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Experimental investigation of FRP reinforced RC frames under cyclic in-plane loading

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Abstract

Fibre reinforced polymers (FRP) are getting increasingly popular as strengthening and internal reinforcement for reinforced concrete (RC) elements. Lately, in addition to already well-developed research in the direction of reinforcing beams and slabs, the interest in FRP applications for columns, shear walls and frames is gradually increasing. This paper presents the experimental investigation of RC frames reinforced with bended glass fiber polymer bars (GFRP) and their behaviour under reversal cyclic lateral loading. Two RC frames with identical dimensions with scale of 1:3 were built and tested. The control sample was reinforced with bended steel and the results obtained were compared with the behaviour of a sample reinforced with bended GFRP bars. The displacement-controlled cyclic loading according to ACI 374.1-05 was applied to both specimens. Finally, an analysis of the response of the samples at specified drift ratio, such as load-displacement behaviour and energy dissipation, is presented.

Keywords: RC frames, FRP, cyclic loading, experimental investigation, seismic behaviour

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Introduction

The noncorrodible nature of FRPs has been the driving force for many researchers in their attempt to overcome the problems associated with the corrosion of steel. Consequently, many studies have investigated the behaviour of different reinforced concrete (RC) elements reinforced with glass fiber-reinforced polymers (GFRP). Although many of them were focused on individual members, limited research has examined the behaviour of concrete frames reinforced with internal GFRP bars under seismic loading. A pioneer experimental study was undertaken by Fukuyama et.al [1] on a frame reinforced with internal FRP bars and the results were promising. Subsequently, a number of studies [2,3,4] have investigated the overall seismic behaviour of GFRP-RC beam-column joints. The results showed that using GFRP bars as flexural and shear reinforcement in concrete elements subjected to seismic loading is feasible. Similarly, Aliasghar-Mamaghani et al. [5] indicated that frames reinforced with GFRP bars show higher strength than frames reinforced with steel bars under seismic loads. Moreover, Sharbatdar et al [6] have presented the results of an experiment of three large-scale FRP reinforced concrete joints tested under cyclic loading. They concluded that FRP reinforcement can be used effectively in new concrete buildings. Current publications [2,3] for FRP-RC structures indicate that the existing design codes have little or no seismic provisions due to lack of data and research in its use. This paper presents the experimental results of RC frames reinforced with bended glass fiber polymer bars and their behaviour under reversal cyclic quasi-static loading.

Experimental program

Test specimens

The experimental program consisted in the construction and testing up to failure under reversal cyclic loading of two 1/3 scale down frames. The test specimen is shown in figure 1. The first specimen, the control sample (SS), was reinforced with conventional steel bars and stirrups while the second specimen (GS) was reinforced with GFRP bars and steel stirrups. The anchorage of all the bars used in the experiment was done by 90-degree hooks. The test specimens were of identical geometric and reinforcement details. The columns measured 860 mm in the overall length with a cross section of 120x200 mm with 6 longitudinal rebars of 6 mm diameter. The overall length of the beam was 1200 mm with a cross section of 120x180 mm with 4 rebars of 6 mm diameter.

Figure 1: Picture of specimen undamaged (left) and after failure (right)

Materials Properties

All specimens were cast by using normal-weight concrete, mixed in the laboratory with a target 28-day compressive strength of C30/37 and with a maximum aggregate size of 10mm. The samples were cast in horizontal position and wet-cured for 28 days. The GFRP bars used were made with polyester resin and E-Glass and were bent from the manufacturer.

Test set-up and instrumentation

The loading protocol was based on ACI-374.1 [7]. Three fully reversed cycles were applied at each drift ratio under displacement control mode. A 500 kN load cell was attached to the jack to ensure real-time monitoring of the pushing and pulling force. Several LVDTs (strain gauges based with the stroke between 25 and 100 mm) were mounted at different locations to measure the displacement of the sample during testing. Strain gauges (CEA-06-240UZ-120 type) were installed on the reinforcing bars and linear wire gauges (PL-60-11 type) on the concrete. The acquisition rate was 10 readings per second.

Test results and observations

Figure 2 illustrates the load-displacement hysteretic curves. The envelopes of load-displacement relationship are indicated with a red dashed line. The SS sample showed almost symmetric responses in push and pull directions, while the GS specimen exhibited lower resistance in the pushing direction for the first couple of amplitudes. At the drift ratio of 1.75% which is at 13.5 mm displacement, the SS specimen recorded the peak load of 50 kN in pushing direction and of 48 kN in pulling direction. Although the SS specimen had a higher load, the GS specimen withstood loading at higher drift ratios. It reached the maximum load of 41 kN in push direction at the drift ratio of 2.75% which is at 21 mm displacement, while in pull direction, the maximum load was 46 kN at the next drift of 3.5%. The crack formation was almost symmetrical in pushing and pulling directions for both specimens.

