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Experimental research on concrete-filled RPC tubes under axial compression load

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ABSTRACT

An innovative composite column, named concrete-filled RPC (reactive powder concrete) tube (CFRPCT), is presented in the paper. In this hybrid system, high-strength spiral hoops are arranged in the prefabricated RPC tube and then concrete is poured in the RPC tube. Besides serving as formwork, the RPC tube can provide excellent stiffness and can directly carry considerable axial load attributed to its ultra-high compressive strength. Moreover, high-strength hoops in the RPC tube provide lateral confinement for the inner concrete. A total of 27 large-scale columns were tested under axial compression load, to investigate the composite effect between RPC tube and inner concrete. The results show that axial load carrying capacity of the CFRPCT columns is about 6.0% higher than the total capacity corresponding to the hoop-confined column and the hollow RPC tube. The CFRPCT system effectively combines the high strength of RPC and hoop confinement. Based on experimental findings and modified existing model, a confinement model was proposed to predict the axial load carrying capacity of CFRPCT columns and it was also validated with experimental results. This CFRPCT system provides a type of cement-based composite column, which owns high compressive performance, excellent durability and corrosion resistance.

1. Introduction

Structural columns based on composite effect, including concrete-filled steel tube (CFT) columns, fiber reinforced polymer (FRP) confined concrete columns and hoop-confined concrete (HCC) columns, are being more widely used in building and bridge constructions. Compared with the ordinary steel or the reinforced concrete system, these hybrid systems have many advantages due to their high-strength, stiffness, ductility and better seismic resistance.

For the CFT system, the filled-in concrete delays local buckling of steel tube and the tube also acts as a formwork for the inner concrete in construction. However, the load carrying capacity and the stiffness of CFT columns are reduced seriously when they exposure to fire because of the poor fire-resistant properties of steel tube [1,2]. Moreover, the CFT columns may also be subjected to chloride corrosion in offshore structures. The chloride corrosion has noticeable influence on the durability of steel tube and the composite effect of CFT columns [3,4]. These lead to high costs in the construction and the maintenance.

In past 30 years, FRP has become increasingly popular for retrofitting of existing concrete structures or reinforcing concrete due to its well-known advantages, including a high strength-to-weight ratio and excellent corrosion resistance compared with conventional CFT columns [5–7]. However, the disadvantages of FRP composite material include its sensitivity to high temperature [8,9], with the significant reduction of tensile strength and elastic modulus at elevated temperatures [10,11]. Therefore, the FRP-confined concrete system is not suitable for the high-temperature environment.

The HCC columns, especially in the form of spirals and circular hoops, show high strength and high ductility compared with the ordinary reinforced concrete columns [12,13]. But concrete cover of the hoops cracks and spalls before the peak load arrives. Consequently, the unconfined portion does not contribute to the load carrying capacity for the columns [13–15].

Reactive powder concrete (RPC) is a type of ultra-high performance concrete (UHPC), characterized by super-high compressive strength, extreme durability and high toughness. Through eliminating the coarse aggregates and reducing the water-to-cementitious material ratio, RPC realizes the ultra-high performance [16,17]. Nowadays, RPC is regarded as a promising material applied to extreme environmental conditions, such as in nuclear power, marine and military facilities [18,19].

Higher compressive strength and elastic modulus of RPC can lead to

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significantly smaller cross section for structural columns, as compared with conventional concrete. However, the existing cross section geometries for designing RPC column may be resulted in inefficient designs and less cost-effective solution considering the high cost of this material. For example, the axial load carrying capacity of RPC column with solid cross section is probably controlled by stability instead of material strength. In order to make full use of material strength, several types of RPC composite column have been presented with compression tests, recently. Zohrevand and Mirmiran [20,21] tested the compressive properties of UHPC confined by FRP and provided the stress-strain model. Yang and Zohrevand [22] conducted axial compression tests on UHPC confined by steel hoops. These investigations showed that the ultimate strength and strain of UHPC can increase obviously in the composite columns. Lohaus et al. [23] designed a type of UHPC-tube covered by thin steel sheets used as compressive strut for large-scale frameworks. The results of the UHPC-tubes showed a great scatter and the failure mode was the UHPC core crushed in local areas caused by steel sheet buckling similar to steel tube.

Based on the aforementioned discussions, it is necessary to develop new forms of structural components that appropriately and efficiently engage the excellent properties of RPC. A novel composite column, named as concrete-filled RPC tube (CFRPCT), is presented and axial compression tests are reported in this paper. In the proposed hybrid system, high-strength spiral hoops are arranged in the prefabricated RPC tube and then concrete is poured in the tube, as shown in Fig. 1.

The prefabricated RPC tube plays two important roles in the compressive properties of CFRPCT system. Firstly, excellent material properties including multiple cracking characteristics, spalling resistance and deformability make the RPC tube capable to maintain its integrity during loading, unlike the ordinary concrete cover in the HCC system. So the RPC tube can directly carry considerable axial force even under the peak load attributed to its super-high compressive strength. Secondly, high-strength hoops in the RPC tube provide lateral confinement to the concrete infill. The similar strengthening technique has been employed in the ferrocement pipes filled concreter columns [24]. However, the ferrocement pipe is only used as a confining component and cannot directly carry axial force in this composite column [25].

