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Confining of square RC columns with FRP sheets using corner strip–batten technique

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HIGHLIGHTS

- Corner strip–batten method was proposed for FRP confinement of square RC columns.
- The performance of the proposed method was compared with other confining methods.
- FRP rupture point in both IVS-B and IVS-IW methods was observed at middle of sides.
- The maximum increase in bearing capacity was observed in IVS-B and IVS-IW methods.

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ABSTRACT

The application of fiber reinforced polymer (FRP) composites has been successfully promoted for external strengthening of reinforced concrete (RC) columns. Recent studies showed that when these jackets are formed in a wet lay-up process for confinement of columns, an average rupture strain of FRP in specimens substantially fall below those of flat coupon tensile tests. The problem is more important in rectilinear columns because of premature rupture of FRP at corners due to stress concentration.

In this paper, a new method is introduced for confinement of square concrete columns as using FRP strips at corners and FRP battens at sides. In this method, FRP battens do not experience any curvature in confining of section and are stretched as completely flat strips similar to flat coupons. To compare the new proposed method with other FRP-confining techniques, sixteen square RC columns with 133 × 133 mm cross section and 500 mm height were experimentally tested under uniaxial compression. The test parameters included continuity or discontinuity of corner strips along height of column, the volume of fibers used, and the number of confining layers. The experimental results clearly demonstrated that confining battens in the new method of corner strip–batten are uniformly stretched under the tension stresses of confinement; therefore, more uniform distribution of confining pressure on section occurs and the stress concentration at corners is eliminated. Thus, in the proposed method, better performance of FRP in confinement was observed and the compressive behavior of the strengthened column was significantly improved compared to those confined using conventional FRP wraps.

1. Introduction

The use of fiber reinforced polymer (FRP) composites has been recognized as an effective technique for repair and strengthening of reinforced concrete (RC) structures. Among the applications of FRP composites is their use as external confining jackets in retrofit of existing reinforced concrete (RC) columns; which increases both load carrying capacity and ductility of column.

Based on experimental observations, the failure of the concrete column confined with FRP, dominates by the hoop rupture of composite when the overlap length is sufficiently provided [1–4]. Therefore, in column specimens with FRP rupture failure mode, the ultimate state of confined concrete is affected by the ultimate tensile strength and strain of composite measured in experimental tests. Recent studies have shown that the ultimate rupture strain of composite obtained in FRP confined concrete specimens is much smaller than the ultimate strain obtained from flat coupon tensile tests; which shows that the full tensile capacity of composite is not effectively used in confinement. Several reasons have been suggested for the difference between FRP ultimate tensile strain obtained from coupon tests and measured in FRP confined concrete

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specimens as follows [2,5–9]: (1) the curvature of the FRP jacket in confined specimens leads to lower quality of the composite compared to that of flat coupons, (2) the stress state in FRP jacket is not a strictly pure tension condition as that for the flat coupons, (3) non-uniform deformation of cracked concrete causes local stress concentrations beneath the FRP jacket, (4) this is due to local misalignment or defect of fibers in the wet lay-up process of FRP jacket, and (5) the existence of an overlapping zone in which the measured strains have the lowest values leads to non-uniform distribution of strain around the circumference; in this case, an average hoop rupture strain of the jacket in specimen is lower than the ultimate tensile strain of FRP coupons.

The strain efficiency factor, K_{ε}, in ACI 440.2R-08 accounts for the premature rupture of FRP in wet lay-up confined systems. This factor is defined as the ratio of the average FRP hoop rupture strain in confined specimen to the FRP ultimate tensile strain obtained from the flat coupon tensile tests. The values between 0.55 and 0.61 have been suggested for this factor in ACI 440.2R-08 [10].

Recent studies have demonstrated that the FRP jackets provide an effective confinement for circular concrete columns; however, the composite jackets are less effective in confinement of rectilinear columns due to the non-uniform distribution of confining pressure around the section [11]. Besides, stress concentration at sharp corners of rectilinear sections results in premature rupturing of FRP composite at low tensile strains [12]; thus, the composite tensile capacity is not used effectively. On this basis, researchers have investigated different methods to improve the efficiency of composite in confinement of rectilinear sections.

Rounding corners of column section is an effective technique to improve the performance of composite in confinement, which reduces stress concentration and punching (or cutting) of fibers at section corners. In this context, several theoretical and experimental investigations given in literature [13–20] indicate that confinement effectiveness increases gradually with an increase in corner radius; as the corner radius increases and the section varies from square to circular, the distribution of confining stresses around section circumference becomes uniform leading to increase of the ultimate strength and strain for confined specimen. Furthermore, the influence of shape modification in FRP confined square or rectangular columns was recently studied by some researches [21–24]. In their studies, the cross section of rectilinear column was changed to circular or elliptical shape by adding concrete or mortar elements before wrapping the FRP around the section. The results showed that the modified shape of cross section can significantly improve the behavior of rectilinear FRP confined column by reducing stress concentration at the corners and increasing FRP efficacy.

