Construction and Building Materials 131 (2017) 438–448

Contents lists available at ScienceDirect

Construction and Building Materials

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

Impact behavior of concrete columns confined by both GFRP tube and steel spiral reinforcement

Liang Huang [a], Xiaoxun Sun [a,b], Libo Yan [c,d,*], Bohumil Kasal [c,d]

[a] College of Civil Engineering, Hunan University, Changsha 410082, China
[b] Guangzhou Pearl River Foreign Investment Architectural Designing Institute Co. Ltd., Guangzhou 510060, China
[c] Centre for Light and Environmentally-Friendly Structures, Fraunhofer Wilhelm-Klauditz-Institut WKI, Bienroder Weg 54E, Braunschweig 38108, Germany
[d] Department of Organic and Wood-Based Construction Materials, Technical University of Braunschweig, Hopfengarten 20, 38102 Braunschweig, Germany

HIGHLIGHTS

- Axial impact behavior of FRP-SR-confined concrete was investigated.
- Effects of FRP thickness and steel ratio on the impact behavior were considered.
- Effects of impact mass, height and energy on the impact behavior were considered.

ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form 1 November 2016
Accepted 19 November 2016
Available online 25 November 2016

Keywords:
GFRP tube
Spiral reinforcement
Confinement
Impact loading
Dynamic behavior
Drop hammer

ABSTRACT

Previous studies showed that concrete column confined by both glass fiber reinforced polymer (GFRP) tube and inner steel spiral reinforcement (termed as GFRP-SR-confined concrete) is a hybrid structure exhibiting much better static structural performance (e.g. load carrying capacity and ductility) compared with concrete column filled GFRP tube (CFFT) or conventional concrete column with inner steel spiral reinforcement (SR). To date, very few studies have considered the dynamic behavior of this hybrid structure. This research reports an experimental study on the dynamic behavior of GFRP-SR-confined concrete columns under impact loadings using a drop-hammer with large capacities (i.e. impact height up to 6.42 m and weight of hammer up to 588 kg). The test variables considered include the different levels of impact energy and strain rate, GFRP tube thickness and volumetric ratio of SR. The impact behavior of this hybrid structure is also compared with the CFFT and conventional SR column counterparts. The test results indicate that the failure pattern of this hybrid structure is highly dependent on the level of impact energy. Increasing the tube thickness and SR volumetric ratio enhances the impact-resistant capabilities of the structure remarkably. In addition, the impact results are compared with the quasi-static compressive results of the GFRP-SR-confined concrete.

1. Introduction

Nowadays, composite columns are widely used in high-rise building, offshore structures and bridges due to their high strength-to-weight ratio and increased deformability [1–3]. Concrete filled FRP tube (CFFT) is one of the most common composite columns reported in the literature. In this system, the prefabricated FRP tubes serve as permanent formwork for fresh concrete and also provide confinement to the concrete as well as protect the concrete from outer aggressive environment [4–6]. The advantages of FRP composite materials are their light weight, high stiffness and strength and corrosive-resistance, which enable them to be an excellent alternative to conventional steel reinforcement [7–9]. However, because of the elastic tensile stress-strain behavior of FRP materials, normally the failure of CFFT is brittle and explosive [10–15], therefore, usually minimum transversal reinforcement is required within the confined concrete in the concrete structural design codes of CFFT [16–18].

For concrete filled tube composite columns, studies in literature have demonstrated that the structural performance of concrete members confined by both FRP and spiral steel reinforcement (SR) was superior to conventional reinforced concrete (RC) members under various static loading conditions [19–26]. In axial

* Corresponding author at: Department of Organic and Wood-Based Construction Materials, Technical University of Braunschweig, Hopfengarten 20, 38102 Braunschweig, Germany.
E-mail addresses: l.yan@tu-braunschweig.de, libo.yan@wki.fraunhofer.de (L. Yan).

http://dx.doi.org/10.1016/j.conbuildmat.2016.11.095
0950-0618/

compression, several stress-strain models have also been developed to predict the compressive behavior of concrete confined by both FRP and transverse steel reinforcement [27–31]. Except for concrete confined by FRP and transverse steel reinforcement composite columns, some researchers have also investigated the static behavior of concrete-filled steel tube (CFT) composite columns [32,33]. The study [32] had shown that the CFT column system has its own disadvantages, i.e. due to the fact that a steel tube is used as longitudinal reinforcement to resist axial force and moment, when steel tube yields under excessive longitudinal stresses, its transverse confinement (particularly in terms of stiffness) to the internal concrete is drastically reduced [33]. In addition, some authors [22,27,28,31–33] have also investigated a concrete filled FRP tube system where the inner steel reinforcement were embedded into the column longitudinal direction, as illustrated in Fig. 1(a). This system was proposed to have an enhanced seismic performance of the column when compared with conventional RC column. In this system, the tube of the column was not embedded into the beam or the footing. So, the direct transfer of the longitudinal stresses into the tube can be avoided as the outer tube was not subjected to any axial load along the longitudinal direction of the column. Furthermore, experimental observations have also indicated that the internal concrete always showed little sign of damage while the outer steel tubes exhibited local buckling in the impact experiments of CFT [33] and concrete confined by both FRP and steel tube [28], indicating that the high tensile properties of FRP were not fully utilized in those structures. Thus, a better configuration of concrete confined by both FRP and steel should be developed to make the confined concrete column possessing the merits of both FRP and steel materials.

