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Experimental study on seismic performance of partially precast steel reinforced concrete columns

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ABSTRACT

This paper aims to develop two kinds of innovative precast steel reinforced concrete columns, which are partially precast steel reinforced concrete (PPSRC) columns and hollow precast steel reinforced concrete (HPSRC) columns. Both the two kinds of composite columns have precast reactive powder concrete (RPC) shells, and the PPSRC column has a cast-in-place column core. In this paper, a series of cyclic loading tests on 10 column specimens subjected to combined static axial loading and cyclic lateral loading were carried out to explore their seismic performances. All specimens were evaluated by the failure modes, hysteresis characteristics, strength and stiffness degradation, energy dissipation capacity and ductility. The effects of section shape, stirrup spacing, axial compression and concrete strength of cast-in-place inner-part were investigated in details. The experiment results indicated that the PPSRC columns exhibited more satisfactory seismic behavior than the HPSRC columns in terms of hysteretic behavior, strength degradation, ductility and energy dissipation, while their bearing capacities were almost identical under low axial compression. Steel fibers could effectively prevent the cracked concrete from spalling, therefore, the encased steel shape was efficiently confined by the surrounding concrete during the entire test process. Higher stirrup ratio and lower axial compression of the column leaded to more satisfactory energy dissipation capacity, stiffness degradation and higher ductility. Based on the plastic stress theory, the seismic bending moment capacity analysis was conducted, and the results obtained form the formulas agreed well with those from the experiments.

1. Introduction

During the past few decades, steel-concrete composite structural systems have been widely used in constructing new buildings and retrofitting existing structures all over the world. This system combines the rigidity and formability of reinforced concrete members with the strength and convenience of construction associated with structural steel to produce an economic and robust structure [1–4]. As an important part of steel-concrete composite structures, steel reinforced concrete structures (SRCs), have been widely applied in marine, large-span and high-rise structures due to the high bearing capacity, great stiffness, great durability and outstanding ductility performance[5–7]. Nevertheless, cast-in-place SRC structures usually involve the construction procedures both of steel structures and concrete structures, therefore, the application of cast-in-place SRC structures has been limited in conventional buildings due to complex construction process. At the same period, applications of precast structures have increased because of the efficiency and high quality in construction, and it can also provide an advisable solution to the problem of wasted resources for on-site activities [8–10].

With the aim to facilitate the construction process of SRC structures, some researchers have suggested the combination of SRC members and precast concrete members. As a good example, the Fujita steel and reinforced precast concrete system has been adopted in Japan [10]. It indicates that the application of entire precast SRC members seems to be a solution to the problem aforementioned, however, the heavy deadweight and the vulnerable joint area could become new problems to the structure engineers. On the other hand, the builders must employ special large vehicles and cranes to lift the entire precast SRC members, which would directly increase the building cost.

As an alternative method to reduce the deadweight of precast SRC members, Hong et al. [11–14] proposed a new kind of partially precast steel reinforced concrete system and named it as MHS (modularized hybrid system). However, the optimal combination mode, section shape and the structural integrity in the partially precast SRC members must be further investigated for better structural capacity and constructability. Furthermore, the type and strength of concrete in the precast part and cast-in-place part should be altered to match different

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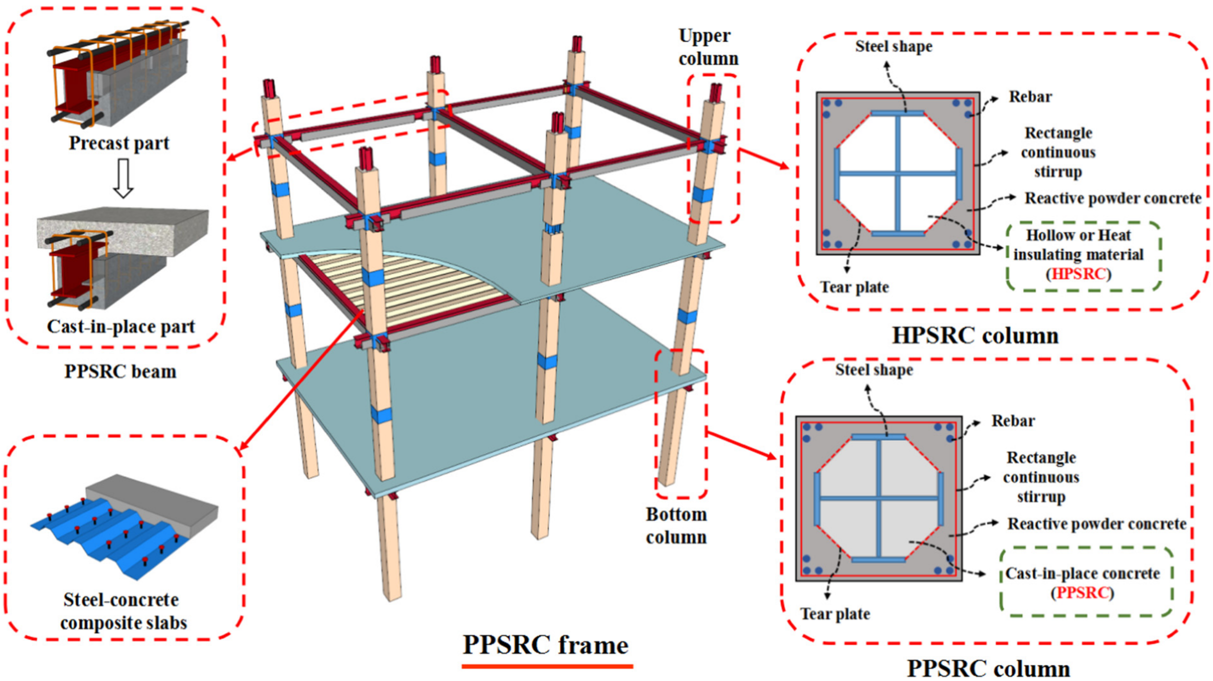

