Construction and Building Materials 168 (2018) 153–168

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Investigation on the behaviour of partial wrapping in comparison with full wrapping of square RC columns under different loading conditions

Anh Duc Mai, M. Neaz Sheikh, Muhammad N.S. Hadi *

School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia

HIGHLIGHTS

- The behaviour of partially and fully CFRP wrapped RC columns is investigated.
- Influence of axial load eccentricities on CFRP wrapped RC columns is investigated.
- Partial and full CFRP wrapping increased the performance of RC columns.
- Axial-load bending moment interactions of CFRP wrapped RC column are presented.

ARTICLE INFO

Article history:
Received 26 September 2017
Received in revised form 30 January 2018
Accepted 1 February 2018

Keywords:
Square columns
Carbon fibre
Partial wrapping
Full wrapping
Concentric axial load
Eccentric axial load
Flexural load
Ductility

ABSTRACT

This study investigates the behaviour of square reinforced concrete (RC) columns partially and fully wrapped with CFRP under different loading conditions. The experimental results of twelve specimens with 150 mm × 150 mm cross-section and 800 mm height tested under concentric axial load, eccentric axial loads and four-point bending are presented in this study. The experimental results showed that partial and full wrapping increased the strength and ductility of square RC column specimens. The increase in the strength and ductility of fully wrapped square RC column specimens was higher than the increase in the strength and ductility of partially wrapped square RC column specimens under all loading conditions. However, the increase in the axial load eccentricity (concentric, 25 mm eccentric and 50 mm eccentric axial loads) resulted in a significant decrease in the maximum axial load with the largest reduction observed for fully wrapped specimens compared to partially wrapped specimens. The experimental axial load-bending moment interaction diagrams showed the better performance of partially and fully CFRP wrapped square RC specimens compared to non-wrapped square RC specimens.

1. Introduction

Strengthening of existing deficient structural members has become a critical issue for the construction industry due to the deterioration of the structures under severe environmental conditions, increase in the load demand and the change of the structural functions [1–3]. Fibre Reinforced Polymers (FRPs) have emerged as efficient materials for strengthening deficient structural members during the past few decades. The FRP has been widely used due to its superior engineering properties including high tensile strength and stiffness, high strength-to-weight ratio, and high corrosion resistance [1,2,4–7].

Transverse wrapping of concrete columns with FRP inhibits the lateral expansion of concrete leading to substantial enhancements in the strength and ductility of the columns [5,8–14]. Most of the available research studies investigated the performance of fully FRP wrapped columns [5,8,10,15–22]. However, only a few studies investigated the behaviour of partially FRP wrapped cylinders and prisms [23–27] and RC columns [28–40]. It was reported that partial FRP wrapping improved the strength and ductility of the RC columns [28–38]. Partial wrapping has some practical advantages compared to full wrapping. Partial wrapping can prevent the formation of possible air-voids between the FRP and the concrete surface [24]. It is cost-effective because less FRP and adhesive are required [36] and easy and fast to construct on site [24]. Partial wrapping is also an efficient way to repair the deteriorated RC columns [41]. Partial wrapping could be an efficient and economical choice for RC columns which are in need of a moderate increase in the strength and ductility. However, ACI 440.2R-17 [2] has not yet provided guidelines for the partial wrapping in strengthening compression members due to inadequate research on the partial wrapping of RC columns. Hence, the behaviour of partially FRP wrapped RC columns needs to be extensively investigated.

* Corresponding author.
E-mail addresses: mad766@uowmail.edu.au (A.D. Mai), msheikh@uow.edu.au (M.N. Sheikh), mhadi@uow.edu.au (M.N.S. Hadi).

https://doi.org/10.1016/j.conbuildmat.2018.02.003
0950-0618/

In practice, RC columns are subjected to combined axial compression and bending moments. The bending moment may be induced due to the position of the columns in the structure, out of straightness of the constructed columns, and unintentional eccentric axial loads [42]. The increase in axial load eccentricity leads to a reduction in the FRP confined area of the columns. Consequently, the confinement effect is less for eccentrically loaded RC columns than for concentrically loaded RC columns [5,9,18,19,21,32,40,43–46].

The effectiveness of FRP confinement is influenced by the cross-sectional shape of the columns. The FRP confinement effect is much lower for non-circular cross-sections than for circular cross-sections [1,3,47–55]. This is because the confinement pressure is non-uniform across the non-circular cross-section compared to the uniform confinement pressure across the circular cross-section. The behaviour of partially FRP wrapped square RC columns was only investigated in a limited number of studies [29–34,36,40]. These studies examined the performance of partially FRP wrapped square RC columns under either pure axial load [36,40] or eccentric axial loads [29–31] or seismic loads [34]. Only a few studies investigated partially FRP wrapped square RC columns under both concentric and eccentric axial loads [32,33]. It is noted that the partially CFRP wrapped square RC specimens investigated in Saljoughian and Mostofinejad [32,33] had the corner radii of 8 mm, which is significantly lower than the corner radius recommended in ACI 440.2R-17 [2] of 13 mm and in FIB bulletin 14 [56] of 20 mm. In addition, the available studies on the partial wrapping of square RC columns did not adequately compare the behaviour of partially FRP wrapped square RC column with the behaviour of fully FRP wrapped square RC columns. However, Barros and Ferreira [23], Pham, et al. [25] and Campione, et al. [27] experimentally investigated the behaviour of partially FRP wrapped concrete cylinders with the behaviour of fully FRP wrapped concrete cylinders under axial compression. The experimental results indicated that the increase in the compressive strength of partially wrapped concrete cylinders was lower than the increase in the compressive strength of fully wrapped concrete cylinders. However, partial wrapping resulted in a higher compressive strength and axial deformation compared to non-wrapped specimens [23,25]. Therefore, for a better understanding of the strength and ductility enhancement of partial wrapping, the behaviour of partially FRP wrapped square RC columns should be extensively studied and compared with the behaviour of fully FRP wrapped square RC columns.

