure 1.The beam height in the specimen SC1was reduced but the specimen SC2 had standard beam height. Two control specimens SC1& SC2 shown in Fig.1 consisting of a column (1900mm in length, as horizontal part) and a beam (1400mm in length, as vertical part) that simulated a exterior joint in middle stories of a two dimensional frame, were designed, casted and tested. The columns cross section at the both control specimens were 250 × 250 mm and the beams cross section in specimen SC1 was 250 mm in width and 150mm in depth and in standard specimen SC2 was 250 mm in width and 200mm in depth. Columns in both specimens such as Fig.2 had $8\phi14$ as longitudinal bars and $\phi8@50\ mm$ as transverse bars in beam-column critical zone. Also the beams in the critical zone in both specimens with same arrangement had $3\phi12$ as longitudinal bars at the top and bottom of section and $\phi8@50\ mm$ as transverse bars, respectively as shown in Figure 2.

Figure 1. Joints specimens of SC1&SC2 before loading

2.2. Retrofitting Method of Tested Specimens

Specimen SC1 damaged under cyclic loading was repaired in critical zone with the same grade of concrete and then retrofitted with steel prop and curb. This prepared and tested specimen was called RSC1. Schematic retrofitting of damaged specimen and retrofitted specimen of RSC1 before cyclic loading test is shown in Figure 3.

Steel props and curbs were used in this retrofitting system. The cross section of steel props as Box was 60×30×2mm section and 500mm length that were erected in two sides of joints. The steel props were subjected to tension and compression force and probably bending moment under cyclic loading at tip of beam. Steel curbs had four edged L-shape plates connected and tied together at edged plates by high strength 10mm diameter bolts. The steel curb played as role of concrete confinement and force transfer from prop to reinforced concrete beam and column. All plates with 5mm thickness and 200 mm width in steel curb were cut and bended in definite points with a gap about 20 mm between edges of curb plates proportional to beam and column cross section. Concrete beam-column critical zone during of cyclic loading are usually damaged and therefore need to be retrofitted such as steel brace system, but due to architectural reasons, the steel curbs were suggested in this paper to be erected at the in and also due to architectural reasons, so the steel curbs were suggested to be erected at end of critical beam-column zone. The erection place of steel curbs center at beam and column were 400mm and 300mm from the side of beam-column joint.

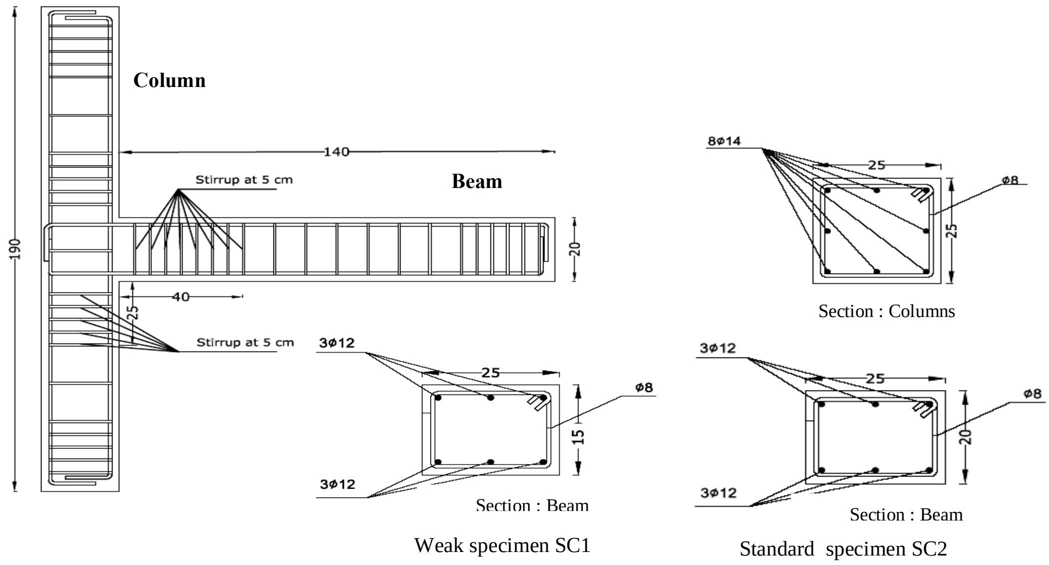

Figure 2. Sections dimensions and arrangement bars of control specimens of SC1&SC2 (in cm)

2.3. Material Property and Test Set-Up

Some joints in RC frames are usually weak due to casting and using low strength concrete, so in order to simulate this situation at the testing specimens, average cylinder concrete strength used in casting the experimental joints was purposely 16 MPa to simúlate weak casting concret and the yielding strength of steel bars $\phi8, \phi12$ and $\phi14$ were 398, 444 and 510 MPa, respectively. Steel prop and curb yielding strengths were 300 and 240 MPa, respectively.

