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ORIGINAL ARTICLE

Stiffening of short small-size circular composite steel–concrete columns with shear connectors

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A R T I C L E   I N F O

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An experimental program was conducted to investigate the effect of shear connectors' distribution and method of load application on load–displacement relationship and behavior of thin-walled short concrete-filled steel tube (CFT) columns when subjected to axial load. The study focused on the compressive strength of the CFT columns and the efficiency of the shear stud in distribution of the load between the concrete core and steel tube. The study showed that the use of shear connectors enhanced slightly the axial capacity of CFT columns. It is also shown that shear connectors have a great effect on load distribution between the concrete and steel tubes.

Introduction

Concrete-filled steel tube (CFT) columns are widely used in the construction of high-rise buildings, bridges, subway platforms, and barriers. Use of CFT columns improves mechanical properties under static and cyclic loading including strength, ductility, stiffness and energy-absorption capacity. CFT columns combine the benefits of both steel tube and concrete core. The steel tube supports axial load, confines concrete core, and eliminates the need for permanent formwork. The concrete core sustains the axial load and prevents or delays local buckling of the steel tube**.** Because of the importance of CFT, they have been under extensive investigation for many years. In CFT columns, it is of great practical and economic interest to have mechanical shear connectors at the interface between the concrete core and the steel tube to achieve the composite action with the help of natural bond. It is believed that the bond strength has a significant effect on the behavior of the CFT column. Although numerous tests have been carried out within this area, there is still uncertainty about the effect of bond strength and the stress transfer is not well understood.

A survey of the available literature showed that very little research has been performed to investigate experimentally the behavior of small-size CFT using shear connectors when subjected to axial loading. An experimental study was performed by Schnider [1] to investigate the effect of the steel tube shape and wall thickness on the ultimate strength of short composite concrete-filled steel tube columns concentrically

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loaded. Confinement of the concrete core provided by the tube shape was also addressed. Various ratios of the depth-to-tube wall thickness and the length-to-tube depth ratios were investigated. The behavior of eccentrically loaded CFT columns was studied by Fujimoto et al. [2] through an experimental program containing sixty-five specimens. The aim was to investigate the effect of section shape, diameter-to-thickness ratio, and the combination of strengths on the flexural behavior of the steel tube and filled concrete. An experimental study containing several specimens composed of circular steel–concrete composite stub columns was performed by Johansson and Gylltoft [3]. The study indicated that the mechanical behavior of the column was greatly influenced by the method of load application to the column section. Sakino et al. [4] studied the behavior of centrally loaded concrete-filled short steel-tube columns to clarify the synergistic interaction between steel tube and filled concrete, and to derive methods to characterize the load–deformation relationship of CFT columns through an experimental program containing 114 specimens. The studied parameters included the following: tube tensile strength, tube diameter-to-thickness ratio and concrete strength. The flexural behavior of large CFT was investigated experimentally by Probst et al. [5] through four full-scale tests. Two beams were rectangular 12 in. wide and 18 in. deep and the other two were circular with a diameter of 18 in. The results showed that composite action is significantly improved by shear connectors only for circular CFT beams and that the AISC moment capacity prediction is not conservative for circular CFT beams without shear connectors. The strength and stiffness of CFTs were studied by Roeder et al. [6] when subjected to combined axial and flexural loadings through an experimental program. The results showed that current specifications provide inaccurate predictions of the flexural stiffness, and a new stiffness expression was proposed. The cyclic behavior of CFT was investigated through a series of experimental works presented by Hanswille et al. [7]. Based on the test results, an improved damage accumulation hypothesis considering load sequence effects and an analytical expression determining the cyclic deformation behavior of headed shear connectors were derived.

Shear connectors were tested by Shim et al. [8] to investigate the effects of group arrangement on the ultimate strength of stud shear connection. This study dealt with a group of shear studs connectors for precast decks. Push-out tests were conducted to evaluate the ultimate strength according to the expected failure modes. The main parameters studied were as follows: stud spacing, reinforcement details and stud diameter. Test results showed that current design provisions for the stud connectors can be used for the design of group stud shear connection when the design requirements on the minimum spacing of studs are satisfied and the splitting failure of concrete slab is prevented. Wang et al. [9] presented an experimental study on high strength large diameter stud shear connectors used in many composite structures, through twelve push-out tests. The comparison with formulas issued by design codes showed that these formulas are all conservative and can be used to calculate the shear resistance of studs with large diameter and high strength.

Several numerical attempts were also paid to investigate and study the CFT columns. Kuranovas and Kvedaras [10] showed that the behavior of hollow CFST elements is more complicated than that of solid ones due to complex stress states. Nonlinear analysis was conducted by Hsuan et al. [11] using finite element program ABAQUS to study the behavior of axially loaded CFT columns. It was shown that circular tubes can provide a good confining effect to the concrete compared to square ones. An analytical study aiming to calculate the mechanical behavior and ultimate strength of circular CFT columns subjected to axial compression loads was paid by Lu and Zhao [12]. The concrete confinement, which depends mainly on the ratio of the external diameter of the steel tube to the plate thickness, the yield stress of the steel tube and the unconfined compressive strength of the filled concrete, was empirically deduced. An analytical study was conducted by Choi and Xiao [13] to analyze the behavior of concrete-filled steel tubular (CFT) stub columns under axial compression and predict various modes of lateral interactions between steel tube and filled-in concrete under axial compression.

Most of previous experimental researches, conducted on circular composite columns, were performed to examine the effect of change of load application, strength of material, dimensions of columns. Little attention was paid for using shear studs with different arrangement and distribution especially with thin-walled columns. The aim of this research is to investigate experimentally the behavior of thin-walled short concrete-filled steel tubes under concentric compression with the presence of shear stud connectors. The effect of shear studs distribution on pipes ductility and axial buckling capacity was also studied. Different load application methods were investigated through the experimental program. A total of ten short stub cold-formed CFT columns using steel tube were tested. A detailed description of the test specimens, the experimental setup and instrumentation, is highlighted next.

Experimental

Test specimens

A series of nine circular hollow steel short columns sections filled with concrete were loaded to failure. The tests were conducted at the laboratory of the Housing and Building Research Center (HBRC) located in Dokki, Cairo, Egypt. All specimens consisted of a small part of a circular steel section fabricated from cold formed galvanized steel plates longitudinally welded with electric resistance welding. The outer diameter of pipes was chosen equal to 114.3 mm while the thickness was 4 mm. The chosen dimensions give a D/T ratio of 28 to avoid local buckling effect. Specimen height was taken 600 mm to be in the range of 3D < H < 20 r_y (where r_y is the minimal radius of gyration of the composite section) to avoid the overall buckling. Holes were drilled in the shell to allow fixation of the shear connectors. High strength bolts (10.9) with smooth shank were used as shear connectors with nominal diameter of 9.5 mm and a length of 134.3 mm. The bolt holes in the pipes were one mm oversized to facilitate erection adjustments. Test specimens are shown in Fig. 1a and the summary is listed in Table 1. The tests were divided into four groups I, II, III and IV. One steel specimen was tested unfilled and the other specimens were provided with shear connectors with different distribution. The studied parameters were the number and arrangement of the shear connectors. All other parameters such as column size, column height, shell thickness, connectors section, steel and concrete quality were not changed. The first