Construction and Building Materials 158 (2018) 624–639

Contents lists available at ScienceDirect

Construction and Building Materials

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

Seismic behaviour of steel-jacket retrofitted reinforced concrete columns with recycled aggregate concrete

An He [a], Jian Cai [a,b], Qing-Jun Chen [a,b,*], Xinpei Liu [c], Peizhou Huang [a], Xu-Lin Tang [a,d]

[a] School of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510640, PR China
[b] State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510640, PR China
[c] Centre for Infrastructure Engineering and Safety, The University of New South Wales, UNSW Sydney, 2052, Australia
[d] Guangzhou Jishi Construction Group Co. Ltd, Guangzhou 510115, PR China

HIGHLIGHTS

- Cyclic tests on steel-jacket retrofitted columns with RAC were undertaken.
- Variable Poisson's ratio of material was considered in the finite element model.
- The parametric study on the retrofitted columns was conducted.

ARTICLE INFO

Article history:
Received 21 June 2017
Received in revised form 9 October 2017
Accepted 10 October 2017

Keywords:
Steel jacket
Retrofit
Recycled aggregate concrete
Cyclic behaviour
Finite element model

ABSTRACT

This paper presents the experimental and numerical investigations on the seismic behaviour of steel-jacket retrofitted reinforced concrete (SJRRC) columns with recycled aggregate concrete (RAC). An unstrengthened reinforced concrete (RC) column and nine SJRRC columns tested under lateral cyclic loading are reported. The experimental results manifest that by using the steel-jacket retrofitting approach with RAC, the initial stiffness, ultimate strength, deformation ductility and energy dissipation ability of the columns are improved significantly. The peak strengths of the SJRRC columns are about 1.86–3.44 times of the counterpart of the original RC column. The retrofitted columns also show ductile post-peak load behaviour with the ductility coefficients ranging between 4.05 and 7.93. As the applied axial compressive loads increase, the failure mode of the SJRRC specimens is transited gradually from tension-controlled failure to compression-controlled failure. The specimens failed in compression-controlled mode exhibit plumper hysteresis curves, better energy dissipation ability, and higher secant stiffness than those failed in tension-controlled mode. The specimen having 100% recycled coarse aggregate replacement ratio has slightly lower lateral strength and secant stiffness than the specimens with 0% or 50% recycled coarse aggregate replacement ratio, and shows more serious pinching effect on its hysteresis curve. The effects of the preload and pre-damage of original column could be unfavourable on the cyclic performance of retrofitted column. The finite element analyses are also performed to further investigate the lateral behaviour of SJRRC columns. The proposed finite element model is validated by a comparison with the experimental results. By using the developed finite element model, parameter studies are undertaken and indicate that the applied axial compressive load and the thickness of steel jacket are the dominant factors affecting the lateral performance of SJRRC column.

1. Introduction

The reinforced concrete (RC) columns are substantial structural components in contemporary building infrastructures. However, most exiting RC columns built in 90's or even earlier in China could be damaged severely under earthquake loading due to the shortage and incompetency of the previous RC structures design code, which has been confirmed unfortunately during the 2008 Sichuan earthquake [1]. In order to resolve this crucial problem, developing advanced technologies for RC columns retrofitting are much needed nowadays. Among various developed RC columns retrofitting solutions viz. carbon fibre-reinforced polymer composite wrapping [2], concrete jacketing and steel jacketing [3,4], the steel jacketing method is usually the preferred one because of its high

* Corresponding author at: School of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510640, PR China.
E-mail address: qjchen@scut.edu.cn (Q.-J. Chen).

https://doi.org/10.1016/j.conbuildmat.2017.10.053
0950-0618/

retrofitting effectiveness and economic efficiency [5]. In this method, a common RC column is encased by a thin steel jacket. The gap between the steel tube and the original column is filled with the concrete or grout for integration purpose. The steel jacket plays a role as constraint to the core concrete. Several experimental studies have been reported showing the effectiveness of steel jacketing approach on improving the seismic performance of RC columns. Chai and Priestley [6–9] firstly applied the steel-jacket retrofitting method for bridge columns in California, and found great improvement on the lateral strength, shear strength, the resistance of lap splice and the ductility of the columns after being retrofitted by circle and ellipse steel jacket. The effectiveness of steel jacket retrofitted bridge columns was also tested under shake-table excitation [10]. Aboutaha [11] investigated the effectiveness of the rectangular solid steel jackets and partial steel jackets. Xiao [12,13] described the influence of partially stiffened steel jacket and prefabricated composite jacket on enhancing the strength and ductility of the RC column. Some other types of steel jacket sections such as corrugated steel jacket [14] and octagonal steel jacket [15] have also been proposed and evaluated. Recently, Choi [16,17] introduced a new steel-jacketing method by applying lateral pressure to attach steel jacket on the surface of original columns. The retrofitted columns were tested under a combination of axial and lateral loadings and the applicability of the proposed method were assessed. It could be summarised that the seismic performance of the steel-jacket retrofitted columns were enhanced significantly compared with that of the original column.