Figure 3. Retrofitted specimen RSC1 before testing

Figure 4. Test set-up view

Real view of test set-up is shown in Figure 4 with an axial horizontal load at column and a horizontal cyclic load at beam according to loading hystory. Axial load of column was equal to $0.15P_n$ = 170 kN (P_n is nominal axial strength of RC columns) applied by 500 kN hydraulic jack to one end of column and the cyclic lateral load was applied by two 200 kN compression hydraulic jacks at tip of joint beam at the distance of 120 cm from the side of column. The column acted as simple support specimen with roller and hinge ends. Cyclic loading history of tests was based on displacement control at 0.25,0.5,0.75,1,1.5,2,3,4,5,6 and 7% drifts at the tip of beam with double cycles at eleven steps and totally 22 cycles.

3. OBSERVATIONS AND GENERAL BEHAVIOR

Flexural cracks in the specimen SC1 were initiated on the two sides of joint and following forming of diagonal X-shape cracks in panel zone at the drift 3% as shown in Figure 5-a. Finally the concrete cover was damaged at drift 7% at the end of test. Moreover, formation of cracks in the side of joint and in length of beam in specimens SC2 was same as those in specimen SC1 but X-shape cracks in panel zone began at drift 2% and then sever degradation of force was occurred at drift 6% at the one direction of loading due to spalling of concrete at bottom of panel zone. Following concrete spalling, the test was ended at drift 7% by crushing of concrete cover, as shown in Figure 5-b. In specimen RSC1, damaged specimen SC1 after retrofitting, no failure and yielding were observed in bolted connections of retrofitting system and steel props. Initial flexural cracks, observed at beam up to 5% drift, morever, were usually propagated from pervious cracks formed at damaged specimen, diagonal X-shape shear cracks were observed at beam at 5%, 6% drift at above of curb. X-shape diagonal cracks in panel zone were observed at drift 4%, therefore displacement delay was accompanied relative to specimen SC1. Final condition of Specimen RSC1, as shown in Figure 5-c, indicate that the final step of test was occurred up to 7% drift once the crack width of concrete in the side above of steel curb was increased. So based on test observations, the proposed retrofitting system decreased damages particularly in the panel zone and those damages were formed far from that zone and then the plastic hinge was transferred to above of curb at the beam.

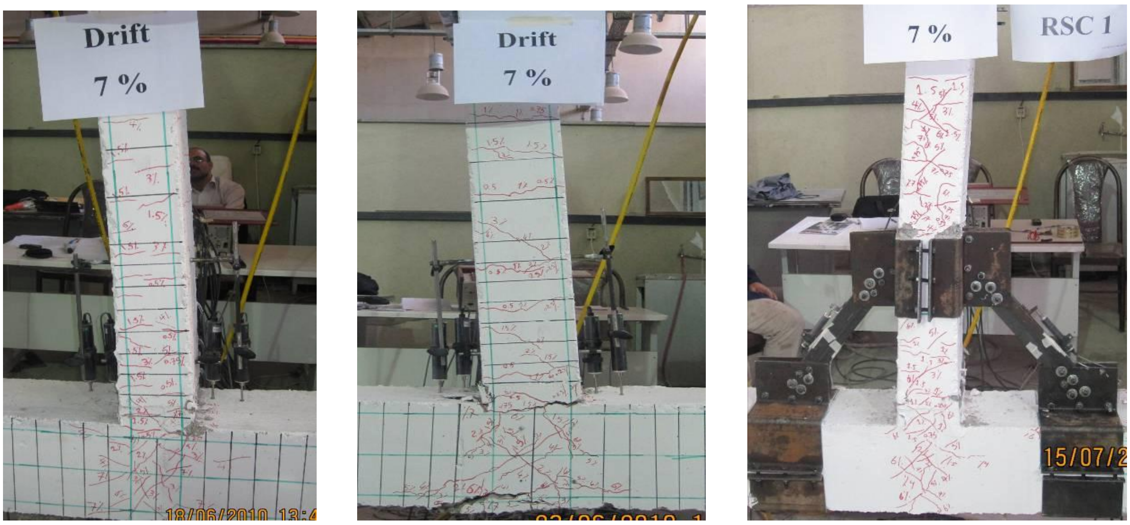

Figure 5. Control and retrofitted joint specimens at end of test (drift7%)

4. RESULTS AND DISCUSSION

4.1. Original Results

Maximum strength P_{max} and ultimate strength P_u (corresponding to the maximum displacement prior to failure) of each specimen and average increasing percentage retrofitted specimen related to control specimens were given at Table 1. Hysteresis load-beam tip displacement curves of specimens up to 7% drift were plotted in Figures 6, 7, 8. Hysteresis envelop curves of joints were plotted and compared together in Figure 9.

