Composite Structures 94 (2012) 851–864

Contents lists available at SciVerse ScienceDirect

Composite Structures

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

Seismic strengthening of shear critical post-heated circular concrete columns wrapped with FRP composite jackets

C.G. Bailey [a,*], M. Yaqub [b]

[a] Faculty of Engineering and Physical Sciences, The University of Manchester, UK
[b] University of Engineering & Technology, Taxila, Pakistan

ARTICLE INFO

Article history:
Available online 8 October 2011

Keywords:
Columns
Heat
FRP
Cyclic load

ABSTRACT

An experimental study was carried out to investigate the seismic performance of post-heated circular reinforced concrete columns wrapped with glass or carbon fibre reinforced polymer jackets. Eight shear critical reinforced circular columns with a shear span-to-depth ratio of 2.5 were tested under a combined constant axial and cyclic lateral displacement history, simulating earthquake loading. The columns were tested in three groups, unheated, post-heated and post-heated repaired with either glass fibre reinforced polymer (GFRP) or carbon fibre reinforced polymer (CFRP). In terms of seismic performance the test results indicated that using GFRP or CFRP jackets significantly increased the shear capacity, ductility and energy dissipation of the post-heated damaged columns. However, the GFRP or CFRP did not increase the stiffness of the post-heated damaged columns. It was found that the unheated and post-heated damaged columns failed in a brittle shear mode while the mode of failure of posted-heated columns repaired with GFRP or CFRP was successfully shifted from a shear to a ductile flexural failure.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

In terms of accidental or malicious fire damage, experience has highlighted that fires in concrete structures rarely result in overall collapse and most fire damaged concrete structures can be reinstated successfully. Therefore, it is generally more preferable and economical to reinstate fire damaged buildings rather than to completely demolish and rebuild. Following the repair of a fire damaged concrete structure the safety of the structure to withstand any earthquake loading, if constructed within a seismic zone, must be determined. In earthquakes, reinforced columns within concrete structures are subjected to lateral cyclic loads with coexisting axial loads. The two main modes of failure are flexural and shear. It has been previously shown that columns with small cross-sections and large shear span-to-depth ratios experience large deformations due to the yielding of the main reinforcement and fail in a ductile flexural mode. For columns with small shear span-to-depth ratios, large cross-sections, low reinforcement ratios, and insufficient transverse reinforcement, brittle failure due to shear generally occurs [1,2].

Ideally, during design, brittle shear failure should be avoided and the geometry of the column should be such that failure is governed by flexure. However, in some cases this may not be possible and 'short columns' having small shear span-to-depth ratios, rather than 'longer columns', are required [1–4]. When a reinforced concrete column is subjected to seismic loading, its energy absorption capacity, rather than its load capacity, is the main concern [5]. Traditionally, the energy absorption capacity of columns can be increased, or a damaged column repaired, by using concrete or steel jacketing. However, the use of steel or concrete jacketing results in a significant increase in the column's stiffness, which may lead to additional earthquake forces within the column [5]. Additionally, concrete jacketing increases the cross-section size of the column and consequently the shear span-to-depth ratio will reduce, which could result in the dominate failure mode transferring from flexural to shear failure during a subsequent earthquake.

To overcome the problematic issues of traditional strengthening and repairing techniques, engineers are now looking to new materials to prolong and extend the service life of deteriorated or accidentally damaged concrete structures economically and effectively. The use of fibre reinforced polymer (FRP) has emerged as an attractive alternative to conventional strengthening measures for structures. Over the past few decades, there has been significant research conducted on structural retrofitting, strengthening, repairing and rehabilitation of reinforced concrete structures with FRP. For example, Sheib et al. [3], Promis et al. [6] and Harajli [7,8] investigated the effectiveness of various forms of FRP for the retrofitting of reinforced concrete columns. Chung et al. [9] examined the seismic ductility of formerly damaged reinforced concrete bridge piers using FRP. Whereas, Harajli and Khalil [10] investigated the effectiveness of FRPs for retrofitting reinforced concrete

* Corresponding author.
E-mail address: colin.bailey@manchester.ac.uk (C.G. Bailey).

0263-8223/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compstruct.2011.09.004

columns focusing on defined critical hinging regions. Saatcioglu et al. [11] investigated the seismic behaviour of both square and circular columns confined with FRP 'stay-in-place' formwork. Ozcan et al. [12] investigated the use of carbon FRP wrapping as a method of retrofitting non-ductile square reinforced concrete columns with low strength concrete and plain reinforcing bars. Colomb et al. [13] evaluated the seismic retrofit of reinforced concrete short columns wrapped with carbon FRP. Tastani and Pantazopoulou [14] explored the design issues and detailing rules for reinforced concrete members strengthened or repaired with FRP. Maaddawy [15] investigated the effectiveness of carbon FRP to upgrade corrosion-damaged eccentrically loaded reinforced concrete columns. Breña and Schlick [16] investigated bridge columns with inadequate reinforcement detailing consisting of short lap splices at the base and widely spaced transverse reinforcement rehabilitated with FRP. Shan et al. [17] investigated the residual performance of FRP retrofitted columns damaged after simulated seismic loading. Pantelides et al. [18] investigated the application of FRP in the retrofitting of concrete bridges and developed design specifications for carbon FRP composite column jackets. Ye et al. [19] investigated the seismic performance of reinforced concrete columns strengthened with carbon FRP. Ye et al. [20] also focused on the shear strength of reinforced concrete columns, strengthened with carbon FRP, tested under lateral reversal cyclic loading and a constant axial load. Xiao and Ma [21] conducted experimental and theoretical studies on seismic retrofitted reinforced concrete circular columns, with poor lap-splice details, using prefabricated composite jackets. Saadatmanesh et al. [22] investigated the flexural behaviour of earthquake-damaged reinforced concrete columns repaired with prefabricated FRP wraps. However, according to the authors' knowledge, there is currently no published research work on the repair of fire damaged concrete columns using FRPs, tested under seismic loading. It has been found that FRPs can perform adequately in subsequent fires provided suitable additional fire protection measures are applied to the FRPs [23–27]. Therefore it is important that the behaviour of this type of repair is thoroughly investigated to ensure that it can safely be used in seismic zones.