Fig. 1. Schematic diagram of the PPSRC column and HPSRC column.

purposes.

With the aim to promote the applications of SRC structures and solve the problems mentioned above, an innovative partially precast steel reinforced concrete structure system (PPSRC) was proposed by the authors, as illustrated in Fig. 1. The PPSRC frame structure is composed of PPSRC beams, PPSRC columns and PPSRC joint, and the mechanical performance of PPSRC beams has been thoroughly investigated in reference paper [15,16]. In this paper, two innovative partially precast SRC columns, which are partially precast steel reinforced concrete (PPSRC) columns and hollow precast steel reinforced concrete (HPSRC) columns, are presented here. In the PPSRC column, the precast outer-part, which is composed of a cruciform steel shape, high-performance concrete, continuous rectangle stirrups and longitudinal rebar, can be prefabricated in factory, and the cast-in-place inner-part can be cast by conventional strength concrete, lightweight aggregate concrete or recycled aggregate concrete on the construction site after the outer-part erected. For the HPSRC columns, the outer-part is the same as that of PPSRC columns, but the column core is kept hollow to further reduce the deadweight or can be filled with heat insulating material to enhance the anti-fire performance. Meanwhile, the HPSRC columns can be regarded as formwork of the inner-part of PPSRC columns.

With the aim to further improve the performance of precast outer-part, the reactive powder concrete (RPC) is applied here. As a kind of ultra-high performance concrete, reactive powder concrete has been widely studied due to some favorable characteristics, such as high durable and mechanical performance [17,18]. Especially, the steel fibers in RPC can significantly show down the crack growth in concrete [19]. Continuous rectangle stirrups are also adopted here to avoid the invalidation of stirrup hooks in severe earthquakes. For the inner-part, it can be cast by conventional strength concrete with the beam core of PPSRC beams and adjacent slabs at the same time to ensure strutural integrity of PPSRC structures and to save the expensive high-performance concrete.

As shown in Fig. 1, the PPSRC columns and HPSRC columns can be composite in a high-rise building vertically. For the columns in the ground floor, the PPSRC columns with inner concrete will meet the needs of great axial capacity and sufficient ductility under proper design, and for the columns in upper floors, the use of HPSRC columns with hollow core can efficiently reduce the deadweight of the entire building with the limited loss of rigidity. Meanwhile, the dimensions of the PPSRC and HPSRC columns can be unified along the building height to facilitate the conventional variable section design.

As an essential issue in composite members, the connecting and bonding behaviors should be emphasized [20,21]. Because there are two kinds of concrete in the same cross-section of PPSRC columns, it is necessary to examine the integrity of PPSRC columns under seismic loads, therefore, a series of cyclic loading tests on 10 column specimens subjected to combined static axial loading and cyclic lateral loading were carried out. The crack patterns, failure modes, hysteretic loops, skeleton curves, strength and stiffness degradation, energy dissipation capacity and ductility of the specimens were critically examined. The effects of section shape, stirrup spacing, axial compression and concrete strength of cast-in-place inner-part on the seismic performance of the specimens were also explored in details. Based on the experimental observations and test results, an analytic model for calculating seismic bending moment capacity is also presented later in this paper.

2. Experimental program

2.1. Test specimens

Ten column specimens were designed and constructed, including six PPSRC columns, and four HPSRC columns. The key parameters are summarized in Table 1. These ten specimens were similar in cross section shape and dimensions, except for the HPSRC columns with hollow cores. As shown in Fig. 2, the columns were 300 mm × 300 mm square in cross section, with a height of 900 mm from the point of lateral loading to the top of the stub. The specimens were designed to represent the structural columns of lower stories of high-rise structures and were designed at one second of full scale to match the capacity of the specimen with that of the test device. A reinforced concrete stub footing with a cross section of 500 mm by 550 mm was cast together with the specimen, representing a relative rigid foundation. The steel shape in all specimens was cruciform and weld by two HN175 × 90 × 5 × 8 steel of Q235 grade according to the Chinese standards. The total height and the width of the steel shape were 175 mm and 90 mm, respectively, and the thickness of the web and flange were 5 mm and 8 mm, respectively. As shown in Fig. 2, the steel