Another effective method to improve the efficiency of composite in confining the square sections is the use of single vertical strips of FRP (with horizontal fibers) locally applied at the sharp corners beneath the horizontal wraps around the column as suggested by Campione et al. [25–27]. Their results illustrated that local reinforcement at the corners before the application of horizontal wrap avoids premature rupture of FRP at the corners and improves the confinement effectiveness of horizontal layers which significantly increases the bearing capacity and ductility of column. Moreover, Kiani in 2010, modeled square concrete specimens strengthened with the aforementioned technique and examined the influence of different parameters including the number of confining layers, the ratio of the corner strip width to column dimension and the effect of intermittent wrapping. His results showed that local reinforcing of the column corners eliminates stress concentration at these parts and makes the distribution of the confining pressure almost uniform around the section. Furthermore, an increase in the width of corner strips induces more increase in ultimate strength and ductility of the confined column [28].

It can be inferred from the above explanations that development of new practical techniques is necessary to improve the efficiency of composite in confinement of square sections; so that, the FRP rupture strain of confined specimen approaches to ultimate tensile strain of composite obtained from flat coupon tensile tests. Accordingly, a new technique was proposed in this study for confinement of square columns as using CFRP strips at corners and CFRP battens at column sides. CFRP battens are used as completely flat strips at all four sides of the column section; each is bonded onto corner strips at both ends. In this case, the confining battens attached to the specimens are stretched without having any curvature (similar to flat coupons), leading to more uniform distribution of confining pressure around the column section circumference. The experimental program of the current study is aimed to investigate the performance of the new proposed technique in confinement of square column compared with the other existing confining methods. Further, the effect of different parameters including continuity or discontinuity of corner strips along height of column, the amount of fibers used, and the number of confining layers are studied in this paper.

2. Experimental program

2.1. Specimens details and material characteristics

The experimental specimens used in this study included sixteen square RC columns with cross section of 133 × 133 mm, height of 500 mm and corner radius of 8 mm which are classified in four groups. One specimen at each group is considered as reference column (without external strengthening) and the others are strengthened with CFRP composite using different methods.

All columns were longitudinally reinforced with four φ 10 steel bars (ρ = 1.78%) and laterally reinforced with 8 mm diameter tie steel bars spaced at 85 mm on center. The clear concrete cover was 20 mm on each side of the specimen as well as top and bottom of the column to prevent direct loading of longitudinal bars. The yield strength of the bars was 406 MPa for 10 mm diameter bars and 550 MPa for 8 mm diameter bars. Details of the specimens' reinforcement and steel cages used are shown in Figs. 1 and 2, respectively.

Concrete mix proportion designed for target compressive strength of 28 MPa based on ACI-211 [29]. To obtain this compressive strength, 398 kg/m^3 of type I Portland cement, 888 kg/m^3 of sand, 783 kg/m^3 of coarse aggregate, and 240 kg/m^3 of water were used. The average compressive strength of column specimens was determined by testing three 150 × 300 mm standard concrete cylinders for each group. All the specimens were removed from the mold one day after casting and were cured in water bath up to 28 days under standard condition. The specimens were then strengthened with CFRP sheets through wet lay-up procedure.

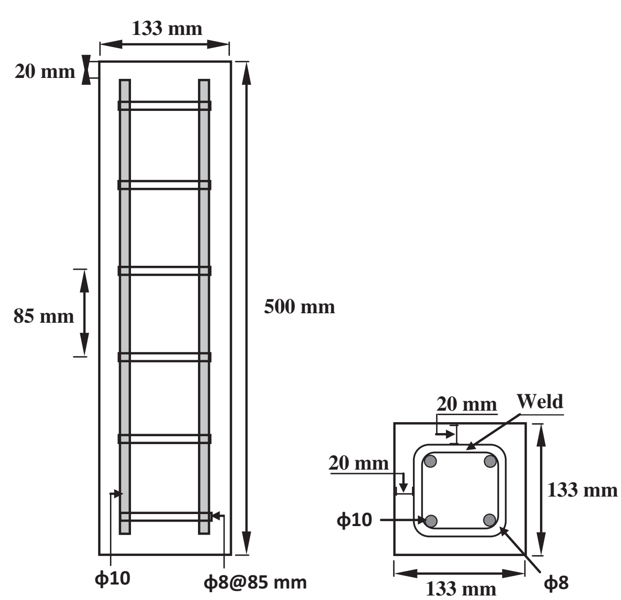

Fig. 1. Details of specimens' reinforcement.