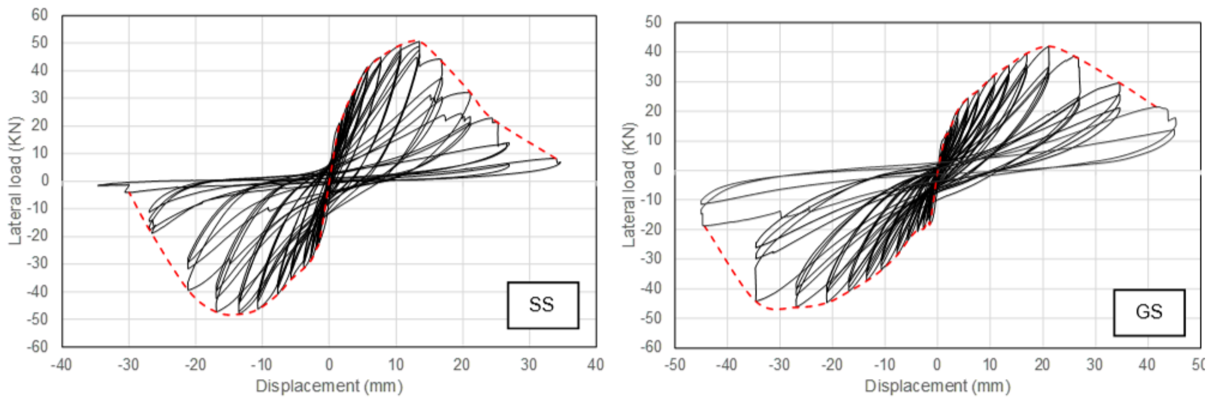

Figure 2: Hysteretic curves for SS (left) and GS (right) specimens

Figure 3 shows the average maximum loads and the cumulative energy dissipation versus the displacement for both specimens. The maximum average load was calculated as per average of the maximum load from pushing and pulling directions from the 1st cycle at each amplitude. The cumulative energy dissipation was calculated by summation of the enclosed area in the hysteretic loops in successive load-displacement cycles.

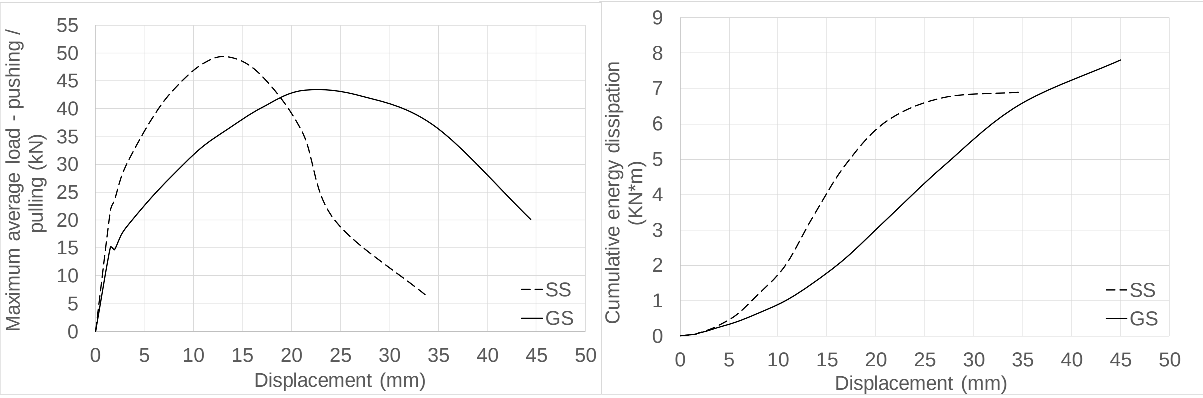

Figure 3: Max load envelope (left) and cumulative energy dissipation (right) for SS and GS

Conclusion

Both tested specimens were able to sustain drift ratios higher than 2.5%. It should be noted that while the SS specimen reached its maximum load at 1.75% drift, the GS specimen had the peak at a drift of 2.75% in pushing direction and at 3.5% in pulling direction. Even though the SS sample had a slightly higher ultimate capacity of 49kN than the GS sample with 43kN, the former reached its ultimate load at early stages of displacement. The energy dissipation of the SS specimen was higher than that of the GS specimen up to 35 mm displacement and then decreased above this drift.

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