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Experimental investigation on exterior RC beam-column connections subjected to cyclic loadings using Steels, Fiber Reinforced Polymers reinforced bars

H. Rezaee Azariani, H. Shariatmadar *, M. R. Esfahani
Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ABSTRACT: In the present experimental research, the behavior of exterior reinforced concrete (RC) beam-column connections subjected to cyclic loading is studied using steel and Glass Fiber-Reinforced Polymer (GFRP) reinforcing bars. In this research, 8 specimens of exterior RC beam-column connections were tested in which four specimens included GFRP reinforcing bars and the remaining four specimens included steel bars. The confinement of beam longitudinal bars was different in the connections. Also, two types of concretes were used with the strengths 30 and 45 MPa, respectively. The specimens were tested under cyclic loading. The results showed that GFRP has great ability in dissipation of energy, yet the amount of the dissipated energy by GFRP is less than that of steel bars. Although the amount of energy absorbed by GFRP materials was lower than steel bars, they could be used instead of steel bars or in combination with steel bars due to the resistance to the corrosion. Load-story drift envelop for GFRP strengthened specimens with high strength concrete has the essential requirements for acting as a member of a moment frame in seismic regions, while all the specimens with steel bars have these requirements. In case of GFRP strengthened specimens with high and normal strength concrete, increasing the cyclic loading results in flexural failure of the beam in the beam-column connection region. Increasing the confinement of concrete beams leads to the reduction of crack width. Furthermore, at higher drifts, spalling was not observed in concrete surface in beam-column connection region.

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1. INTRODUCTION

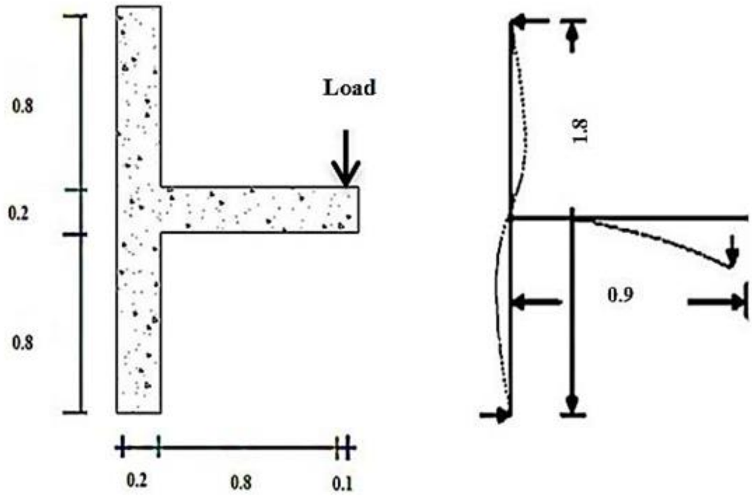
According to field observations of damages on reinforced concrete buildings due to earthquakes, it was proved that they usually occurred in beam-column connections of these structures. Consequently, Park and Paulay comprehensively studied the behavior of beam-column connections [1]. Recently, self-consolidating concrete has been widely used due to its high deformability and workability in casting heavily reinforced sections. Based on the results proposed by Chien et al [2] the ductility and crack controllability of self-consolidating concrete columns are better than normal concrete ones. In the past few decades, composite materials have been extensively applied in repair and strengthening of reinforced concrete structures. Recently, fiber reinforced polymer has been widely used as a reinforcing material in civil engineering for its light weight, high resistance and being corrosion resistant [3]. Leung and Balendran [4] used hybrid bars in concrete beams to avoid ductility reduction. Saikia et al. [5] and Said and Nehdi [6] performed experiments on the beam-column connections reinforced with FRP bars under reverse cyclic loading. These researchers indicated that usage of FRP bars maintained the integrity of the beam-column connection.

This paper makes a comparison between the exterior beam-column connections reinforced with FRP bars and with steel bars. In this process, the normal and high-strength concrete have been utilized. Also, with regard to the confinement due to the transverse reinforcement and detailing, the behavior of the FRP bars have been compared with the steel ones.

*Corresponding author's email: shariatmadar@um.ac.ir

2. EXPERIMENTAL PROGRAM

In this study, 8 different exterior concrete beam-column connections were constructed and tested. Four of these connections are reinforced with the fiber reinforced polymer bar while the others reinforced with the steel ones. The GFRP type of FRP bars were used in the aforesaid specimens due to the fact they were available. Two types of concrete including the normal and high strength (self-consolidating) concrete were employed for construction of the aforesaid specimens. The self-consolidating concrete was utilized because of its high-strength and workability. A beam-column connection specimen is a part of a frame and made by cutting through a beam's points of contra-flexure on both sides of the column and cutting through the column one-half story height above and below the connection as shown in Fig. 1. In Table 1, the detailing of the specimens and the abbreviated names of the steel and FRP bars are listed. Row 1 to 4 of this table belongs to the specimens reinforced with steel bars, and rows 5 to 8 are related to the specimens with FRP bars.



A: Free body diagram of the connections   B: the geometrical properties (m)

Fig. 1. Details of the exterior beam-column connections

Table 1. The details of the specimen and the abbreviated names of the steel and FRP bars

Specimens	Names
1	CONF-STEEL-C30
2	UNCONF-STEEL-C30
3	CONF-STEEL-C45
4	UNCONF-STEEL-C45
5	CONF-FRP-C30
6	UNCONF- FRP -C30
7	CONF- FRP -C45
8	UNCONF- FRP -C45

Fig. 2. The details of the LVDTs

3. TEST DEVICE

To apply cyclic load, a hydraulic jack of 600 kN capacity was utilized at the end of the beam. To measure the applied force, a load cell of 200 kN capacity was employed. As shown in Fig. 2, steel plates were installed on the beam and column ends for preventing the lateral displacements and equilibrium maintenance of the specimens.

Fig. 3. The test device and LVDTs

It should be mentioned that the first LVDT connected to the PC measured the vertical displacement of the beam end. Besides, to assess the vertical

Displacement of the connection at the distance of 2h the LVDT2 was installed on the beam. This LVDT was connected to the PC and recorded the vertical displacement of the beam Δ2 in the critical zone. Additionally, the LVDT5 was installed on the beam for measuring the vertical displacement of the connection, and the LVDT 3 and 4 were placed on the column to find the rotation of the connection. It should be reminded that the LVDTs 3, 4 and 5 measured displacements Δ3, Δ4 and Δ5, respectively. Recall that; LVDT5 was installed on the connection core and LVDT3 and 4 were placed in the column. The details of LVDTs at the connection and the test device with the LVDTs are shown in Figs. 2 and 3, respectively.

4. CONCLUSIONS

In this paper, the behavior of the connections reinforced with the GFRP and steel bars under cyclic loading was experimentally assessed. The experimental obtained results are summarized below:

1. Based on the findings, the reinforced steel bars can dissipate 25% more than FRP ones. Nevertheless, the FRP bars are more resistant to corrosion, in comparison to the steel ones. For this reason, they are usually used instead of or with the steel ones in marine structures.
2. Based on the load-displacement envelope curves, usage of FRP bars in connection made of high strength concrete and the specimens reinforced with steel bars can satisfy the seismic criteria.
3. In specimens reinforced with FRP bars and made of normal or high strength concrete, the crack in the connection core were negligible, and the cyclic loading closed them. By increasing the applied load, the flexural fracture occurred in the beam-column connection. Moreover, increasing the confinement level reduced the crack width.

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