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Experimental behaviour of high performance concrete-filled steel tubular columns

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Abstract

In recent years, the utilization of high performance concrete has been the interests of the structural engineers and researchers. As a high performance concrete, self-consolidating concrete (SCC) is a highly flowable concrete that can fill formwork without any mechanical vibration. SCC's unique property gives it significant economic, constructability and engineering advantages. The aim of this paper is thus an attempt to study the possibility of using thin-walled hollow structural steel (HSS) columns filled with very high strength SCC. Tests on 28 HSS columns filled with very high strength SCC were conducted, where the main parameters varied are: (1) section types, circular and square; (2) slenderness ratio, from 12 to 120; and (3) load eccentricity ratio, from 0 to 0.6. Comparisons are made with predicted column strengths using the existing codes such as AISC, EC4 and DBJ13-51-2003.

Keywords: Composite columns; Hollow sections; High performance concrete; Design; Bearing capacity

1. Introduction

It is well known that, hollow structural steel (HSS) sections filled with concrete can form a composite column. Such types of composite columns have the advantages of high bearing capacity and ductility, easy construction, high fire resistance and costing saving.

In the past, there were a large number of studies carried out on HSS columns filled with normal concrete [1–9]. These studies have contributed a lot to the development and revision of currently well-known design codes, such as ACI [10], AISC [11], EC4 [12] and DBJ13-51-2003 [13].

In recent years, the application of high performance concrete in buildings has been the interests of the structural engineers and researchers. As far as concrete-filled steel tubes are concerned, the use of self-consolidating concrete (SCC), which is a new generation of high performance concrete, is becoming increasingly popular in recent years [14–16]. SCC is a highly flowable concrete that can fill the tubes without any mechanical vibration, thus leading to significant economic, constructability and engineering advantages.

Han and Yao [14], Han et al. [15] and Lachemi et al. [16] have studied columns and beam-columns of HSS filled with SCC. The concrete cubic strength of their studies ranged from 50 to 90 MPa. It was found that, the behaviour of SCC filled steel tubular columns are generally similar to those of the composite columns while normal concrete was used. It seems that the conclusion regarding strength predictions using existing design codes developed for normal concrete-filled HSS columns remains valid for SCC filled HSS columns within the scope of tested concrete strength. However, there is still a lack of information on SCC filled steel tubular columns while the concrete strength is higher than 100 MPa.

This paper is an attempt to study the possibility of using thin-walled HSS columns filled with SCC, where concrete strength is higher than 100 MPa. Tests on 28 HSS columns filled with high performance concrete were conducted. The main parameters varied in the tests are: (1) section types, circular and square; (2) slenderness ratio; and (3) load eccentricity ratio. Comparisons are made with predicted column strengths using the existing codes such as AISC [11], EC4 [12] and DBJ13-51-2003 [13].

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Nomenclature

A_c	concrete cross-sectional area
A_s	steel cross-sectional area
D	sectional dimension, mm
e	load eccentricity, mm
e/r	load eccentricity ratio, $r = D/2$
E_c	concrete modulus of elasticity
E_s	steel modulus of elasticity
f_c'	characteristic compressive cylinder strength of concrete
f_{cu}	characteristic concrete cube strength
f_y	yield strength of steel
L	effective buckling length of column in the plane of bending, mm
N	axial load
N_u	ultimate strength of the composite columns
N_{uc}	predicted ultimate strength
N_{ue}	experimental ultimate strength
t	wall thickness of steel tube, mm
u_m	mid-height deflection of the column, mm
$\varepsilon_{A\max}$	extreme fibre strain at the mid-height of specimen corresponding to peak load
ε	strain
λ	slenderness ratio, given by $4L/D$ and $2\sqrt{3}L/D$ for column with circular section and square section, respectively.

2. Experimental program

Twenty-eight specimens, including eight stub columns and 20 beam-columns were tested. The main parameters varied in the tests are: (1) column section types, circular and square; (2) slenderness ratio λ, from 12 to 120; and (3) load eccentricity ratio e/r (e is load eccentricity, $r = D/2$, D is overall sectional dimension), from 0 to 0.6. The slenderness ratio λ is given by $4L/D$ or $2\sqrt{3}L/D$ for column with circular section or square section, respectively [15], where L is effective buckling length of column in the plane of bending.

All steel tubes were manufactured from mild steel sheet. Only one plate was cut from the sheet and rolled into a circular tube, while four plates were cut to be welded for each square tube. The prepared plates were tack welded into circular or square shape. A figure shown cross-sections of both circular and square tubes was presented in [14], which depicted specimens with sketch on the weld locations.

Tension tests on three coupons were conducted to measure material properties. The average yield strength (f_y) of the steel was found to be 404 MPa with a modulus of elasticity (E_s) of 207,000 MPa and an ultimate strain of about 0.3.

A kind of SCC mix was designed. The mix proportions were as follows: cement: 420 kg/m^3; blast furnace slag: 160 kg/m^3; water: 172 kg/m^3; sand: 757.5 kg/m^3; coarse aggregate: 925.5 kg/m^3; and additional high-range water reducer (HRWR): 5.88 kg/m^3.

L-box was used to measure rheological parameters of fresh concrete. The flow time from the sliding door to the front door of the L-box, the flow speed, as well as the flow distance of the SCC were recorded. The fresh properties of the SCC mixture were as follows: slump flow: 270 mm; unit weight: 2391 kg/m^3; flow speed: 19.3 mm/s; and flow distance: 600 mm.

In fabricating specimens, the ends of the steel tube sections were cut and machined to required length. One end of each tube was tack welded by a steel bottom plate with a thickness of 12 mm before filling the tube with concrete. The SCC was filled in layers without any vibration. In order to ensure the compaction of SCC, the maximum height of each layer was kept about 0.5 m, and the interval of filling was about 3 min for maximum air emitting from the concrete during the consolidation process. The specimens were placed upright to air-dry. All loose mortar was removed from the top surface of the hardened concrete after 3 days of curing. A high-strength epoxy was used to fill the longitudinal gap in 2 weeks so that the concrete surface was flush with the steel tube at the top. Three months later, the top surfaces of the composite columns were ground smooth and flat using a grinding wheel with diamond cutters. Another steel end plate with a thickness of 12 mm was then welded to the top of each of those specimens.

The fabricated specimens were left to cure in the laboratory environment at room temperature for about 6 months before testing. The average cube strength (f_{cu}) and modulus of elasticity (E_c) at the time of test was 121.6 and 42,600 MPa, respectively.

2.1. Stub-column tests

A total of eight stub columns, including four specimens with circular sections and four square ones, were tested. A summary of the specimens is presented in Table 1.

All specimens were designed to have a same width or diameter (D) of 100 mm, as well as a same tube thickness (t) of 1.9 mm. The length of stub columns (L) were chosen to be three times the diameter (for circular specimens) or the width (for square specimens) to avoid the effects of possibly overall buckling and end conditions [9]. Therefore, all four circular or square stub columns are duplicate. This was so designed to check the repeatability of the experimental work since the brittleness for very high strength concrete is more severe compared to normal-strength concrete.