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Creep behavior of thin-walled circular steel tubular columns filled with demolished concrete lumps and fresh concrete

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HIGHLIGHTS

- Creep tests conducted on 4 thin-walled CFST columns with compound concrete.
- Creep tests conducted on 6 cylinders with compound concrete.
- Modified Counto model proposed to predict creep of compound concrete in cylinders and CFST columns.
- Basic creep of the specimens are well predicted by the proposed model.

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ABSTRACT

Structural members containing large-scale (60–300 mm) demolished concrete lumps (DCLs), proposed previously by the authors, are new approaches for recycling demolished concrete to reduce the consumption of cement and the cost of labor during manufacturing of conventional small-scale recycled aggregates (≤31.5 mm) from existing buildings. The authors' previous researches focused on the short-term mechanical behaviors of thin-walled circular steel tubular columns with compound concrete (referred to as compound CFST columns). In this paper, study is extended to experimental and theoretical studies on the long-term creep behaviors of compound CFST columns (4 specimens) and their cylindrical core counterparts (6 specimens), in which the effect of DCL replacement ratio and axial compression ratio on their creep behaviors were considered. Test results show that: (1) the basic creep of cylindrical compound concrete specimens was greater than those of the cylindrical FC or demolished concrete specimens, but increased with the rise of DCL replacement ratio; (2) the compound CFST specimens had nearly identical creep behaviors with the CFST specimens with FC only; (3) the experimental elastic modulus and basic creep were over- and under-estimated, respectively, by the Counto model, a two-phase composite model that regards the DCL and FC as the aggregate and matrix phases, respectively. A modified Counto model that considers the effect of micro-cracks within the DCLs and the DCL replacement ratio is proposed to predict the basic creep of the compound concrete with and without circular tube. Effectiveness of this approach is validated by experiments finally.

1. Introduction

With the development of society, many aging concrete buildings have been demolished for the need of urban renewal, resulting in lots of waste concrete. Environmental benefit and conservation of natural resources have promoted recycling of the waste concrete in construction industry. Nowadays, waste concrete recycling mainly focuses on the use of recycled aggregate in place of new aggregate during the production of fresh concrete. Several studies have been conducted recently on mixture design [1], durability [2], mechanical properties [2–4] and structural behaviors [5] of recycled aggregate concrete (RAC). Although potential benefits of the RAC could be evident, several drawbacks of using RAC could still be observed in these prior researches. One of the main shortcomings should be the high labor costs and time-consuming procedures during manufacturing process of waste concrete fine crushing, screening and purification, making the RAC more expensive and higher energy consumption in actual practice.

To simplify the manufacturing process of recycling demolished concrete, a new compound concrete material using large-scale demolished concrete lumps (60–300 mm, referred to as DCLs), rather than conventional small-scale recycled aggregates

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(≤31.5 mm), with mixture of fresh concrete (FC), was proposed by Wu et al. [6–11]. Due to the larger scale of DCL compared with normal-sized recycled aggregates, application of the DCLs represents replacement of the concrete material level, but not the aggregate level for the traditional RAC. Since the coarse recycled aggregate (CRA) contains both the coarse aggregate and the surrounding mortar with comparable weight, direct application of the entire CRA for replacement of the coarse aggregates in normal concrete could lead to variation of the actual mixture proportion of the RAC (more mortar but less coarse aggregates). However, for compound concrete, the replacement ratio of DCLs represents the ratio between the weight of DCLs and the total weight of the compound concrete; therefore, such a replacement level does not have a significant influence on the mixture proportion of the final compound concrete if the fresh concrete and DCLs share the same design mixture proportion. As a result, the compound concrete and RAC cannot be seen as the same kind of recycled concrete material, and mechanical behaviors of the structural members made with the compound concrete need to be investigated even though many studies have been conducted on the RAC.

Previous experiences showed that it would be more convenient for application of such new compound concrete into circular steel tubes to obtain recycled concrete filled steel tubular (CFST) columns, due to absence of concrete cover, reinforcing bars and stirrups. A series of studies have been conducted by the authors to investigate the short-term compressive behaviors of cylindrical specimens [7,9] and thin-walled circular steel tubular columns with the new compound concrete [11]. Test results showed that the mechanical properties of these new recycled specimens were comparable to or slightly poorer than those filled with FC only [7,10,11]. As for the long term creep behavior, the outer tube of CFST would prevent the inner concrete from having significant creep effects due to the longitudinal friction between the tube and concrete. However, such an interaction would also cause stress redistribution between the concrete and steel tube, and as a result, gradually increase the axial force demand on the steel tube during the creep of inner concrete. This behavior would cause premature yielding and local buckling in the tube of CFST columns, and thus the creep behaviors of concrete in CFST columns became one of the concerned issues in the past [12–15]. Hence, in addition to the short-term behavior, the long-term creep behavior of the recycled CFST columns with the new compound concrete is also an important issue prior to applying these new columns into practice.

