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Experimental study of shear retrofit of RC beam-column joints using external post-tensioned bolts

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ABSTRACT: RC beam-column joints play a crucial role in transferring gravity and lateral loads from beam to column. By examining damaged buildings in recent earthquakes, RC beam-column joints are among the most vulnerable members of RC moment frames. Joint failure can pose a threat to the structure, ending up destroying the structure. The main type of failure of RC joints is shear failure due to the lack of transverse reinforcement and confinement in this area. The laboratory program of the current study suggests external post-tensioned bolts to retrofit RC joints. External post-tensioned bolts increase the confinement and enlargement of the joint panel zone and subsequently eliminate the deficient shear joints. Regarding the forces applied to the joint panel zone are implemented diagonally, the external post-tensioned bolts were used in two horizontal-vertical (HV) and diagonal (Di) patterns around the joint. The horizontal-vertical pattern was chosen owing to placing the resultants of the retrofit bolts forces in the direction of the applied forces. Furthermore, the diagonal pattern was adopted due to the placement of the retrofit bolts in the direction of the applied forces. The testing program includes four RC beam-column joint specimens with half-scale. One specimen was constructed as a standard criterion with all seismic requirements, and three specimens were made at the joint without implementing transverse reinforcement. One deficient specimen was used as a control specimen, and two specimens were subjected to cyclic loading after retrofitting by the proposed patterns. In order to investigate the effect of the proposed method, parameters such as; the force-displacement hysteresis response, energy absorption and damping value of the specimens were considered. The test results confirm the significant effect of the retrofit system against seismic loading. Accordingly, the failure was exited from the joint panel zone and transferred to the beam in retrofitted specimens. The final capacity of the retrofitted specimens increased by nearly 50% and their energy absorption by about 200%. In addition, the damping values and the ductility factors increased by about 100% and 32% in retrofitted specimens, respectively.

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1- Introduction

Correct functioning of joints in RC moment frames is necessary to maintain the structure's stability during severe earthquakes. In the past four decades, several researches have been conducted to evaluate the seismic performance of beam-column joints in RC structures designed according to the criteria of different countries [1-4]. Moment frames designed according to the pre-1970 codes generally lack ductile joints, and therefore joint shear failure due to an earthquake is quite possible; consequently, the ductility and energy dissipation of the structure is reduced, which will lead to the collapse of the entire structure. The lack of transverse reinforcement, non-observance of the development length of the positive longitudinal reinforcement of the beam due to not taking into account cyclic load effects and the strong beam-weak column phenomenon are among the major weaknesses of concrete structures joints. In this research, based on the forces applied performance on the joint, the use of external post-tensioned bolts Horizontally-Vertically (HV) and Diagonally (Di) as methods to improve the RC beam-column joints performance against seismic loads are introduced (Figure 1).

2- Methodology

In order to investigate the proposed method, four RC beam-column joints were tested. One of them was the standard specimen (St) that meets all the seismic requirements according to ACI 318M-19 code [5], while the rest were designed non-seismically so that all of them lacked transverse reinforcement at the joint panel zone. One of the weak specimens was selected as a control specimen (C) in order to compare with the retrofitted specimens and the rest were retrofitted. The nomenclature for the specimens are shown in Table 2. The details of the retrofitting parts can be seen in Figure 2.

