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Experimental investigation on concrete-filled stainless steel stiffened tubular stub columns

M.A. Dabaon, M.H. El-Boghdadi, M.F. Hassanein *

Department of Structural Engineering, Tanta University, Tanta, Egypt

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ABSTRACT

This paper presents an experimental investigation on concrete-filled normal-strength stainless steel stiffened tubular stub columns using the austenitic stainless steel grade EN 1.4301 (304). The stiffened stainless steel tubes were fabricated by welding four lipped angles or two lipped channels at the lips. Therefore, the stiffeners were formed at the mid-depth of the sections. In total, five hollow columns and ten concrete-filled columns were tested. The longitudinal stiffener of the column plate was formed to avoid shrinkage of the concrete and to behave as a continuous connector between the concrete core and the stainless steel tube. The behavior of the columns was investigated using two different nominal concrete cubic strengths of 30 and 60 MPa. A series of tests was performed to investigate the effects of cross-section shape and concrete strength on the behavior and strength of concrete-filled stainless steel stiffened tubular stub columns. The measured average overall depth-to-width ratios (aspect ratio) varied from 1.0 to 1.8. The depth-to-plate thickness ratio of the tube sections varied from 60 to 90. Different lengths of columns were selected to fix the length-to-depth ratio to a constant value of 3. The concrete-filled stiffened stainless steel tubular columns were subjected to uniform axial compression over the concrete core and the stainless steel tube to force the entire section to undergo the same deformations by blocking action. The column strengths, load–axial strain relationships and failure modes of the columns are presented. Several comparisons were made to evaluate the test results. The results of the experimental study showed that the design rules, as specified in the European specifications and the ASCE, are highly conservative for square and rectangular cold-formed concrete-filled normal-strength stainless steel stiffened stub columns.

1. Introduction

The general term "composite column" refers to any compression member in which a steel element acts compositely with a concrete element, so that both elements resist compressive force. There is a wide variety of composite columns of varying cross-section, but the most commonly used and studied types are encased I-section and concrete-filled steel tubes. In contrast to the encased composite column, the concrete-filled column has the advantage that it does not need any formwork or reinforcement. The concrete-filled column offers several advantages, related to its structural behaviour, over pure steel, reinforced concrete or encased composite column. The location of the steel and the concrete in the cross-section optimizes the strength and stiffness of the section. The steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moments. Also, the stiffness of the concrete-filled column is greatly enhanced because the steel is situated farthest from the centroid, where it makes the greatest contribution to the moment of inertia. The concrete forms an ideal core to withstand compressive loading and it delays and often prevents local buckling of the steel tube. The lateral confinement provided by the steel tube improves the strength, ductility and deformability of the concrete. The steel tube also prevents the spalling of concrete and minimizes the accumulation of reinforcement in connection zones. It can be said that a concrete-filled column delivers the economies of a concrete column with the speed of construction and the constructability of a steel column which results in significant economies in the overall structure of a building project [1].

In recent years, cold-formed stainless steel sections have been increasingly used in architectural and structural applications, e.g. curtain wall panels, roofing and siding, mullions, railings, columns, etc., due to their superior corrosion resistance, ease of maintenance, attractive appearance and high strength. However, there are limited test data on concrete-filled stainless steel tube columns.

The behaviour of stainless steel sections is different from that of carbon steel sections. Stainless steel sections have a

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* Corresponding author.
E-mail addresses: m_dabaon@yahoo.com (M.A. Dabaon), mhboghdadi@yahoo.com (M.H. El-Boghdadi), mostafa.fahmi@yahoo.com (M.F. Hassanein).

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rounded stress–strain curve with no yield plateau and have a low proportional limit stress compared to that of carbon steel sections.

Young and Ellobody [2] investigated experimentally concrete-filled cold-formed high-strength stainless steel tube columns. In this study, concentrically loaded rectangular hollow section columns were tested. The depth-to-plate thickness ratio of the tube sections varied from 25.7 for compact sections to 55.8 for relatively slender sections. Generally the local buckling failure mode of the high-strength stainless steel tubes was observed for specimens with relatively slender sections. A concrete crushing failure mode together with local buckling of the high-strength stainless steel tubes for specimens with compact sections was also observed.

However, no experimental test data were found in the literature on concrete-filled stainless steel stiffened tubular stub columns.

On the other hand, several methods were used for column stiffening. The first method is to use longitudinal stiffeners. The second method is to fill the cross-section of the column with concrete, which avoids the inward buckling of the stainless steel plates. The third one is to use the previous two methods together.

