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Behavior of partially and fully FRP-confined circularized square columns under axial compression

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HIGHLIGHTS

- Compressive behavior of partially FRP-confined CSCs was investigated.
- Strengthening square columns by and partially FRP confinement is promising.
- Net spacing influences the behavior of partially FRP-confined concrete.
- Stress-strain behavior is influenced by FRP volume ratio and confinement stiffness.
- The vertical confinement effectiveness coefficient is reasonably accurate.

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ABSTRACT

Fiber-reinforced polymer (FRP) jacketing has become an attractive strengthening technique for concrete columns. Existing research has demonstrated that FRP confinement is effective for circular columns, whereas it is less effective for square columns. The lower FRP confinement effectiveness in a square column is predominantly attributed to the non-uniform FRP confinement in the column, while the concrete in an FRP-confined circular column is uniformly confined. Although rounding the corners of a square column can enhance the effectiveness of FRP confinement, its benefit is still not satisfactory as the radius of rounded corners is usually limited owing to the presence of internal steel reinforcement. An appropriate approach to enhancing the confinement effectiveness of FRP strengthening technique for square columns is to circularize a square column before FRP jacketing. This paper aims to study the compressive behavior of circularized square columns (CSCs). A total of 33 column specimens were prepared and tested under axial compression in this paper. The column parameters include FRP wrapping schemes (including fully wrapped and partially wrapped), FRP volumetric ratio, sectional shapes and unconfined concrete strength. The test results have indicated that the section circularization of square columns can significantly improve the effectiveness of FRP confinement, and strengthening square columns using section circularization in combination with partial FRP confinement is a promising and economical alternative to the fully FRP strengthening technique. Comparisons between the theoretical predictions and the test results were conducted, and the accuracy of existing partially FRP-confined concrete models were also examined.

1. Introduction

Over the past three decades, fiber-reinforced polymer (FRP) composites have been widely used for the confinement of existing concrete columns. Extensive research has been conducted to investigate the confinement mechanics and the stress-strain characteristics of FRP-confined concrete. The research outcomes have demonstrated that the FRP confinement can significantly enhance the strength and deformation capacities of circular concrete columns e.g., [4,9,17,24,19,20,23,28,29,36,33,34,40,49]. However, the FRP confinement is much less efficient for square columns, mainly due to the existence of flat sides and sharp corners of these columns. Rounding the sharp corners of a square section is usually

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recommended to improve the FRP confinement through reducing the detrimental effect of sharp corners on the hoop tensile strength of FRP jackets e.g., [1,11,13,14,18,22,30,31,35,42,46,54]; however, its benefit is still not satisfactory as the corner radius is usually limited due to the presence of internal steel reinforcement.

Square columns are more common in practice due to the following two reasons: (a) architects tend to prefer square columns because of their regular appearance, and (b) square columns are more easily constructed than circular columns due to the easier availability of square molds for concrete casting. As has been explained earlier, the effectiveness of FRP confinement in a square column is lower than that in a circular one. Also, it is not a good idea to increase the bending stiffness of FRP jacket by enlarging the FRP jacket thickness. For an efficient use of FRP in square columns, one of the most appropriate approaches is to implement an appropriate shape modification of square sections before FRP jacketing needs.

The concept of column shape modification was initially introduced by Priestley et al. [44,45]. Their test results indicated that the strength and deformation capacities of the columns were significantly enhanced after implementations of the shape modification. Shape modification generally refers to modifying a rectangular column to an elliptical/oval/curvilinear column or a square column to a circular/curvilinear column. Shape modification of square columns can be achieved in practice by the following two approaches [21,51,61]: (a) attaching precast concrete bolsters or casting the additional concrete for shape modification to the existing column before FRP jacketing; (b) using a prefabricated FRP shell of the desired shape as the stay-in-place form for casting new concrete (usually made of self-compacting concrete) between the column and the shell. For a square column shape-modified by circularization, the process is called section circularization (i.e., SC) and the resulting shape-modified column is called circularized square column (CSC) in the present study (Fig. 1). For ease of discussions, the concrete in the core square column is referred to as "core concrete" and the new concrete used for circularization as "peripheral concrete" hereafter (Fig. 1). In a CSC, the FRP jacket is loaded primarily in hoop tension from the beginning, resulting in higher confinement to the concrete compared with the square column with only rounded corners.