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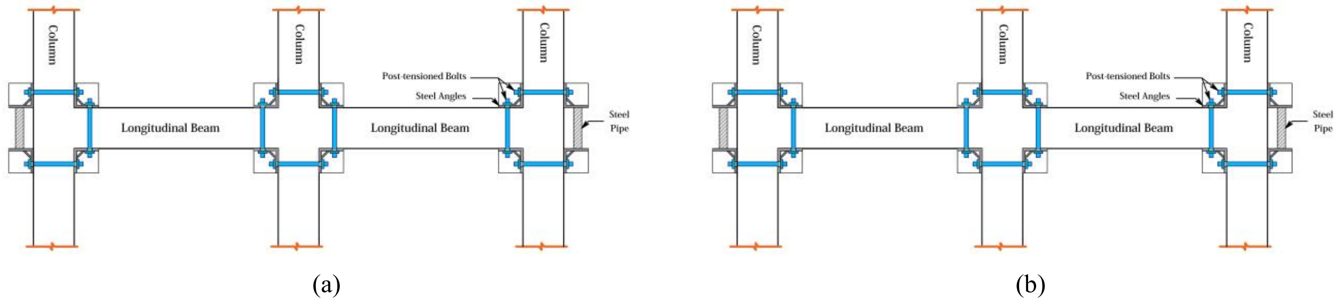

Fig. 1. RC beam-column joints retrofitting system a) Horizontal-vertical pattern (HV); b) Diagonal pattern (Di).

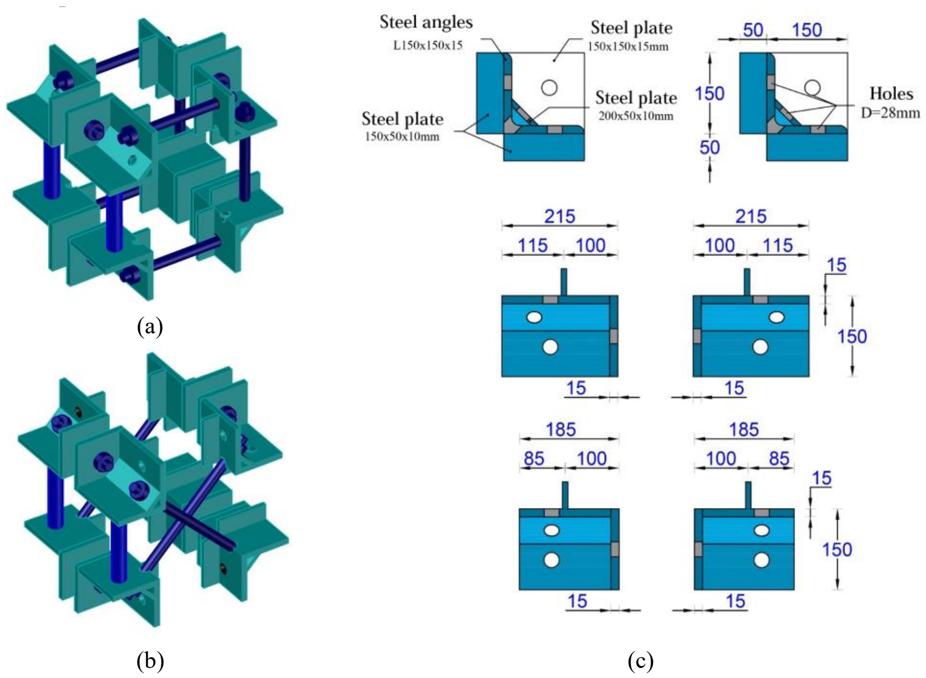

Fig. 2. Retrofitting system details a) Horizontal-vertical pattern (HV);b) Diagonal pattern (Di); c) Retrofitting parts detail.

3- Results and Discussion

In order to investigate the proposed method and its effect on the seismic performance of the joints, the force-displacement envelope curve of the specimens was compared with each other (see Figure 3). By comparing the envelope curves, the significant effect of the proposed method on increasing the shear capacity and ductility of the retrofitted specimens compared to the control specimen is determined.

In order to investigate the seismic performance of the tested specimens, energy dissipation and equivalent hysteresis damping ratio for each specimen were calculated and reported in Figures. 4 and 5. The ductility factor was also investigated as another representative parameter of the structure's seismic behavior. The ductility factor is obtained from the ratio of the final displacement (δ_u) to the yield displacement (δ_y). The ductility factor values of the specimens were reported in Table 2.