On the basis of this, FRP tube and steel spiral (SR) confined concrete (termed as FRP-SR-confined concrete) was proposed in this study, as shown in Fig 1(b). In this system, the merits of both FRP and steel materials can be used with a high potential. In order to overcome the non-uniform pressure imposed by SR, a uniform equivalent steel tube that replaces the discrete steel spirals was introduced [34] like the conventional steel-confined concrete models, as displayed in Fig. 1(b). The following are several expected merits of the GFRP-SR-confined concrete system as compared with the conventional CFT and CFFT structures.

1. In a GFRP-SR-confined concrete system, the functions of the core concrete and the additional transverse reinforcement provided by FRP tube and equivalent spiral tube are separated, the former mainly resists longitudinal stresses caused by axial load whereas the additional reinforcement confine the transverse deformation of core concrete so as to obtain a more ‘pure’ three dimension pressure environment to concrete.
2. The equivalent spiral tube can effectively prevent the collapse of core concrete after the rupture of the FRP tube, thus improving its seismic performance with stable load carrying capacity and ductility.
3. In a conventional CFT column, in order to prevent the local buckling of the steel tube in the plastic hinge regions, a relatively thicker steel tube is required, and typically such thickness is provided throughout the length of the column. The secondary function of the through-tube is to resist shear in the middle portion of the column, and this can typically be achieved by adding longitudinal rebar in GFRP-SR-confined concrete, as which is a composite material. Thus it is expected that even with the addition of the longitudinal rebar for the potential hinge regions, the total amount of steel usage in a GFRP-SR-confined concrete column may be less than the identical CFT and CCFT column, and the corresponding efficiency of steel usage may be higher.

Studies related to GFRP-SR-confined concrete under high strain rate loading are rare in the literature. This study was conducted aimed to explore the dynamic performance of GFRP-SR-confined concrete under impact load, which is expected to be used as high-performance composite columns in construction of earthquake-resistant structures.

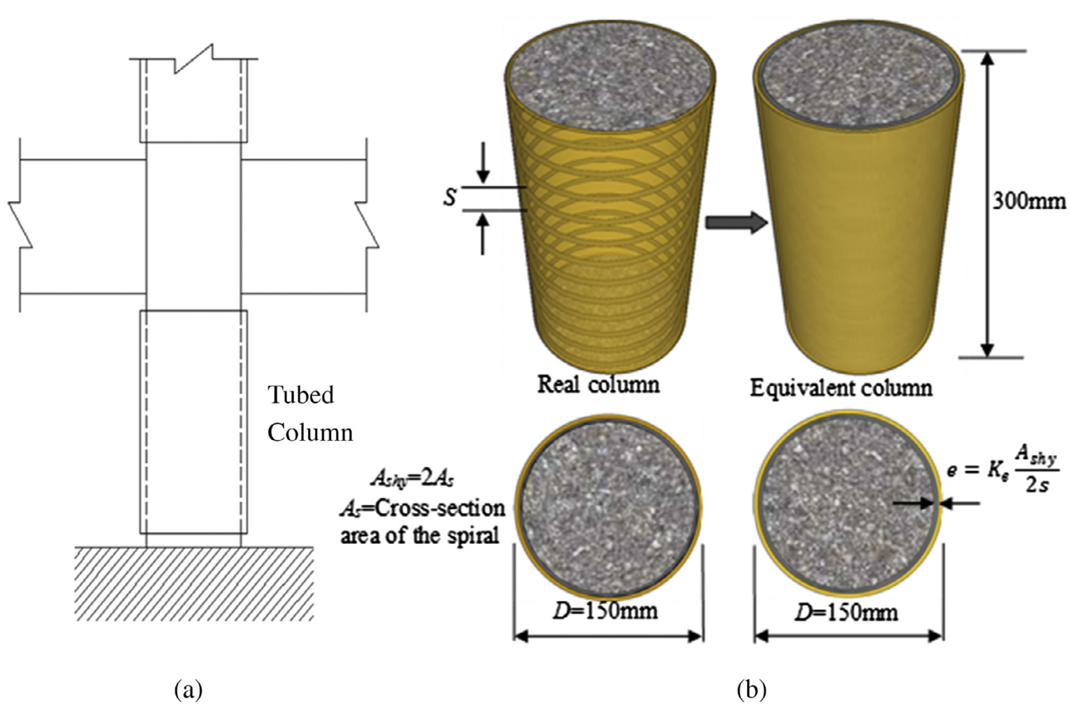

Fig. 1. (a) Tubed column and (b) equivalent steel-confined concrete column concept.