Construction and Building Materials 172 (2018) 717–727

Contents lists available at ScienceDirect

Construction and Building Materials

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

Axial and flexural behaviour of circular reinforced concrete columns strengthened with reactive powder concrete jacket and fibre reinforced polymer wrapping

Muhammad N.S. Hadi *, Atheer H.M. Algburi, M. Neaz Sheikh, Allister T. Carrigan

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

HIGHLIGHTS

- A new strengthening technique for circular RC columns is presented.
- The technique consists of jacketing RC columns with RPC and wrapping with FRP.
- Jacketing with RPC increased the yield and ultimate loads of circular RC columns.
- FRP wrapping of jacketed columns increased the ductility and energy absorption capacity.

ARTICLE INFO

Article history:
Received 11 December 2017
Received in revised form 20 March 2018
Accepted 21 March 2018

Keywords:
Concrete columns
Reactive powder concrete
FRP
Jacketing
Wrapping

ABSTRACT

This paper investigates axial and flexural behaviour of circular reinforced concrete (RC) columns strengthened with reactive powder concrete (RPC) jacket and fibre reinforced polymer wrapping. The experimental results of 16 circular RC column specimens have been presented. The specimens were divided into four groups of four specimens. Column specimens of the first group were the reference RC specimens without any strengthening, specimens of the second group were strengthened by wrapping with two layers of carbon fibre reinforced polymer (CFRP), specimens of the third group were jacketed with a 25 mm thick layer of RPC and specimens of the fourth group were jacketed with a 25 mm thick layer of RPC then wrapped with a single layer of CFRP. Test results demonstrated that jacketing with a thin layer of the RPC enhanced significantly the ultimate axial and flexural loads as well as energy absorption of circular RC column specimens. Wrapping the RPC jacketed specimens with CFRP improved the ultimate axial load, ductility and energy absorption of the specimens.

1. Introduction

Reinforced concrete (RC) columns in buildings, highway bridges and other infrastructure may need to be strengthened in some cases. These cases include deterioration due to corrosion of steel reinforcement, damage after an earthquake event, inadequate design, functional changes and construction errors. Deficient RC columns have to be repaired before strengthening [1]. Jacketing is one of the most practical techniques used for restoring deficient RC columns [2]. The traditional reinforced concrete jacket probably no longer remains an effective jacketing technique as it is associated with several disadvantages including decrease in the available space of the strengthened structure, a significant increase of the dead load, slow construction process and practical problems for the required dowelling with the existing column as well as with the slab and foundation [1,3,4].

The other commonly used jackets for increasing the axial strength of RC columns are steel and fibre reinforced polymer (FRP) jackets [5]. Steel jacket has the problem of low corrosion resistance [6]. Hence, FRP is considered as one of the most suitable jacketing materials for strengthening RC columns. The FRP has a higher strength to weight ratio and superior durability compared to steel [7]. Wrapping RC columns with FRP increases the strength and ductility of the RC columns. However, FRP wrapping cannot be applied directly for strengthening a deteriorated RC column unless the surface of the RC column is suitably repaired. Also, the

* Corresponding author.
E-mail addresses: mhadi@uow.edu.au (M.N.S. Hadi), ahmag930@uowmail.edu.au (A.H.M. Algburi), msheikh@uow.edu.au (M.N. Sheikh), atc277@uowmail.edu.au (A.T. Carrigan).

https://doi.org/10.1016/j.conbuildmat.2018.03.196
0950-0618/

reliability of FRP wrapping decreases under freezing, thawing and temperature changes [8].

Similar to steel jacket, FRP jacket depends mainly on the principle of the lateral confinement pressure [6]. The efficiency of the confinement decreases when a column is subjected to an eccentric axial load [9–11]. Also, the confinement effect decreases when the diameter of the cylindrical concrete specimens increases [12]. Thus, several layers of FRP are required if only FRP wrapping is used for the strengthening of large diameter RC columns. Increasing the FRP layers is not only expensive but also causes bond failure [8]. Moreover, only slight improvement in the yield strength and flexural capacity of the RC column can be achieved by the FRP wrapping [13].

Reactive powder concrete (RPC) is a high performance concrete with high strength and high ductility [14]. The RPC has a dense structure, which is formed mainly by cement, silica fume, fine aggregate, water and superplasticizer. Steel fibre is usually used to improve the ductility of the RPC. The absence of the coarse aggregate in the RPC matrix is the main difference between the RPC and the other types of concrete. The high strength of the RPC reduces the required reinforcement and cross-sectional dimensions for the RPC structural members compared to the conventional RC members [15]. Lee et al. [16] and Chang et al. [17] proposed using the RPC as a durable strengthening and repairing material. Lee et al. [16] and Chang et al. [17] used the RPC to strengthen cylinder and prism specimens exposed to hazardous conditions to increase the compressive and flexural strength of the specimens.