Different from cylindrical concrete specimens, the inner concrete of a CFST column is not exposed to outer air and thus drying shrinkage and drying creep can be ignored [12]. Thus, the stress-related basic creep behavior of the core compound concrete in the CFST column can be only concerned for this type of structural members. To eliminate the influence of outer steel tube, study on the basic creep behavior of the same cylindrical counterpart as the inner compound concrete in the CFST column is also necessary. Although the basic creep behaviors of cylindrical specimens and thin-walled circular steel tubular columns with the new compound concrete have not yet been reported, many experimental and theoretical investigations on the same issue of those filled with normal concrete (NC) or RAC have been conducted. Ranaivomanana et al. [16] carried out creep tests on two cylindrical NC specimens, with a size of Φ110 × 200 mm, an axial compression ratio of 0.5 and more than 200 sustaining days. They found that the basic creep strain kinetics of NC was initially very fast and decreased gradually, and it still remained significant even after 200 days of loading. Gómez-Soberón [17] conducted eight cylindrical RAC specimens with a size of Φ150×450 mm, an axial compression ratio of 0.35 and 90 sustaining days, considering different replacement ratio of recycled aggregates. It showed that the creep coefficients exhibited a direct correlation with the increase of replacement ratio of recycled aggregates. Luo et al. [18] performed tests on fifteen cylindrical specimens made of NC or RAC, with a size of Φ150 × 300 mm, an axial compression ratio of 0.4 and 150 sustaining days, considering different preparation methods, replacement ratio of the RAC and proportion of fly ash. It was found that the basic creep of RAC was significantly greater than NC and grew with the increase of replacement ratio of the RAC. Meanwhile, the basic creep behavior of RAC could be improved effectively by adding proper amount of fly ash. Rossi et al. [19] carried out tests on the basic creep of concrete by using acoustic emission technique, including four types of cylindrical NC specimens (Φ160 × 1000 mm, Φ130 × 50 mm, Φ160 × 320 mm, Φ110 × 160 mm) with axial compression ratios from 0.54 to 0.8 and 250 sustaining days. It was found that the basic creep strain was proportional to the total number of micro cracks in the material and grew with the increase of axial compression ratio. Obviously, research findings from these prior researches provided useful conclusions and research hints for this study.

This research aims to investigate the basic creep behaviors of compound concrete with and without outer tube. By eliminating the influence of steel tube, the basic creep behavior of cylindrical compound concrete specimens was first examined by long-term compressive loading, considering the effects of different axial compression ratios and DCL replacement ratios. Testing was further conducted to investigate the basic creep behavior of the compound concrete in the thin-walled circular steel tube to evaluate the additional influence of outer tube. To this end, ten cylindrical specimens (six with compound concrete, two with FC only, and two drilled from waste shear wall) and six CFST specimens (four with compound concrete, two with FC only) were tested under long-term sustained loads for 200 days. Theoretical study is then presented for prediction of the elastic modulus and basic creep of the compound concrete with and without circular tube.

2. Creep tests on cylindrical and thin-walled circular steel tubular columns with compound concrete

2.1. Specimens

Tables 1 and 2 show the parameters of the cylindrical and CFST specimens, respectively. The cylindrical specimens can be divided into two groups. The specimens are labeled by the notation CR#N#, where "C", "R" and "N" denotes cylinder, replacement ratio of DCLs, and axial compression ratio of the specimens, respectively. For example, "CR20N40" means that the cylindrical specimen with a DCL replacement ratio of 20% and an axial compression ratio of 0.4. Particularly, "CR100N#" and "CR0N#" denote the specimen with waste concrete only (drilled directly from waste shear wall) and fresh concrete only, respectively. The DCL replacement ratio can be determined by the ratio between the weight of in-filled DCLs and the total weight of a compound concrete specimen. Dimensions of the cylinders with 250 × 750 mm and 150 × 300 mm were designed, respectively, for each group. The Group 1 specimens were subjected to sustained axial compressive loads based on the designed axial compression ratios. These loads, however, were absent for the Group 2 specimens (control specimen) that were designed to obtain the deformation induced by the change of environmental temperature and the shrinkage of concrete only. By ensuring the same environmental temperature and moisture conditions, the stress-related basic creep of the cylindrical specimens can be obtained by subtracting the Group 2 specimen responses from the corresponding responses in the Group 1 specimens with the same other parameters. Note that cubic compressive strength of the compound concrete $f_{cu,com}$ is not obtained from material