Table 1. Maximum and Ultimate Strengths

Specimen	P^{+}_{max} (kN)	Pu^{+} (kN)	P^{-}_{max} (kN)	Pu^{-} (kN)	Average Increasing to Con. Specimen (%)	
					P_{max}	P_u
SC1	16.6	15.6	14.67	13	70	86
SC2	22	18.5	24.9	13.67	14	65
RSC1	29.2	29	24.1	24.1	-	-

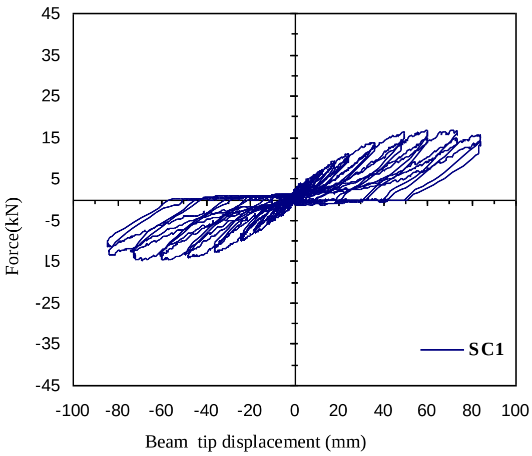

Figure 6. Load-displacement hysteresis curve at SC1 (weak control specimen)

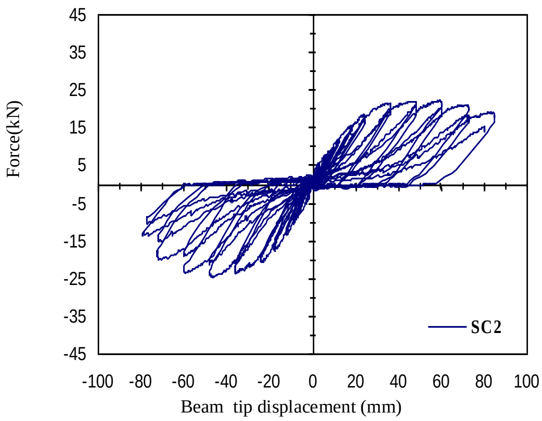

Figure 7. Load-displacement hysteresis curve at SC2 (standard control specimen)

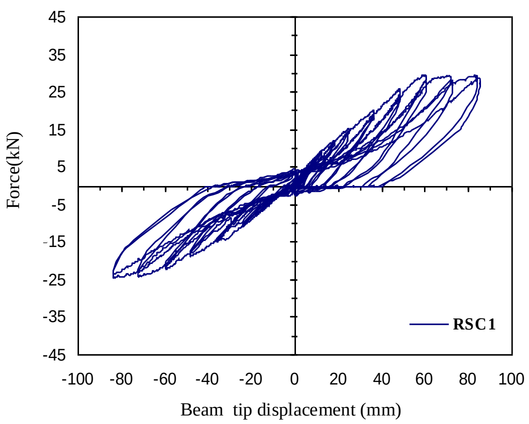

Figure 8. Load-displacement hysteresis curve at RSC1 (weak retrofitted specimen)

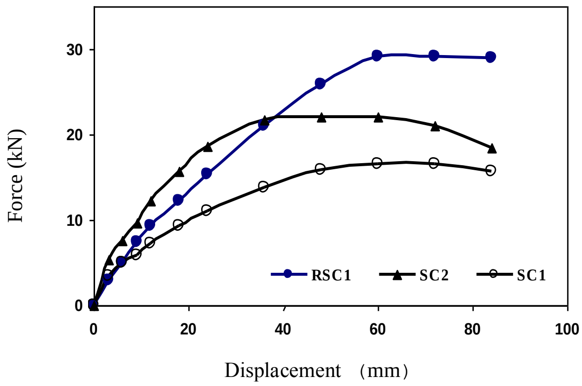

Figure 9. Comparison of Load –Displacement envelope curves of the control & retrofitted specimens