Moreover, similar to the steel tube for a CFT column, the RPC tube can be used as formwork for casting inner concrete and shoring support during construction. The CFRPCT system is economical compared with the CFT system considering the lower price of RPC in the hybrid section. The fire resistance and the corrosion resistance of CFRPCT columns are also much better than those of the CFT columns. Since both of the tube and the inner concrete belong to the cement-based material with the similar physical properties, once cast together, they can function as essentially a more uniform structural system.

2. Experimental program

2.1. Specimens and materials

The total of 27 specimens were divided into 9 groups, in which seven groups were the CFRPCT columns. Other two groups including the hollow RPC tubes and the hoop-confined concrete columns served as control specimens. Three identical specimens were prepared for each group to ensure repeatability of test results. All columns were 300 mm in outer diameter (D) and 600 mm in height (H), as shown in Fig. 1. In Table 1, specimens name as type (C, H and T) followed by spiral spacing (s)-wall thickness (t, only for the CFRPCT specimens) -batch, in which C, H and T denote CFRPCT, HCC and hollow RPC tube, respectively. For instance, C20-20-1 means this specimen is the No.1 CFRPCT column with spiral spacing of 20 mm and wall thickness of 20 mm.

For the CFRPCT specimen series, the spiral spacing in the RPC tube (s), and wall thickness of RPC tube (t) were selected as the two main testing parameters. The hoops were placed in the mid-thickness section ($t/2$) of the RPC tube. The spiral spacing increased from 20 mm to 100 mm, corresponding to the volumetric hoop ratio (ρ_s) decrease from 2.02% to 0.40%. The ρ_s is defined as ratio of the volume of spiral hoops to the volume of confined concrete core according to confinement model proposed by Mander et al. [13]. The wall thickness (t) varied among 15 mm, 20 mm and 25 mm, respectively. Two groups of control specimens were tested in order to investigate the composite effect between RPC tube and inner concrete. The spiral hoops and the concrete of H20, hoop-confined concrete columns, were consistent with the C20-20 except for the slight difference on the center-to-center diameter of spiral (d_s). In the H20 columns, the inside diameter of hoops was equal to the inner diameter of RPC tube (d_c) considering the necessary concrete cover for ordinary concrete column.

The raw materials of RPC used in prefabricated tubes were as follows: Grade 42.5 ordinary Portland cement (Chinese cement standard); silica fume with the specific surface area of 20500 m^2/kg; fly ash with the specific surface area of 615 m^2/kg; quartz sand mixed by maximum nominal sizes of and 0.2 mm and 0.4 mm with the ratio of 1:1; quartz powder with the specific surface area of 485 m^2/kg; polycarboxylate used as a superplasticiser; brass-coated steel fibers with length of 13 mm and diameter of 0.12 mm.

High-strength steel wire, with the yield strength of 1255 MPa and diameter of 6 mm, was chosen for the spiral hoops. The inner concrete

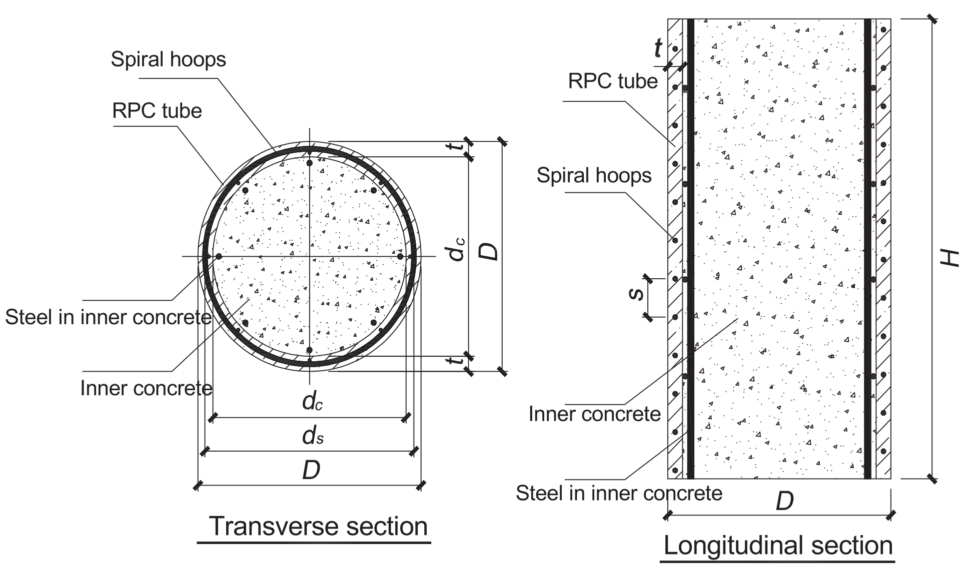

Fig. 1. Typical cross section of CFRPCT.