It is evident from the above literature review that the behaviour of partially FRP wrapped square RC columns under concentric and eccentric axial loads have not been adequately investigated. Therefore, the aim of this study is to experimentally investigate the performance of partially CFRP wrapped square RC columns under different loading conditions in comparison with fully CFRP wrapped square RC columns. The main parameters investigated in this study included wrapping schemes (non-wrapping, partial wrapping and full wrapping) and the magnitude of load eccentricity (concentric axial load, eccentric axial loads, and four-point bending). Theoretical investigation on the performance of partially CFRP wrapped square RC columns is considered beyond the scope of the paper.

2. Experimental program

2.1. Design of specimens

The test matrix consisted of 12 square RC specimens of 150 mm × 150 mm cross-section and 800 mm height. The specimens were divided into three groups including reference group (Group R), partial wrapping group (Group P), and full wrapping group (Group F). Each group included four specimens. The first three specimens were tested as columns under concentric axial load, 15 mm eccentric axial load and 25 mm eccentric axial load. The last specimen of each group was tested as a beam under four-point bending. The beam specimens were flexural dominant. The dimension of the specimens was chosen to simulate the short columns according to ACI 318-11 [57] and to fit the capacity of the available testing facility in the Structural Engineering Laboratory of the University of Wollongong, Australia. According to ACI 318-11 [57], the concrete columns are defined as vertical members, which are used primarily to carry compressive axial load, with the ratio of height-to-least lateral dimension greater than 3. In this study, the ratio of the height-to-least lateral dimension of the tested specimens was 5.3. The influence of the size of column specimens was considered beyond the scope of the paper.

The specimens of Group R were considered as reference RC specimens without any wrapping. The specimens of Group P were partially wrapped with three layers of CFRP strips. The width and clear spacing of the CFRP strips were chosen to be the same as the width of the CFRP strip commonly used in the available experimental studies in the literature [23,31–34,58]. The CFRP strips had the width and clear spacing of 60 mm. One CFRP strip was located at the mid-height of the specimens in order to avoid the failure at the mid-height, which was reported as the principal failure location for partially FRP wrapped RC columns [29,32,33,40]. The specimens of Group F were fully wrapped with three layers of CFRP. The amount of CFRP used for specimens of Group F (1,437,440 mm^2 per specimen (length × width × number of layer) was 1.6 times of the amount of CFRP used for Group P specimens (898,400 mm^2 per specimen (length × width × number of layer)).

The notations of the specimens consist of two parts. The first part represents the name of the group and the second part represents the loading conditions of the tested specimens. In the first part of the specimen notation, the letters R, P, and F refer to the reference group, partial wrapping group and full wrapping group, respectively. The second part of the specimen notation is either the numbers 0, 15, 25 or the letter B in which 0 refers to concentric axial load, 15 refers to 15 mm eccentric axial load, 25 refers to 25 mm eccentric axial load, and B refers to four-point bending. For example, Specimen P-25 is partially wrapped with three layers of CFRP and subjected to 25 mm eccentric axial load. Specimen F-B is fully wrapped with three layers of CFRP and subjected to four-point bending.

Each specimen was reinforced longitudinally with 4 N12 bars (12 mm diameter deformed steel bars) and transversely with R6 bars (6 mm diameter plain steel bars) at 80 mm centre-to-centre spacing. The steel reinforcement of the specimens was chosen based on the available studies to represent deficient columns [3,5,20,21,26,32,33,41]. The concrete cover at the ends and at the sides of the specimens was 20 mm. The four corners of CFRP wrapped specimens were rounded to 20 mm radius over the length of the specimen to obtain higher confinement effect of CFRP wrapping [51,56]. The corner radius of 20 mm was chosen based on the recommendations in ACI 440.2R-17 [2] and FIB Bulletin 14 [56]. It is noted that the four corners of the reference specimens were also rounded to 20 mm radius, as the ends of the reference specimens were wrapped with CFRP to avoid premature failure due to stress concentration at the ends during testing [20,43]. The details of the geometry and the reinforcement of the specimens are presented in Fig. 1. Table 1 presents the configuration of tested specimens.

2.2. Specimen preparation

All steel cages were manufactured at the Structural Engineering Laboratory of the University of Wollongong, Australia. The steel