In this paper, an experimental series of tests to investigate the behaviour and strength of concrete-filled hollow-section stainless steel stiffened stub columns is reported. The principle aim was to improve the current knowledge of the mechanical behaviour of concrete-filled stainless steel stiffened stub columns, which would lead to a more efficient use of concrete with higher compressive strength. A series of tests was conducted on square and rectangular hollow-sections by using two different in-filled concrete strengths with no use of discrete mechanical shear connectors to improve the bond at the stainless steel interface or additional reinforcement besides the stainless steel tubes. The stiffened stainless steel tubular stub sections were fabricated by welding four lipped angles or two lipped channels at the lips. Therefore, the stiffeners were formed at the mid-depth of the sections. The longitudinal stiffener of the column plate was formed to avoid shrinkage of the concrete and to behave as a continuous connector between the concrete core and the stainless steel tube. The dimensions of the stainless steel tubes were chosen to include relatively slender sections [3].

2. Experimental program

2.1. Problem statement

The strength enhancement in excess of uniaxial strength and the deformation improvement of concrete can be observed when concrete is subjected to passive confinement. Common examples of passively confined concrete can be seen in unstiffened concrete-filled stainless steel tubular columns. Concrete-filled hollow-section stainless steel columns, with a high value of depth-to-thickness ratio, provide inadequate confinement for the concrete core due to the local buckling of the stainless steel tubes. On the other hand, concrete-filled hollow-section stainless steel columns with a small value of depth-to-thickness ratio provide remarkabley good confinement for the concrete core. In addition, stainless steel structural shapes are becoming increasingly complex as cold-forming techniques are advancing. This leads to the ability to generate several different stainless steel cross-section shapes; see Dabaon et al. [4]. Considering the stainless steel cross-sections, as shown in Fig. 1, the value of the lateral confining pressure of the stainless steel tube is expected to increase for those stiffened longitudinally. This means that the confinement of concrete will increase and affect the strength of concrete-filled hollow-section stainless steel columns. This idea encouraged the authors to experimentally investigate this type of stainless steel column. Accordingly, this paper presents the experimental results of concrete-filled stainless steel stiffened tubular stub columns. The work described in this paper is extended by the same authors in [5], where a comparative study between stiffened and unstiffened concrete-filled stainless steel tubular stub columns is conducted. In paper [5], further discussions, mainly concerning the confinement effect for both types of columns, are presented.

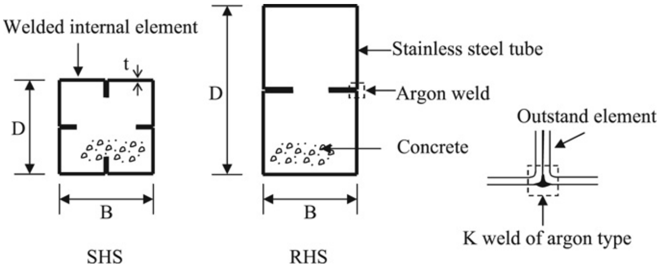

Fig. 1. Definition of symbols for concrete-filled stainless steel stiffened tubular stub columns.

2.2. Test specimens

Concrete-filled normal-strength tubes using square hollow sections (SHS) and rectangular hollow sections (RHS) were tested. The tubes were cold-formed from flat strips of stainless steel material. The stainless steel strips were all of constant thickness equal to 2 mm. Each test specimen was prepared from two or four parts welded together by argon welds, as presented in Fig. 1. The test program consisted of five test series, including two series of concrete-filled SHS tubes (SHS1 and SHS2) and three series of concrete-filled RHS tubes (RHS1, RHS2 and RHS3). Table 1 summarizes the dimensions of the specimens. The cross-section dimensions D and B are outside measurement. The lengths were chosen so that the length-to-depth ratio (L/D) generally remained at a constant value of 3 to prevent flexural buckling. The specimens were tested using nominal concrete cubic compressive strength of 30 and 60 MPa. The depth of the stiffeners was fixed at a constant value of 30 mm for all test specimens. The classification of cross-sections and the effective cross-sectional area of the test series are calculated according the EN 1993-1-4 [6] and the ASCE [7].

The concrete-filled stainless steel stiffened tube column test specimens are labelled such that the shape of stainless steel tube and concrete strength can be identified from the label. For example, the label "SHS1C30" defines the specimen with a square hollow section that belonged to test series SHS1, and the letter "C" indicates the concrete strength followed by its value in MPa (30 MPa). Five tests were conducted on stainless steel hollow stiffened tubular columns (without in-filled concrete) denoted by "C0" for each series.

2.3. Stainless steel properties

The austenitic stainless steel grade EN 1.4301 (304) was used in this experimental investigation. The properties of the stainless steel used for tube specimens were determined by tensile coupon tests. The stress–strain relationship obtained from tensile coupon tests reflected the average behaviour of the material through its thickness. For this reason, the tensile coupon test specimens were taken from the centre of the longitudinal direction of the flat portion of the cross-section depth from an untested rectangular specimen, where the stainless steel columns were formed using the same coil of stainless steel sheet, as shown in Fig. 2. It is important to note that the coupons were taken away from the longitudinal weld. Therefore, the bending residual stresses arising from cold-forming are included in the coupon results, while the welding residual stresses are not taken into account, as previously discussed by the same authors in [4].