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Cyclic testing of thin-walled circular steel tubular columns filled with demolished concrete blocks and fresh concrete

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ABSTRACT

To simplify the waste concrete recycling process, the authors have proposed several new kinds of structural members containing demolished concrete with a distinctly larger size than conventional recycled aggregates. Previous researches and applications have preliminarily verified the suitability of these new environment-friendly structural members. The objective of the presented research is to provide new test data to study the seismic performance and to evaluate the strength and ductility of the thin-walled circular steel tubular column filled with demolished concrete blocks (DCBs) and fresh concrete (FC). Fifteen specimens, including 10 columns filled with DCBs and FC and 5 reference columns filled with FC alone, were tested under combined constant axial compression and reversed cyclic lateral loadings. Test variables are: replacement ratio of DCBs, thickness of steel tube, and axial load ratio. Based on the concept of combined strength of new and old concrete in steel tube, some design codes are employed to predict the lateral strength of the specimens. Research findings indicate that: (1) the seismic performance of thin-walled circular steel tubular columns filled with DCBs and FC is similar to that of the reference columns filled with FC alone; (2) the lateral strength of the columns filled with DCBs and FC is slightly lower than that of the reference columns filled with FC alone; and (3) even though the diameter-to-thickness ratio is only 168, the ultimate drift ratio of such a specimen filled with DCBs and FC with an axial load ratio of 0.4 can reach 4%, showing good deformation capacity.

1. Introduction

Ever-deteriorating environmental problems and natural resource depletion require sustainable development in many fields, including civil engineering. Waste concrete recycling, capable of contributing to the sustainable development, has a great potential to protect environment, to save natural resource, to build closed-loop material cycles, and to reduce the amount of solid waste dumped at landfill sites. The current interest in waste concrete recycling focuses primarily on the use of recycled aggregate in place of natural aggregate in production of new concrete. This recycled concrete material, usually called recycled aggregate concrete (RAC), has been extensively studied in terms of its material-level properties during the last half century, as documented by a rich literature [1–8]. In recent years, significant concerns have also been raised over the performance and suitability of structural members manufactured with RAC (including RAC slabs [9], beams [10,11], columns [12,13], beam-column joints [14], and frames [15]). The prime finding from these studies is that, generally, although the presence of RAC may impair the elastic stiffness and ultimate capacity of the structural members to some extent, the performances of RAC structural members with appropriate design are comparable to those of the companion members made of conventional concrete.

Concrete filled steel tubular (CFST) columns offer a number of advantages in both design and construction and have been used in a diversity of applications. The steel tube can be used as permanent formwork to provide well-distributed confinement to the concrete core, whereas the concrete core delays the local buckling and forces the steel tube to buckle outwards rather than inwards. In view of these advantages of CFST columns, Konno et al. [16,17], Yang and Han [18,19], and Liu et al. [20] conducted some studies on the recycled aggregate concrete filled steel tube (RACFST), in which the natural aggregates are partly or totally substituted with the recycled aggregates. Xiao et al. [21] also proposed the RAC members confined by steel tubes or glass fiber reinforced plastic tubes. These authors found that, in general, both the strength and deformation capacity of the RAC filled steel tubes are significantly improved due to the confinement effect. Meanwhile, the mechanical properties of the RACFST columns are generally similar or slightly inferior to those of the companion CFST columns. Yang et al. also investigated the seismic performance of circular RACFST

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columns [22], and they concluded that the cyclic behavior of RACFST columns under combined constant axial compression and cyclic lateral loadings are similar to that of the reference normal CFST columns, and the RACFST columns can also exhibit high ductility levels and fine energy dissipation abilities.

While the RAC provides an attractive choice of recycling demolished concrete, manufacturing quality RAC is often, however, costly and time-consuming, making it less economical and energy-saving in actual practice. To simplify the process of recycling demolished concrete, the authors have proposed several new kinds of environment-friendly structural elements in which the demolished concrete is allowed to be reused in a straightforward and simplified manner [23–26]. These proposed structural elements are formed by pouring a blend of fresh concrete (FC), and demolished concrete with a distinctly larger size than conventional recycled aggregates, into formwork or hollow steel sections. To avoid ambiguity and to distinguish in size and form from *recycled aggregates*, the terms *demolished concrete blocks* (DCBs) and *demolished concrete segments* (DCSs), rather than *crushed concrete* or *recycled coarse aggregates*, are used to represent such demolished concrete with a larger size for recycling. Because the hollow steel section can serve as formwork and reinforcement to the concrete core, the steel tubular columns filled with FC and DCBs (or DCSs) are more recommendable. In these new composite columns, the recycling and reusing of demolished concrete are promoted from an aggregate level (i.e., ≤ 40 mm) to a larger size level (e.g., 50–300 mm for DCBs and >500 mm in one direction for DCSs). Prior tests conducted by the authors have shown that the static mechanical properties, such as compressive strength, of these new composite columns are similar to or slightly lower than those of the counterpart steel tubular columns filled with FC alone. Recent applications also demonstrate that these green structural elements are especially suitable for on-site recycling of demolished concrete, and the concreting work is smooth-operating. The transporting of DCBs and FC can be conducted by means of wheelbarrows, material hoists, or crane-mounted buckets, depending on the scale of the concreting job and the accessibility of these composite columns. The DCBs and FC can be mixed roughly in the concrete container, and then the concrete mix is discharged in the steel tube with further vibrating. Fig. 1 illustrates an example of practical application of these new green composite columns in a real multistory building.