Even though RPC has a superior compressive strength compared to other types of concrete, studies on the use of RPC in the columns are still very limited. Malik and Foster [18] however, conducted an experimental study on circular RPC column specimens wrapped with carbon fibre reinforced polymer (CFRP). The study reported that the axial strength of the CFRP confined RPC column specimen was 19% higher than the axial strength of unconfined column specimen. Also, Huynh et al. [19] examined the behaviour of square RC specimens constructed of high strength concrete (HSC) and RPC under three-point bending. The test results indicated that the partial replacement of the HSC by the RPC enhanced the strength and energy absorption capacity of the tested specimens. However, strengthening of RC columns with RPC jacket has not been investigated yet. This study proposes using RPC jacket for strengthening existing deficient circular RC columns.

The objective of this study is to develop an effective strengthening technique with RPC jacket and FRP wrapping for the existing deficient circular RC columns. The experimental investigation results of circular RC column specimens strengthened with a thin layer of RPC jacket and wrapped with FRP tested under different loading conditions have been presented. The loading conditions included concentric axial load, eccentric axial loads and four-point bending. The innovating strengthening technique of using RPC jacket and FRP wrapping has been found to be effective in increasing the yield load, ultimate load and energy absorption capacity of existing deficient circular RC columns.

2. Experimental program

2.1. Test matrix

The experimental program of this study included preparing and testing of 16 RC column specimens. These specimens were divided into four groups of four specimens based on the adopted strengthening technique. All base specimens (assumed to be existing columns) had a diameter of 150 mm with a height of 800 mm. Each base specimen was reinforced longitudinally with 6N10 (6 deformed steel bars of 10 mm diameter) and transversely with R6 (smooth steel bar of 6 mm diameter) helices at a centre to centre spacing of 50 mm. A clear concrete cover of 15 mm was provided at the sides and at the top and bottom of the specimen. All base specimens were cast with normal strength concrete (NSC) having a target compressive strength of 25 MPa. The NSC was supplied by a local company. The first group was the reference RC base specimens without any strengthening and was identified as Group C specimens. Specimens of the second group were wrapped with two layers of CFRP and were identified as Group CF specimens. The specimens of the third group were strengthened with a 25 mm thick RPC jacket and were identified as Group CJ specimens. The thickness of 25 mm was chosen for RPC jacket because the thickness of 25 mm was considered as the minimum practical thickness of the RPC jacket for the ease of cast and compaction. The specimens of the last group were strengthened with a 25 mm thick RPC jacket then wrapped with a single layer of CFRP. The specimens of the last group were identified as Group CJF specimens. The plan views of the reference and the strengthened specimens are shown in Fig. 1. From each group, one specimen was tested under concentric axial load, two specimens were tested under 15 mm and 25 mm eccentric axial loads, respectively, and the remaining specimen was tested under four-point bending. To identify the loading condition, a number or a letter were added to the labels of the specimens. The first part of each specimen label refers to the group name and the second part refers to the loading condition. For instance, Specimen CF-25 refers to the specimen that was wrapped with two layers of CFRP and tested under 25 mm eccentric axial load. Specimen CJ-B was jacketed with 25 mm thick RPC and tested under four-point bending. The details of the specimens are presented in Table 1.

2.2. Preparation of RPC

Typical RPC mix usually includes cement, silica fume, fine sand, superplasticizer, water and steel fibre. General Purpose cement (Type GP) according to AS 3972-2010 [20] was used to prepare the RPC. Densified silica fume was used as a supplementary cementitious material. The silica fume was produced in SIMCOA silicon plant, Western Australia [21], and was supplied by Australasian (iron & steel) Slag Association [22]. The sand used for the RPC was washed fine river sand with particle size ranging between 150 μm and 600 μm. Master Glenium SKY 8700 used as

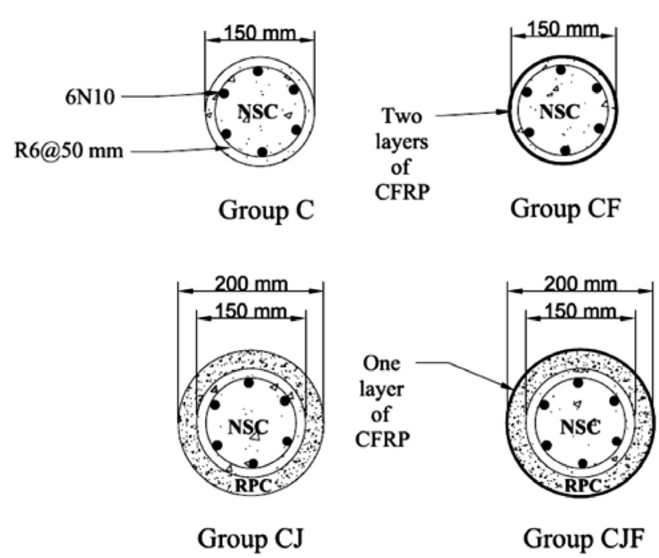

Fig. 1. Plan view of the reference and the strengthened specimens.