A number of studies were conducted on shape-modified columns from rectangular sections to elliptical/oval/curvilinear sections e.g., [37,38,50,60,61,62] or from square sections to circular/curvilinear sections e.g., [21,41,60,61,63]. However, in most of these studies, shape-modified columns were confined by longitudinally continuous FRP jackets (referred to as fully FRP-confined columns). It is obvious that the strength and deformation capacities of these fully FRP-confined columns are better than those of their counterparts without the shape modification. Alternatively, the shape-modified columns can be confined using evenly spaced FRP strips along the longitudinal axis (referred to as partially FRP-confined columns). Although the vast majority of previous studies related to FRP-confined concrete columns focused on fully FRP-confined concrete, a number of studies were conducted on partially FRP-confined concrete [5,8,29,39,43,47,52,56,58,59], owing to its easier and faster application. Partially FRP-confined columns have also been demonstrated to process an adequate increase in strength and a considerable increase in axial deformation capacity compared to their unconfined counterparts [43]. Under certain circumstances, partially FRP strengthening technique is a reasonable choice, especially for columns requiring moderate enhancements in strength and deformation capacities. Additionally, although both the SC before FRP jacketing and partially FRP confinement can enhance the strength and deformation capacities of concrete, the compressive behavior of partially FRP-confined CSCs has never been studied.

On the other hand, the available design guidelines for FRP-confined concrete columns are mainly accounted for fully FRP-confined concrete columns, only *fib* [16] and CNR-DT 200 R1 [12] provide design specifications for partially FRP-confined concrete columns. As per these codes, a longitudinal confinement effectiveness factor is suggested for the ultimate axial stress and the ultimate axial strain of partially FRP-confined concrete. While the longitudinal confinement effectiveness factor for partially FRP-confined concrete seems to be plausible, limited test results are available to validate its accuracy. For partially FRP-confined concrete columns to be widely used, further experimental and theoretical investigations are indispensable.

Against the above background, this paper aims to investigate axial compressive behavior of fully or partially-FRP confined CSCs. A total of 33 columns were fabricated and tested in the present study. The test results in terms of the failure modes, stress-strain characteristics, and the ultimate axial stresses and ultimate strains were reported in detail. A theoretical analysis was conducted for predicting the compressive behavior of partially-FRP confined CSCs based on the FRP-confined concrete models [12,16,25]. Through the comparisons between the theoretical predictions and the test results, the accuracy of these models were examined.

2. Experimental program

2.1. Test specimens

In total, 33 concrete columns were prepared and tested to investigate the effects of vertical spacing ratio, FRP thickness, sectional shape and peripheral concrete strength. As shown in Fig. 2, the vertical spacing ratio is defined as s_f'/s_f where s_f and s_f' are

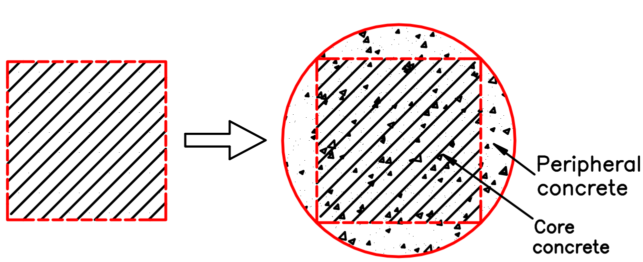

Fig. 1. Section circularization for a square column.

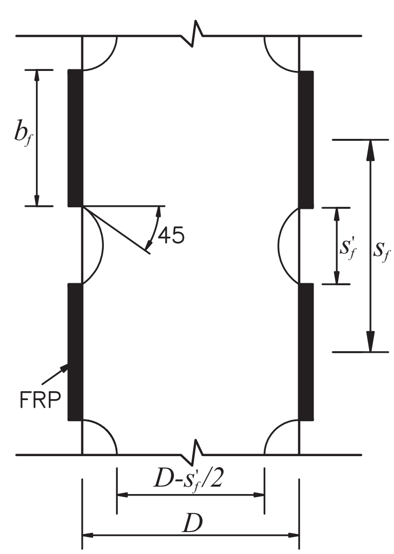

Fig. 2. Partially FRP-confined square column.