Available online at www.sciencedirect.com
ScienceDirect
Cement & Concrete Composites 29 (2007) 609–615
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Behaviour of reinforced concrete rectangular columns strengthened using GFRP

R. Kumutha [a,*], R. Vaidyanathan [a], M.S. Palanichamy [b]

[a] Department of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi-626 005, TN, India
[b] Vice-Chancellor, TamilNadu Open University, Chennai, TN, India

Received 30 October 2005; received in revised form 15 March 2007; accepted 21 March 2007
Available online 18 April 2007

Abstract

Rectangular columns are often used in bridge pier design, and they make up the majority of building columns. Columns in need of strengthening and retrofit are very common. This paper presents results of a comprehensive experimental investigation on the behavior of axially loaded rectangular columns that have been strengthened with glass fibre reinforced polymer (GFRP) wrap. This paper is intended to examine several aspects related to the use of glass FRP fabrics for strengthening rectangular columns subjected to axial compression. The objectives of the study are as follows: (1) to evaluate the effectiveness of external GFRP strengthening for rectangular Concrete Columns (2) to evaluate the effect of number of GFRP layers on the ultimate load and ductility of confined concrete and (3) to evaluate the effect of the aspect ratio of the column on the effectively confined cross-section. To cover a wide range of cross-sectional dimension ratios, three aspect ratios (a/b, where a and b are, respectively, the longer and shorter sides of the cross-section) were studied: $a/b = 1.0$, $a/b = 1.25$, and $a/b = 1.66$. Specimens with zero, one, and two layers of GFRP wrap were investigated. Totally nine specimens were subjected to axial compression which includes three control specimens. All the test specimens were loaded to failure in axial compression and the behavior of the specimens in the axial and transverse directions was investigated.

Keywords: Glass fibre reinforced polymer; Wrap; Ultimate load; Ductility; Aspect ratio; Confined

1. Introduction

In recent years, the use of externally bonded fibre-reinforced polymers (FRP) has become increasingly popular for civil infrastructure applications, including wrapping of concrete columns. Significant research has been devoted to circular columns retrofitted with FRP and numerous models were proposed. Shahawy et al. [1] verified a confinement model which was originally developed for concrete filled glass FRP tubes by conducting axial compression tests on a total of 45 carbon – wrapped concrete stubs of two batches of normal and high strength concrete and five different number of wraps. It was concluded that, the wrap significantly enhanced the strength and ductility of concrete by curtailing its lateral dilation and the adhesive bond between concrete and the wrap would not significantly affect the confinement behaviour [1]. The performance of concrete columns externally wrapped with aramid fibre reinforced polymer composite sheets has been studied by Toutanji and Deng [2]. Concrete cylinders confined with AFRP composite sheets were tested in axial compression and their stress–strain response was determined. It has been found that, the confinement with AFRP composite sheets constrains the lateral strain, producing a tri-axial stress field in concrete, which results in improving the compressive strength, maximum strain and ductility. Also the performance of the wrapped concrete specimens subjected to severe environmental conditions such as wet–dry and

* Corresponding author. Tel.: +91 4562 235222; fax: +91 4562 235111.
E-mail address: kumuthar@yahoo.co.in (R. Kumutha).

0958-9465/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconcomp.2007.03.009

freeze–thaw cycles was investigated by them. Results show that specimens wrapped with aramid fibre experienced no reduction in strength due to wet–dry exposure, but some reduction was observed due to freeze–thaw exposure.

The behavior of FRP wrapped concrete cylinders with different wrapping materials and bonding dimensions has been studied by Lau and Zhou using finite element (FEM) and analytical methods [3]. It was found that, the load carrying capacity of the wrapped concrete structure is governed by the mechanical properties such as modulus and Poisson's ratio, of the wrapping sheet. An analytical equation was provided to estimate the shear stress distribution of an adhesive material for different wrapping geometries. A study on the compressive behaviour and strength of elliptical concrete specimens wrapped with CFRP has been described by Teng and Lam [4]. From the study it was found that, the axial compressive strength of FRP confined concrete in elliptical specimens is controlled by the amount of confining FRP and the major to minor axis length ratio a/b of the column section. The confining FRP becomes increasingly less effective as the section becomes more elliptical but substantial strength gains from FRP confinement can still be achieved even for strongly elliptical sections. The ultimate axial strain of the confined concrete was also shown to increase as the FRP confinement becomes larger. Based on the test results, a simple compressive strength model for FRP confined concrete in elliptical columns was proposed, in which the effect of the section shape is taken into account by a shape factor.

The confinement model describing the behaviour of rectangular concrete columns retrofitted with externally bonded fiber-reinforced polymer material and subjected to axial stress was presented by Omar Chaallal et al. [5]. The derivation of the proposed model was based on the findings of an extensive experimental investigation involving the testing of 90 rectangular specimens representing three cross-sectional aspect ratios, two concrete strengths and five different numbers of FRP layers. It was found that the stiffness of the applied FRP jacket is the key parameter in the design of external jacket retrofits. In a study by Toutanji [6], tests were performed to evaluate the durability performance of concrete columns confined with fibre reinforced polymer composite sheets. The influence of wet/dry exposure using salt water on the strength and ductility of FRP wrapped concrete columns was evaluated. It was found that confinement of concrete cylinders with FRP sheets improves the compressive strength and ductility and the improvement in strength and ductility is dependent on the type of FRP composite sheets. The technique of wrapping thin, flexible high strength fiber composite straps around the columns for seismic strengthening, to improve the confinement and thereby its ductility and strength has been presented by Saadhatmanesh et al. [7]. Analytical models that quantify the strength and ductility of concrete columns externally confined by means of high strength fibre composite straps were presented. The results indicate that the strength and ductility of concrete columns can be significantly increased by wrapping high strength fibre composite wraps around the columns.

Thus, FRP wrapping of circular columns has proven to be an effective retrofitting technique. In contrast very limited data have been reported on rectangular columns retrofitted with FRP wrap, even though rectangular columns in need of retrofit are very common. The objective of the present paper is to study the behaviour of reinforced concrete rectangular columns with three different aspect ratios strengthened with externally applied GFRP jackets and subjected to axial compressive loading.

1.1. Research significance

The use of externally bonded FRP composite for strengthening and repair can be a cost-effective alternative for restoring or upgrading the performance of existing concrete columns. Even though a lot of research has been directed towards circular columns, relatively less work has been performed on square and rectangular columns, to examine the effects of external confinement on the structural performance. However, the vast majority of all columns in buildings are rectangular columns. Therefore their strength and rehabilitation need to be given attention to preserve the integrity of building infrastructure. This paper is directed towards this endeavor.

2. Experimental programme

2.1. Parameters of study

The following parameters were considered in this experimental investigation:

(a) The aspect ratio of the cross-section: To cover a wide range of cross-sectional dimension ratios, three aspect ratios (a/b where a and b are, respectively the longer and the shorter sides of the cross-section) were studied: $a/b = 1$, $a/b = 1.25$, and $a/b = 1.66$.
(b) The number of GFRP layers: Specimens with zero, one and two layers of GFRP wrap were investigated.

2.2. Materials

Ordinary locally available Portland cement having a specific gravity of 3.15 was made use of, in the casting of the specimens. Locally available river sand having a fineness modulus of 2.54, and a specific gravity of 2.62 was used. Crushed granite coarse aggregate of 20 mm maximum size having a fineness modulus of 7.94 and specific gravity of 2.94 was used. Water conforming to the requirements of water for concreting and curing as per IS: 456–2000 was used through out. The average standard 28-days