Journal of Constructional Steel Research 67 (2011) 904–916

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

journal homepage: www.elsevier.com/locate/jcsr

Response of self-compacting concrete filled tubes under eccentric compression

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ARTICLE INFO

Article history:
Received 7 March 2010
Accepted 8 November 2010

Keywords:
SCC
Buckling
Concrete filled tube
Confined concrete

ABSTRACT

Self-Compacting Concrete (SCC) use is spreading worldwide and it is becoming a regular solution in some special applications, including steel–concrete composite columns. In the particular case of Concrete Filled Tubes (CFT), the main advantage from a practical point of view in the use of SCC consists in employing the steel tube as a formwork to directly cast concrete inside it, without the need of vibration. The study of three different concretes for structural applications as composite elements is presented, each of them designed for a 28-day cylindrical compressive strength of 50 MPa: (i) a Normal Vibrated Concrete, (ii) a Self-Compacting Concrete, (iii) an expansive SCC (with the goal of an increase in bond strength as a consequence of the expansion).

CFT with critical length ranging from 131 cm to 467 cm have been experimentally and analytically investigated in uniaxial compression. In each case the steel case presents a cross section of 139.6 mm of external diameter and 4.0 mm thickness and with a fixed eccentricity of the applied load equal to 25 mm. The bond strength at the steel–concrete interface is reported for each of the three mixes.

The experimental and analytical results show that the behavior of eccentrically loaded columns is governed by the bending moment–axial load interaction. As a consequence, perfect bond at the interface can be assumed and the axial capacity of the column is only a function of its geometry and of the mechanical properties of the materials.

A numerical procedure is proposed to evaluate the increase in the axial capacity of the composite columns consequent to the confinement of the internal concrete in case of zero-eccentricity of the applied axial load with respect to the column's axis.

Finally, the obtained numerical results are introduced into code provisions to evaluate modified axial force N-bending moment M interaction diagrams to predict the axial capacity of the column in the particular test configuration.

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1. Introduction

Self-Compacting Concrete (SCC) is drawing increasing interest because it allows casting of concrete without the need of trained personnel even in presence of a high congestion of the reinforcement.

The applications of SCC are becoming more and more common, although some issues concerning the material characterization, code specifications and quality control still remain unsolved.

In general, SCC is used for specific constructions or in precast plants.

In some cases, the choice of SCC instead of ordinary concrete depends on other factors besides the absence of vibration, such as dense reinforcement, novel form of construction, economic benefits (i.e. reduced construction time, reduced labor cost) and environmental conditions. Nowadays, many precast plants worldwide are using SCC because of the advantages related to the absence of vibration such as reduced illness of workers, lower maintenance costs and energy consumption. These advantages balance the higher cost of the material.

Domone [1] analyzed more than sixty case studies reported in literature and derived that in most cases the use of SCC is due to technical advantages compared to conventional concrete. SCC in situ is used for a wide range of applications: bridges (towers and anchor blocks), filled columns in high rise buildings, tunnel linings and walls.

Nevertheless, since the requirements of high workability and segregation resistance have both to be satisfied, the ratio among SCC constituents and, as a consequence, its mechanical properties, differ with respect to NVC. In particular the most significant difference concerns bond behavior [2].

Nonetheless, building codes have not yet been adapted to SCC. Several investigations [3–6] have been performed in order to possibly exploit the applications of Normal Vibrated Concrete (NVC) codes to SCC while a still-open question is related to the procedure adopted to check the concrete at the building site [7].

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0143-974X/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2010.11.003

Among the special applications in civil buildings, steel–concrete composite columns are beginning to be used more frequently, in particular Concrete Filled Tubes (CFT). From a practical point of view the main advantage is employing the steel tube as a formwork to directly cast concrete inside it, in case a limited amount of ordinary reinforcement is added. Usually, in these applications the beams also converge on the column are composite elements such that one single operation of casting is generally done for both columns and beams. The main concern is thus related to the ability of guaranteeing a proper vibration and of avoiding the absence of segregation, that is a characteristic of a self-compacting concrete, indeed.

Nonetheless, some objections have been recently raised concerning the influence of bond between steel and SCC on the global behavior of the columns in presence of long-term or second-order effects.

Extensive research on composite columns, in which structural steel sections are encased in concrete, has been carried out. However, in-filled composite columns, and in particular CFT, have received limited attention compared to the first ones (for an extensive review see [8]).

In recent years, a few studies have been carried out on stubby SCC Filled Columns [9,10], and very few indications exist on the bond behavior [11,12].