4- Conclusions

The results obtained from the experiments confirmed the use of steel angles and externally post-tensioned bolts for shear retrofit of RC beam-column joints as a completely effective method. The key findings of this experimental program are;

1- The maximum load capacity in the HV and Di retrofitted specimens increased by 55% and 64% in the pull direction and 38% and 46% in the push direction compared to the C specimen, respectively.

2- The proposed method significantly reduced the pinching of the hysteresis curves and increased the energy dissipation capacity by 190% and 198% for the HV and Di retrofitted specimens compared to the C specimen.

3- The equivalent hysteresis damping ratio value in retrofitted specimens compared to the control specimen shows an average increase of 97%.

Table 1. Specimen's nomenclature.

Specimen	Specimen conditions and retrofit patterns
St	Standard specimen according to ACI 318-19 code
C	Control specimen according to pre-1970 code
HV	Retrofitted specimen by horizontal-vertical bolts
Di	Retrofitted specimen by diagonal bolts

Table 2. Yielding displacement, ultimate displacement, and ductility factor for all specimens.

Specimen	Yielding displacement (mm)	Ultimate displacement (mm)	Ductility factor
St	20.95	90.31	4.32
C	20.19	71.52	3.52
HV	24.52	109.32	4.46
Di	23.87	116.07	4.86

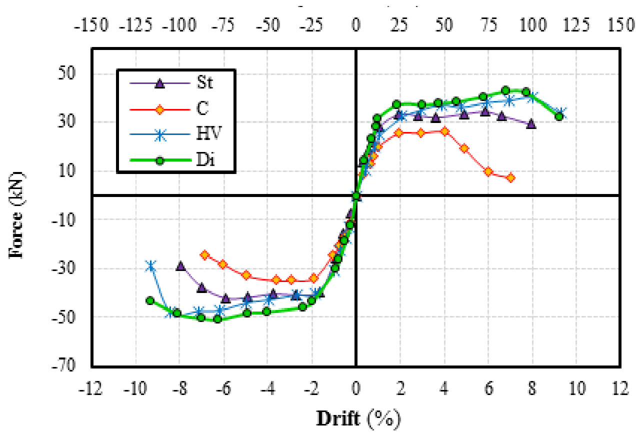

Fig. 3. Comparison of force-displacement envelope curves of the experimental specimens

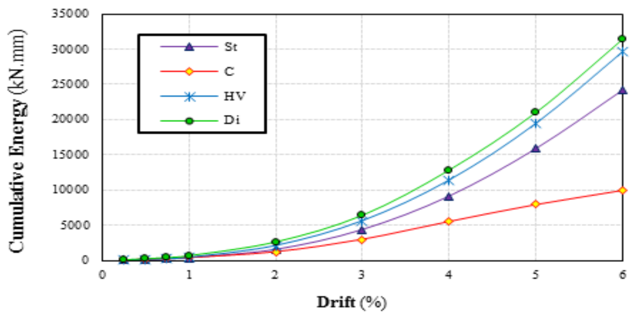

Fig. 4. Comparison of cumulative energy dissipation.

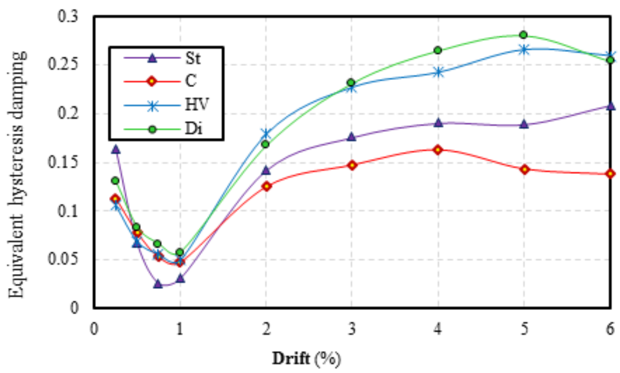

Fig. 5. Comparison of equivalent hysteresis damping ratio.

4- The ductility factor for the HV and Di retrofitted specimens increased by 27% and 38% compared to the C specimen, respectively.

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