4.2. Strength Degradation

Load-displacement curves, given at Figure 9, show the variation rates and increasing of load capacity in the retrofitted specimen relative to the control specimens. Even thought retrofitted specimen caught self own maximum load at more displacement but no strength degradation was observed up to drift 7% at end of test. Trends of envelop curves show that the retrofitted specimen can suffer more displacements without degradation while force degradation of control specimens were begun from drift 5%. Based on design calculations, if steel props don't yield and not much lateral displacement is observed at curb position on the beam, the steel props can act as a lateral support and consequently the resistant moment of section can be increased up to 33% relative to control specimens while the moment arm was reduced. Despite this point, experimental results, as shown in Table 1, were increased up to two times, the reason maybe due to abundant confinement of concrete at the erection point of the curb and high stiffness of the joint at the side of beam-column joint. Another reason for force increasing was due to prevention of beam longitudinal bars from sliding by retrofitting of weak cast concrete joint. Hysteresis curves showed that the amount of pinching in retrofitted specimen was less than those at the control specimens.

4.3. Rigidity Variations And Degradation

Rigidity slop at each loading cycle could be obtained from the line connecting the negative and positive maximum load at each loop. The variation rates and rigidity degradation during the loading up to drift 7% are presented in Figure 10. Rigidity variations present the rate of damages in concrete and bars. Comparison of initial rigidity at the control specimens SC1 and SC2 showed that the rigidity was decreased up to 58% by 25% reduction at the section height of concrete beam. Due to existence of previous cracks and damages, the retrofitted specimen had generally lower initial rigidity relative to control specimens but the amount of rigidities were significantly reduced and more rigidity degradation in the control specimens had observed relative to retrofitted specimen at higher drifts. The ultimate rigidity of SC1 and SC2 specimens were equal 0.17 and 0.19 and also was 0.32 for retrofitted specimen, indicating that retrofitting system increased rigidity up to 88% by upgrading of indefinite degree and confinement of reference joints.

The rigidity variations and degradation rates in the retrofitted specimen was less than this at control specimens at loading cycles even thought didn't vary in some states of loading. The initial damages in retrofitting system were concentrated at all the length of beam but those damages were transferred to above of the steel curb at the higher drifts and so more slop rigidity degradation was observed. Rigidity degradation of control specimens SC1 and SC2 at drift 7% were 47 and 56% more than RSC1 respectively, therefore rigidity degradation can be reduced by increasing of steel prop to beam stiffness ratio.

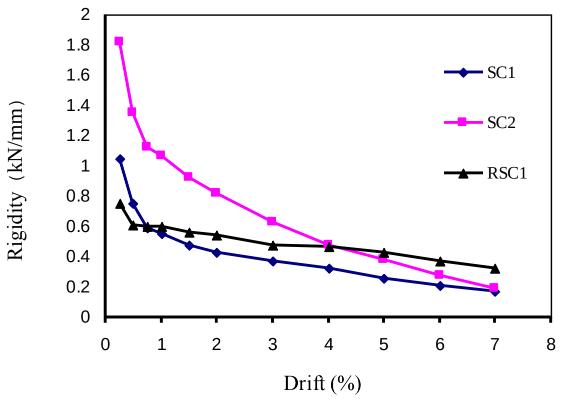

Figure 10. Variations rate of rigidity

5. CONCLUSION

According to behavioral observations and obtained results of experimental cyclic loading of three reinforced concrete beam-column joints including one weak and one standard RC joints as control specimens and retrofitted weak RC joint by steel prop and curb method suggested in this paper, the following results were obtained:

1- By 25% reducing standard beam height RC joints; initial rigidity and maximum strength were decreased 43% and 37% respectively.
2- Two-side steel prop and curb retrofitting suggested system was usable for rehabilitation of either damaged joints or strengthening of undamaged joints. Test Results and observations, cracking pattern showed that stresses at panel zone were reduced and the amount of damages and cracking were minimized. Also this system were could be effective to relocating the plastic hinge to the above beam curb from side of joint and panel zone.
3- By retrofitting of damaged joint with two side steel prop and curb system, the rigidity degradation could be controlled during of cyclic loading up to drift 7%, so rigidity degradation of retrofitted joint was 34% less than control joints.
4- This retrofitting system increased average maximum loads between 14 to 86% relative to control joint specimens, and joint were able to displace up to drift 7% without force degradation.

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