This research was undertaken to experimentally study the effect of the presence of the DCBs on the seismic performance of the thin-walled circular steel tubular columns filled with DCBs and FC, and to address the influence of the very thin steel tube on the strength and ductility of these new composite columns. Choosing the thin-walled steel tube in preference to the thick-walled one has two intentions: (a) to minimize the structural steel costs, making the steel ratio of the new composite column close to that of an ordinary RC column (often in a range of 0.6–5% [27]); and (b) from a research point of view, to highlight the possible detrimental effects, if any, caused by the existence of the DCBs. In the latter regard, the thin-walled steel tube, which provides less concrete confinement, is more helpful to examine such effects than the thick-walled one. Furthermore, heretofore, considerable researches have been devoted to the seismic behaviors of circular CFST columns with low or moderate diameter-to-thickness (D/t) ratios, as summarized by Shams and Saadeghvaziri [28], Hajjar [29], Shanmugam and Lakshmi [30], Han [31], and Gourley et al. [32]. However, only limited experimental studies that address the seismic behaviors of circular CFST columns with large D/t ratios (e.g., ≥ 100) are available. In this study, 10 thin-walled circular steel tubular columns filled with DCBs and FC, and 5 reference columns filled with FC alone were tested to failure under combined constant axial compression and lateral loading reversals. It is shown that using DCBs in the thin-walled circular steel tubular columns is feasible and dependable in seismic regions.

2. Experimental procedure

2.1. Specimen design and material properties

The experimental program consisted of 10 columns filled with DCBs and FC and 5 reference columns filled with FC alone (note that DCBs are often more readily obtained than DCSs, so only DCBs were used in the present tests). All these cantilever columns had the same external geometry with a diameter of 300 mm, and a test length of 1200 mm (measured from the lateral loading point to the upper surface of the RC stub footing). Details of the specimens are illustrated in Fig. 2. The specimen test variables were: (1) nominal thickness of steel tube: 2 (1.78) mm, 3 (2.76) mm and 6 (5.50) mm (the data in parentheses are the measured values); (2) nominal axial load ratio: 0.2 and 0.4; and (3) replacement ratio of DCBs: 0%, 25% and 40%. Here, the replacement ratio of DCBs denotes a ratio of the total weight of DCBs to the total weight of filled-in concrete. Based on the previous test procedures, 40% was considered the maximum acceptable replacement ratio of DCBs in view of concrete workability. The specimens are identified by

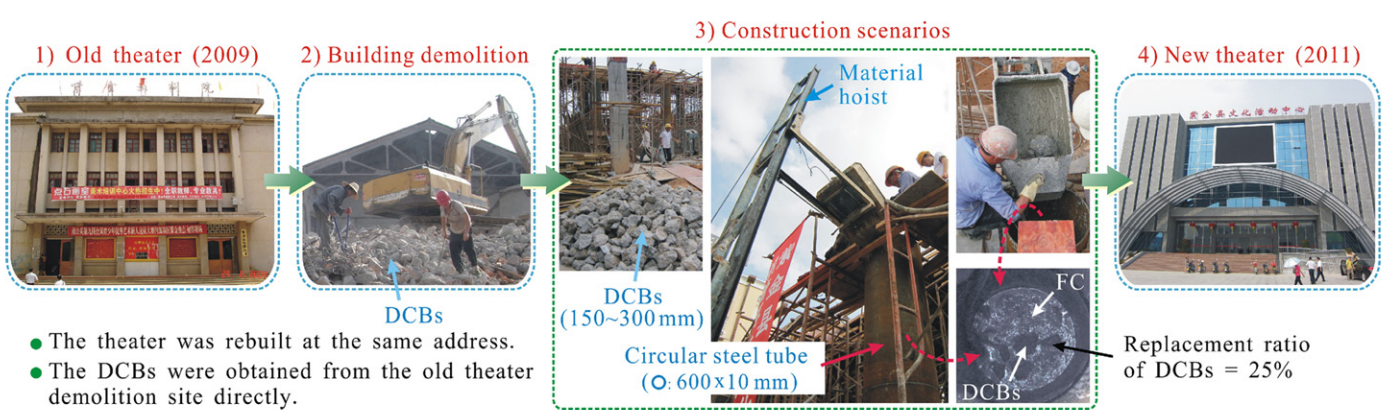

Fig. 1. Application of proposed green composite columns in a theater building in Guangdong, China. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)