An experimental and numerical investigation of short circular steel tubes filled by means of expansive cement is presented in [12]; furthermore [13] studied the bond capacities of similar short CFT. Nevertheless, to the authors' knowledge, no previous studies have been performed on the bond of Self-Compacting Concrete Filled Tubes.

Referring to the results reported on NVC Filled Tubes, the following factors are relevant:

- L/D ratio: columns with $L/D \leq 11$ (for $D/t \leq 60$, [14]) and with $L/D \leq 15$ (for $D/t \cong 90$, [15]) exhibit a higher capacity due to the increase of concrete strength resulting from triaxial confinement effects; for columns with higher L/D ratios the composite section fails due to column buckling before reaching the strains necessary to induce concrete confinement.
- D/t ratio: increasing the D/t ratio reduces the axial ductility performance of thin-walled CFST columns [16]; for concrete-filled steel tube columns, smaller D/t ratios provide a significant increase in the yield load and exhibit more favorable post-yield behavior; these effects diminish for large diameter columns [17].
- Shape effect: concrete confinement can be observed in circular and in many octagonal cross sections; square tubes provide very little confinement of the concrete only in corner regions because the wall of the square tube resists the concrete pressure by plate bending, instead of the membrane-type hoop stresses [18,19].
- Load transfer: the point of application of the load has a small influence on the overall behavior; nevertheless, when the steel tube and the concrete core are loaded simultaneously, the tube provides confinement only after yielding, while the effects of confinement are visible when the load is applied on the concrete surface only [20].
- Failure mode: it is generally found [21] that short columns fail for steel yielding leading to local buckling associated with the crushing of concrete; medium length columns behave inelastically and fail by partial yielding of steel, crushing of concrete in compression and cracking of concrete in tension; slender columns fail according to an overall buckling mode.

Table 1
Geometry of steel tubes.

Tube length L (mm)	Diameter D (mm)	Thickness t (mm)	L/D	D/t	Eulerian slenderness λ
800	139.6	4.0	5.7	39.9	24
2000	139.6	4.0	14.3	39.9	48
3000	139.6	4.0	21.5	39.9	74
4000	139.6	4.0	31.5	39.9	106

Table 2
Mix proportions (kg/m^3).

	NVC	SCC	SCC-E
CEM IIAL 42.5R	440	420	420
Filler	60	370	340
Sand	1085	730	730
Coarse aggregate	585	610	610
Water	180	190	190
Super-plasticizer	2.5	8	7.5
Expansive agent	0	0	33
Shrinkage inhibitor	0	0	4.2
Volumic mass	2353	2328	2335

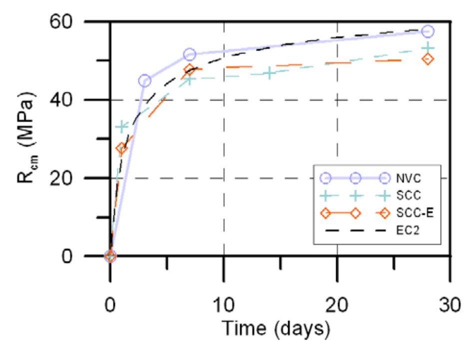

Fig. 1. Compressive strength development curves.

The experimental program presented in this paper investigates the effectiveness of Self-Compacting Concrete as an infill of steel tubular columns, the possible increase in the structural performance when introducing expansive SCC and the suitability of the code prescription when referring to SCC. Ordinary steel tube with lengths ranging from 800 mm to 4400 mm were selected. Table 1 reports, for each specimen, the tube geometry, the length to diameter and diameter to thickness ratios and the Eulerian slenderness in the test configuration. The load was applied on the concrete surface only.

2. Experimental program

2.1. Mix design

Three different concretes are studied, each of them designed for a 28-day cylindrical compressive strength of 50 MPa:

- a Normal Vibrated Concrete (NVC);
- a Self-Compacting Concrete (SCC);
- an Expansive SCC (SCC-E, with the intention that the expansion should produce an increase in bond strength).

Details of the mix compositions are given in Table 2 (quantities of the constituents are all expressed in kg/m^3).

The strength development curves for the three mixes are shown in Fig. 1. The Eurocode 2 [22] curve for NVC is also plotted according to the equation:

$$f_{cm}(t) = \beta_{cc}(t) f_{cm} \quad \text{where} \tag{1}$$

$$\beta_{cc} = \exp\{s[1 - (28/t)^{0.5}]\} \tag{2}$$

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