This paper reports on the experimental programme, conducted by the authors, covering fire damaged circular reinforced concrete columns strengthened with FRP. The columns had a shear span-to-depth ratio of 2.5 resulting in a dominate shear failure mode, tested under simulated seismic loading. The tests reported here allowed the effectiveness of FRP on the seismic shear behaviour of repaired fire damaged concrete columns to be assessed for the first time.

2. Experimental programme

Eight identical circular reinforced concrete columns were cast with gravel aggregate concrete and tested under a constant axial and reversal lateral cyclic loading in the Structural Engineering Laboratory, at the University of Manchester. Two columns were tested as unheated control specimens while two post-heated columns, which were heated to a uniform temperature of 500 °C, were tested as heat damaged control specimens. The remaining four post-heated columns were heated to a uniform temperature of 500 °C and, once cooled, wrapped with a single layer of unidirectional glass (two columns) or carbon (two columns) FRP with the main fibres of the FRP oriented in the transverse direction in all cases. The eight tests are summarised in Table 1. The 500 °C temperature was selected in this study since at this temperature normal strength, gravel aggregate, concrete has generally lost 50% of its compressive strength [28].

No definitive design method is currently available to determine the number of layers of FRP for the repair of fire damaged concrete circular columns. Current design recommendations are generally based on un-heated concrete. Under a given load, post-heated (fire damaged) concrete displays more strain than un-heated concrete resulting in the FRP jacket becoming 'more activated' when wrapped around a post-heated concrete compared to an un-heated column due to greater deformation in the post-heated concrete. Therefore, in this study no calculation for the repair design system was attempted to estimate the required number of CFRP or GFRP layers. Instead only one layer of CFRP or GFRP jacket was used in this study to investigate the effectiveness of the FRP for the repair of post-heated circular columns, enhancing the understanding in this area.

All the columns were 1000 mm long with 200 mm diameter and reinforced longitudinally with six 10 mm diameter deformed bars, providing a reinforcement ratio of 1.5%. One end of each longitudinal bar was threaded up to 40 mm in length in order to bolt the columns to a stiff steel plate base at the time of testing. All bars were evenly distributed in a circle with a cover of 30 mm to the main reinforcement. The link-bars were 6 mm diameter and spaced at 100 mm centres throughout the length of the columns. The link-bars were overlapped 60 mm at their ends without providing any hook or extension into the concrete core, as shown in Fig. 1. The columns were tested over a height of 425 mm from the centre of the pin where the cyclic loading was applied to the column footing. The test specimens were designed to fail by shear due to the small shear span-to-depth ratio (2.5).

The concrete mix comprised sand, gravel aggregate and ordinary Portland cement (OPC). The cement content, water content, fine and coarse aggregates used in the mix were 370 kg/m^3, 203.5 kg/m^3, 647.5 kg/m^3 and 1295 kg/m^3 respectively. The measured cube strengths (recorded at the time of testing) corresponding to each tested column, are shown in Table 1. In terms of the heated columns, the cube-strength measured consisted of both unheated and heated cubes, taken at the time of casting. The measured yield strength of the main reinforcing bars and link-bars was 553 MPa and 570 MPa respectively. Two types of

Table 1
Summary of tests showing maximum lateral loads and displacements in the pushing and pulling parts of loading.

Test no.	Test conditions	Compressive strength MPa (based on 100 mm cubes)		Drift ratio (%)	Maximum pushing lateral load (kN)	Maximum displacement in pushing (mm)	Maximum pulling lateral load (kN)	Maximum displacement in pulling (mm)
		Unheated	Post-heated					
1	Unheated	56	–	8 (1st cycle)	68.6	34	68.4	34
2	Unheated	57	–	8 (1st cycle)	72.7	30	62.7	34
3	Post-heated	52	25	7 (1st cycle)	46.2	30	42.3	30
4	Post-heated	53	25	7 (1st cycle)	52.2	30	46.4	30
5	Post-heated wrapped with GFRP	54	24	12 (1st cycle)	69.1	51	58.0	51
6	Post-heated wrapped with GFRP	53	24	12 (1st cycle)	68.4	51	66.1	51
7	Post-heated wrapped with CFRP	52	22	11 (1st cycle)	68.6	47	67.2	47
8	Post-heated wrapped with CFRP	53	22	11 (1st cycle)	69.9	47	68.0	47

Download English Version:

https://daneshyari.com/en/article/252314

Download Persian Version:

https://daneshyari.com/article/252314

Daneshyari.com