In general, normal fine aggregate concrete or grout is adopted as padding filling the gap between the original column and steel jacket for integrity propose. In recent years, the recycled aggregate concrete (RAC) in which the natural coarse aggregates are partially or entirely substituted by the recycled coarse aggregates has received increasing attention in academic research and industrial application, and has been extensively studied. Accordingly, a solution of steel-jacket retrofitting with RAC was proposed [18], in which the RAC replaces the normal fine aggregate concrete or grout as the padding material. The typical cross-sections of the steel-jacket retrofitted columns with RAC are shown in Fig. 1. The application of this method not only can serve the principal purpose for infrastructure retrofitting to avoid reconstruction, but also takes full advantage of using RAC which can reduce carbon dioxide emission. Experimental studies have illustrated that using the steel-jacket retrofitting approach with RAC could improve significantly the strength, stiffness and ductility of the RC column under axial compression. However, the seismic performance of steel-jacket retrofitted column with RAC has not been studied yet.

Many researches have been undertaken on the seismic behaviour of RAC structural members. It was illustrated that the RAC might be unfavourable to be used for the structural members under seismic loading compared with the use of normal aggregate concrete. Yang [19] studied the cyclic performances of RAC-filled steel tubular columns and found that both the load carrying capacities and sectional flexural stiffness of the RAC-filled steel tubular columns were quite comparable to those of the normal concrete filled steel tubular columns. Wu [20,21] proposed the use of demolished concrete with distinctly larger coarse aggregate sizes and investigated the cyclic behaviour of the thin-walled steel tubular columns filled with demolished concrete lumps or demolished concrete segments. They mentioned the minor reduction on the lateral strength of the column compared with the counterpart of the normal concrete filled steel tube column. Xiao [22] performed experimental tests on a cast-in situ normal aggregate concrete column and a cast-in situ RAC column as well as four semi-precast RAC columns under cyclic horizontal loading. It was concluded that the semi-precast RAC columns had similar seismic behaviour as the fully cast-in situ columns. Ma [23,24] processed the tests on steel reinforced RAC column under cyclic loading. The test results showed that the seismic performance of the columns decreased slightly as the RCA replacement percentage increases. Shi [25,26] firstly proposed a new construction material called geopolymeric recycled concrete (GRC) and tested the structural properties of GRC filled steel tube (GRCFST). It was found that with the increasing of the recycled aggregate replacement ratio, the ultimate strength of GRCFST was reduced while the peak strain and the ductility of the columns were improved. Tang [27] conducted low cyclic loading tests on nine seamless steel tube columns filled with RAC and found the RAC-filled steel tube columns had appreciably better lateral bearing capacity and ductility, but slightly lower energy dissipation ability, than the normal concrete filled steel tube columns.

The object of the current paper is to present a comprehensive study on the cyclic behaviour of steel-jacket retrofitted reinforced concrete (SJRRC) columns with RAC. The effects of the steel tube thickness, recycled coarse aggregate replacement ratios, axial compressive load, the preload and pre-damage conditions are considered in this paper. Physical tests on ten columns are reported and the experimental results are discussed. A finite element model verified by comparing its results against the experimental results is also implemented and extended for further investigation.

2. Experimental program

2.1. Test specimens

Nine reinforced concrete (RC) columns with strong base ends were fabricated. The cross section of the RC columns is 200 mm × 200 mm, as Fig. 2 shows. The SJRRC columns were fabricated based on the RC columns. The diameters of steel jackets D and the effective heights of all SJRRC columns were the same as 320 mm and 1320 mm respectively. The variables among the SJRRC columns included the thickness of steel tube t, the replacement percentage of recycled coarse aggregate η, the axial compressive load applied on the column N_0, the preload on original RC column N_{pre} and the damage condition of original RC column. Details of the specimens are shown in Table 1.

Among the specimens, the unstrengthened RC column C0 was chosen as the control sample. Specimen C8 is the SJRRC specimen with pre-damage. After the cyclic loading testing on Specimen C0, the damaged C0 specimen was retrofitted by steel-jacket and RAC, and re-named as Specimen C8. Specimen C9 is the SJRRC specimen with preload. The preload was applied on Specimen C9 by using the post-tensioned prestressing construction technique as shown in Fig. 3. The original RC column of Specimen C9 was firstly

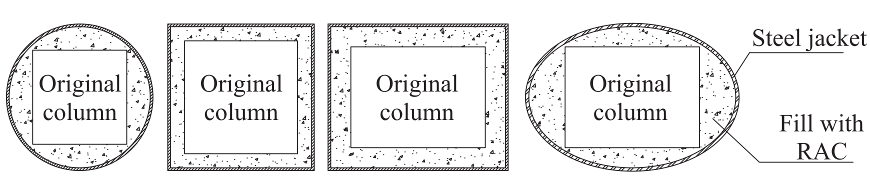

Fig. 1. Various cross-sections of steel-jacket retrofitted columns with RAC.